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# Development of a Turbomachinery Design Optimization Procedure Using a Multiple-Parameter Nonlinear Perturbation Method

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# SUMMARY

An investigation was carried out to complete the preliminary development of a combined perturbation/optimization procedure and associated computational code for designing optimized blade-to-blade profiles of turbomachinery blades. The overall purpose of the procedures developed in this study is to provide demonstration of a rapid nonlinear perturbation method for minimizing the computational requirements associated with parametric design studies of turbomachinery flows. The method reported here combines the multiple-parameter nonlinear perturbation method, successfully developed in previous phases of this study, with the NASA TSONIC blade-to-blade turbomachinery flow solver, and the COPES-CONMIN optimization procedure into a user's code for designing optimized blade-to-blade surface profiles of turbomachinery blades. Results of several design applications and a documented version of the code together with a user's manual are provided.

# 1. INTRODUCTION

The remarkable success of advanced computational methods for determining complex fluid dynamic phenomena has created a continuing demand both for increasing the accuracy and generality of these methods, as well as the desire to incorporate these methods into a routine use mode needed for design and parametric investigations. However, a major impediment to such routine use of many of these current and emerging computational codes is the high computational cost required in their direct application to situations requiring repetitive high-frequency use. Consequently, a real need exists for determining the means to reduce these costs while retaining the required accuracy in such nonlinear applications. While this need exists in virtually all engineering applications when relatively sophisticated numerical codes are employed, for turbomachinery applications it is particularly severe since both the underlying aerodynamic computation of the flow field is costly and also the number of flow and geometry parameters needed to be varied in design studies is large.

The ultimate objective of this investigation is to develop and demonstrate methods that would provide the means to reduce substantially the overall computational requirements necessary for turbomachinery design studies. It is conceived that these methods would be coupled with high run-time general turbomachinery computational flow field solvers and would be used in conjunction with them in applications where large numbers of related nonlinear turbomachinery solutions are required.

That such methods can be realized has been successfully demonstrated in the previous phases (Refs. 1-3) of this study. In the first of those investigations (Ref. 1), several candidate methods were studied and the most promising method was identified. Extensive development and testing of that method was then carried out in the subsequent phase (Ref. 2). This testing was performed for a wide variety of both flow and geometry parameters for turbomachinery flows past isolated blades and compressor cascades at both subcritical and supercritical conditions. Emphasis was placed in particular on strongly supercritical flows which exhibited large surface shock movements over the parametric range studied. Comparisons of the perturbation predictions with the corresponding exact nonlinear solutions indicated a remarkable accuracy and range of validity of the perturbation method. In the most recently completed phase (Ref. 3), the perturbation method was extended to treat simultaneous multiple-parameter perturbations. Extensive testing of the method has demonstrated remarkable accuracy and range of validity of the multiple-parameter perturbation procedure in direct correspondence with the previous results obtained for single-parameter perturbations. Additionally, initial applications of the multiple-parameter perturbation method combined with an optimization procedure were made (Ref. 3) to several turbomachinery blade design problems. The results demonstrated the potential of the perturbation method for reducing the computational work in such applications by an order of magnitude with no degradation in accuracy.

The work reported here describes the continued development of the combined multiple-parameter perturbation method/ optimization procedure. The primary objective of this phase is on the development of that combined procedure into an operational method for designing optimized blade-to-blade profiles of turbomachinery compressor blades.

## 2. ANALYSIS

### 2.1 Perturbation Concept

The obvious method of carrying out a perturbation analysis, that is by establishing and solving a series of linear perturbation equations in the manner of Van Dyke (Ref. 4), appears to be an obvious choice for the current application. The initial phase of this study (Ref. 1) established that for sensitive flows, such as occur in turbomachinery, the basic linear variation assumption fundamental to the technique is sufficiently restrictive that the allowable range of parameter variation is so small as to be of little practical use. A novel alternative to the linear perturbation equation approach was then subsequently developed and successfully tested (Refs. 1-3) in which a correction method is used that employs two or more nonlinear solutions obtained from the basic nonlinear flow solver, rather than just one as in the linear perturbation equation approach. For this alternative method, the basic perturbation solution is determined simply by differencing two nonlinear flow solutions removed from one another by some nominal change of a particular flow or geometrical quantity. A unit perturbation solution is then obtained by dividing that result by the change in the perturbed quantity. Related solutions are determined by multiplying the unit perturbation by the desired parameter change and adding that result to the base flow solution. This simple procedure, however, only works directly for continuous flows for which the perturbation change does not alter the solution domain. For those perturbations which change the flow domain, coordinate stretching is necessary to ensure proper definition of the unit perturbation solution. For discontinuous flows, special coordinate straining is necessary to account for movement of discontinuities due to the perturbation.

At this point, the perturbation concept based on these ideas has both been implemented and thoroughly tested in a wide range of applications (Refs. 1-3, 5-11). These applications have purposely involved a number of different nonlinear flow field solvers to provide the base solutions necessary for the perturbation calculation. The most extensive and systematic of these studies are reported in References 2, 3, 9, and 11, where results are provided for case studies involving a variety of different flow and geometry parameter perturbations of nonlinear subsonic and transonic flows past isolated blade and compressor cascade geometries. For those applications, emphasis was placed in particular on strongly supercritical transonic flows which exhibit large surface shock movements over the parameter range studied. By extensive comparisons with the exact nonlinear solutions, these studies have established the accuracy, range of validity, and versatility of the perturbation method.

The underlying reason of the remarkable accuracy of the perturbation method developed in this study lies in the use of coordinate straining to define the unit perturbation. As shown in Figure 1, where the perturbation between two nonlinear solution states is displayed graphically as the shaded area between the base and the strained and unstrained calibration solution, coordinate straining provides the ability to account accurately for the displacement of a multiple number of discontinuities and maxima of high-gradient regions due to a parameter change. This enables the perturbation method to maintain very high accuracy in regions of high gradients where most perturbation methods commonly fail, and to maintain that accuracy over large parametric ranges.

In what follows, we provide a brief account of the theoretical essentials of the strained-coordinate perturbation concept as it configured and implemented in the present design application. This is to predict simultaneous multiple-parameter perturbation flow solutions for blade surface properties of turbomachinery blades for use in optimized blade design. The turbomachinery flow solutions thus considered can contain a total number N of discontinuities or high-gradient continuous regions. Complete details of the mathematical basis of the method, in particular, the application to flow field properties, may be found in Reference 3.

For the prediction of distributions of surface properties involving simultaneous multiple-parameter perturbations of aerodynamic flows where flow properties are required along some contour, the strained-coordinate, first-order, multiple-parameter perturbation approximation can be represented by

$$Q(x;\varepsilon) = Q_o(s) + \sum_{j=1}^{M} \varepsilon_j Q_{1_j}(s) + \ldots \qquad (1)$$

$$x = s + \sum_{j=1}^{M} \varepsilon_j x_1(s) + \ldots \qquad (2)$$

where x is the independent variable measuring distance along the surface contour or some convenient projection of that distance, s is the strained coordinate, and $\varepsilon_j$ a small parameter representing the change in one of M flow or geometrical variables which we wish to vary simultaneously.

In order to determine the first-order corrections $Q_{1_j}(s)$, we require one base and M calibration solutions in which the calibration solutions are determined by varying each of the M arbitrary independent parameters $q_j$ by some nominal amount from the base flow value while keeping the others fixed at their baseline values.

In this way, the first-order corrections $Q_{1_j}(s)$ can be determined as

$$Q_{1_j}(s) = \frac{Q_{c_j}(\bar{x}_j) - Q_o(s)}{\bar{\varepsilon}_j} \tag{3}$$

where $Q_{c_j}$ is the calibration solution corresponding to changing the j*th* parameter to a new value $q_{c_j}$, $\bar{x}_j$ is the strained coordinate pertaining to the $Q_{c_j}$ calibration solution, and $\bar{\varepsilon}_j = q_{c_j} - q_{o_j}$ represents the change in the $q_j$ parameter from its base flow value. If we now desire to keep invariant during the perturbation process a total of N points corresponding to discontinuities or high-gradient maxima, we can represent the first-order solution by

$$Q(x,\varepsilon_j) = Q_o(s) + \sum_{j=1}^{M} \varepsilon_j Q_{1_j}(s) \tag{4}$$

where $Q_{1_j}(s)$ is given above and

$$\bar{x}_j = s + \sum_{i=1}^{N} \bar{\varepsilon}_j \delta x_i x_{1_i}(s) \tag{5}$$

$$x = s + \sum_{i=1}^{N} \varepsilon_j \delta x_i x_{1_i}(s) \tag{6}$$

$$\bar{\varepsilon}_j = q_{c_j} - q_{o_j} \tag{7}$$

$$\varepsilon_j = q_j - q_{o_j} \tag{8}$$

$$\bar{\varepsilon}_j \delta x_i = \left(x_i^c - x_i^o\right)_j \tag{9}$$

$$\varepsilon_j \delta x_i = \frac{\varepsilon_j}{\bar{\varepsilon}_j}\left(x_i^c - x_i^o\right)_j \tag{10}$$

Here $\bar{\varepsilon}_j \delta x_i$ given in Equations (5) and (9) represent the displacement of the *ith* invariant point in the *jth* calibration solution from its base flow location due to the selected change $\bar{\varepsilon}_j$ in the $q_j$ parameter given by Equation (7), $\varepsilon_j \delta x_i$ given in Equations (6) and (10) represents the predicted displacement of the *ith* invariant point from its base flow location due to the desired change $\varepsilon_j$ in the $q_j$ parameter given by Equation (8), and $x_{1_i}(s)$ is a unit-order straining function having the property that

$$x_{1_i}\left(x_k^o\right) = \begin{cases} 1 & k = i \\ 0 & k \neq i \end{cases} \tag{11}$$

which assures alignment of the *ith* invariant point between the base and calibration solutions.

In References 2 and 3, detailed studies were made of the effect of different straining functions on the accuracy of the perturbation result. In Reference 3, identification was made of a superior class of straining functions for use in general nonlinear applications. This class turns out to be comprised of linear piecewise-continuous straining functions, and particular members of this class have proven effective in all case studies undertaken to date. It has been found that this type of straining function is able to maintain high accuracy of the perturbation predictive result in the vicinity of the invariant points, and furthermore, this class of straining function introduces no excessive straining in regions removed from those locations. Occurrence of the latter phenomenon has been found to be a common failure of certain other classes of straining functions (Refs. 2, 3).

The functional forms of the straining for linear piecewise-continuous straining functions can be compactly written. For example, the strained coordinate $\bar{x}_j$, in Equation (5) is given by

$$\bar{x}_j = s + \left\{\frac{x_{i+1}^o - s}{x_{i+1}^o - x_i^o} \cdot \left(x_i^c - x_i^o\right)_j + \frac{s - x_i^o}{x_{i+1}^o - x_i^o} \cdot \left(x_{i+1}^c - x_{i+1}^o\right)_j\right\} H\left(x_{i+1} - s)\right) \cdot H\left(s - x_i^o\right) \tag{12}$$

where H denotes the Heaviside step function. In addition to the points corresponding to discontinuities or high-gradient maxima, it is usually also necessary in coordinate straining to hold invariant both of the end points along the contour. Consequently, for the application developed here, the array of invariant points in the base and calibration solutions are taken as

$$
\begin{aligned}
x_i^o &= \left\{0,\ x_1^o,\ x_2^o,\ \ldots,\ x_n^o,\ 1\right\} \\
x_{i_j}^c &= \left\{0,\ x_{1_j}^c,\ x_{2_j}^c,\ \ldots,\ x_{n_j}^c,\ 1\right\}
\end{aligned}
\qquad (13)
$$

where the contour length has been normalized to unity and where n is the number of invariant points along the blade contour exclusive of the end points.

## 2.2 Combination of Perturbation Method with Optimization Procedures for Blade Design

One of the major objectives of the previous phase of this investigation (Ref. 3) was the demonstration of the capability of the perturbation method to work effectively in an important nonlinear design environment related to turbomachinery. The particular application selected was optimized turbomachinery blade design. Toward the above objective, the perturbation method, configured to treat simultaneous multiple-parameter changes, was combined with proven optimization procedures (Refs. 12, 13). Next, performance and design constraints characteristic of certain turbomachinery blade design problems were constructed. Finally, applications of the combined procedure to several case studies involving blade profile optimization were made. The objectives of these initial applications were to demonstrate the workability of the perturbation concept in a design environment, provide a benchmark of the potential for computational savings of the combined perturbation/optimization procedure for some typical design problems, and determine the accuracy of the perturbation-predicted results for these cases.

Two different types of optimization problems were considered. The first set of case studies involved isolated blades and were more fundamental in nature, while the second set involved a practical turbomachinery compressor blade design. For the first set of studies, the particular isolated blade design optimization problems selected for study involved the alteration of a baseline profile shape by adding to the baseline profile a set of shape functions according to the relation

$$Z(x) = Z_o(x) + \sum_{i=1}^{M} A_i F_i(x) \qquad (14)$$

where $Z_o$ are the ordinates of the baseline profiles, $F_i$ are the shape functions, and the coefficients $A_i$ are the design variables whose values are determined by the optimization process as a result of a search through design-variable solution space to achieve a desired design improvement. The general class of geometric shape functions employed, which have been found to be successful in previous applications involving optimization of supercritical airfoil sections (Ref. 14), consisted of exponential decay functions and sine functions. These are of the general form $(1 - x) \cdot x^p/e^{qx}$ and $\sin(\pi x^r)^n$, where the exponents p, q, r, and n are selected to provide a desired ordinate maximum at a particular chordwise location. The exponential functions are generally employed to provide adjustments near the leading edge, while the sine functions are used to provide maximum ordinate changes at particular chordwise stations. Illustrations of the chordwise variation of typical members of these classes of shape functions are provided in Figure 2, and it can be seen that these functions smoothly concentrate ordinate thickness at selected locations. Consequently, they can be used effectively to add a series of smoothly blended bumps or scallops at selected locations along a baseline blade profile in order to control locally the flow characteristics at particular sections on the blade.

A strategy that has proven convenient for performing optimization studies involving aerodynamic performance parameters (Ref. 14) has been to recontour the profile shape so as to tailor the surface pressure distribution to conform to a desired distribution. This type of objective provides local control over the basic aerodynamic surface flow property of importance, and provides a means of attempting to achieve aft pressure gradients sufficiently weak to avoid separation. An important corollary advantage of using such an objective is that viscous separation can be minimized. This allows use of an inviscid aerodynamic flow solver in the optimization process rather than a much more computationally-expensive viscous solver, and assures that the optimization result thus obtained at the inviscid level is representative of the actual flow.

In such studies, the characteristics that are primarily sought after in the optimization process are the minimization of both the peaky behavior near the leading edge and the compressive gradient on the aft portion of the suction surface that typically exists on the baseline profiles considered. This is illustrated schematically in Figure 3. For two of the three series of case studies undertaken for isolated blades, the objective function was taken as the minimization of the mean squared error between the predicted and desired surface pressure distribution, i.e.,

$$\mathrm{OBJ} = \sum_{k=1}^{K} \left[ C_{P_{\mathrm{predicted}}}(x_k) - C_{P_{\mathrm{desired}}}(x_k) \right]^2 \tag{15}$$

where K represents the number of chordwise locations $x_k$ where desired and calculated surface pressures are compared. For the third series, the objective function was chosen to be the drag coefficient squared, a much more sensitive quantity. The optimization procedure employed was the now-standard CONMIN code (Ref. 12).

The detailed results presented in Reference 3 for the three case studies on isolated blades clearly established the ability of the perturbation method to work accurately in a highly nonlinear multiple-parameter design environment. This was found to be true for both subcritical as well as strongly supercritical flow situations. The supercritical case study employing drag coefficient as the objective function demonstrated the advantages and accuracy benefits of multiple invariant point clustering in high-gradient regions as well as an explicit straining concept for determining the perturbation result. Finally, the potential for computational savings with the perturbation method in such optimization problems was benchmarked at an order of magnitude, and the possibility was demonstrated of even obtaining in some cases improved results in terms of a more global minima of the objective function with employing the perturbation method as compared to not using it.

The final set of case studies involved the optimization of realistic compressor blades and was directed toward laying the foundations of a practical turbomachinery blade design/optimization procedure coupled with the simultaneous multiple-parameter perturbation method. The combined code consisted of the TSONIC blade-to-blade flow solver (Ref. 15) with generalized circular-arc blade geometry routines BLADE (Ref. 16) to describe the blade profiles, and the more generalized COPES-CONMIN optimization procedure (Ref. 13). The combined PERTURB/TSONIC/BLADE/COPES-CONMIN procedure, called BLDOPT, was tested on several NASA designed case studies to demonstrate the accuracy and capability of the combined procedure on problems typical of practical turbomachinery blade design. These case studies involved, as design variables, selected geometry parameters related to the NASA/Lewis circular-arc blade profiles. The optimization objective usually chosen was the minimization of the peak suction surface velocity diffusion. Although that choice of objective is a somewhat sensitive selection since it represents a point quantity in a high-gradient region, the combined procedure was able to demonstrate good results, with computational work savings comparable to those found in the previous case studies (Ref. 3).

In these case studies, however, because the design variables were selected as basic geometry parameters (blade curvature, maximum blade thickness, etc.) related to the circular-arc blade geometry, the optimization search problem itself becomes more sensitive. This occurs because these design variables by their very nature effect more global changes in the aerodynamic solution and therefore tend to interact more strongly with each other than would a corresponding optimization problem which employs, say, local shape functions as the design variables. For the latter case, the design variables generally effect only local changes in the aerodynamic solution and therefore tend to interact much more weakly with one another. Consequently, optimization problems posed with such design variables are usually much more stable and less sensitive to small changes in search direction.

However, the ability to employ basic blade geometry parameters as design variables is very attractive as it relates directly to the capability of performing the more general preliminary blade design problem where a wide universe of basic blade shapes is considered. This contrasts to the problem involving use of local shape functions as design variables which relates to a more specific refined-design problem where the basic blade profile has already been selected. The ability to treat both problems is important, with the former being the more general and more difficult to do.

# 3. RESULTS

Because the ultimate utility of the perturbation methods being developed under this investigation is in optimized turbomachinery design, the primary objective of the current study was to complete the development of the combined PERTURB/TSONIC/BLADE/COPES-CONMIN procedure (BLDOPT) for performing optimized turbomachinery blade-to-blade surface profile design, and to finalize the procedure into a user's code so as to make generally available such a procedure to facilitate future use and testing by the general turbomachinery community. Toward that end, we have completed the assembly and preliminary verification testing of the four component codes configured into a combined program and controlled under a user-friendly executive program.

A number of features have been incorporated into the current version of the BLDOPT program reported here, which were not available in the preliminary version reported in Reference 3. These features considerably enhance both the capability and generality of the method. An explicit straining procedure, which in essence specifies the points at which the final solution results are determined rather than allow these points to be determined implicitly from the straining of the base flow points as was done standardly in the past, has been implemented in the present BLDOPT code. The explicit procedure avoids a double interpolation of the perturbation result and has been found to yield significantly improved accuracy in high-gradient regions at only a very slight increase in computational work. In addition to the explicit straining procedure, the updated BLDOPT code has incorporated several new options available to the user when employing the perturbation method. These options, which are controlled by the parameter IOPT defined in Section A.4 of the user's manual, relate to the way the calibration solution matrix is defined. One of these options provides the user with a basically automatic hands-off procedure for using the perturbation method. Under this option, the user is not required to preselect and input the design variable values for the calibration solution matrix. Rather the matrix is determined completely by the program in the following way. For the first optimization cycle, the perturbation method is not used. Full nonlinear aerodynamic solutions are determined by the flow field code as required as input for the gradient and search optimization calculations. After the first search cycle is complete and a new design point determined, design variable values for the calibration solution matrix are then determined based on the direction that the first search cycle has taken. This results in an extremely good definition of the calibration solution matrix. The result is that the design variable solution space which is subsequently searched on the second and successive optimization searches usually requires only very reasonable interpolations/extrapolations within the design variable parameter range of the defined solution matrix.

This option (IOPT = 3) provides the automatic user-invisible procedure for defining the calibration solution matrix. An additional option (IOPT = 2) which requires user-input for defining the calibration solution matrix has also been incorporated into the code. Within this option, the calibration matrix definition can be accomplished by either individually specifying all the design variables (ICALB = 1) or alternatively (ICALB = 0) by employing a constant-value calibration stepsize which increments each design variable by this fractional change of its base flow value. The automatic IOPT = 3 option requires the additional cost of one optimization search cycle using full aerodynamic flow field solutions over that of the IOPT = 2 option which in contrast requires a user-input of the design variable values for the calibration solutions. Nevertheless, the IOPT = 3 option provides a highly accurate and basically hands-off means of employing the perturbation method and is recommended for use when no information is available on search direction from previous related calculations.

In terms of final design variable accuracy and potential computational time savings using this IOPT = 3 option, in Figures 4 and 5 we present comparisons of a severe test of this option for the optimization results for a 5 design variable supercritical pressure tailoring case study on an isolated blade using blade contour shape functions similar to those reported in Reference 3. Figure 4 provides a comparison of the perturbation-predicted final design variables and objective function (●) with results obtained with not using the perturbation method but employing full nonlinear full potential aerodynamic solutions throughout (⊙). These are the results after 5 optimization cycles. We note the essentially exact correspondence between the final design variable values. Corresponding comparison of the objective function, in fact, indicate a slightly better result obtained by the perturbation method (■). In Figure 5, the corresponding comparison of computational work in CPU seconds and objection function reduction per otimization search cycle is provided. Here we see that after the first cycle is complete, the perturbation procedure actually requires less time to define the calibration matrix solution and complete the second search than does the full nonlinear flow field method with the same reduction in objective. From that point on, the perturbation method requires essentially no time to complete searches 3 to 5, and then an additional increment to calculate the final design result using the nonlinear flow field solver. Time savings achieved with the perturbation method for this case is 58% of that required for the full nonlinear result. These and similar results obtained with the IOPT = 3 option confirm the utility of the automatic user option for defining the calibration solution matrix.

With regard to the particular optimization problem toward which the BLDOPT program has been configured, the following eight blade geometry parameters that are commonly used to characterize NASA circular-arc blade section profiles (Ref. 16) have been incorporated as design variables:

| Blade Geometry Parameter | Program Name |
|---|---|
| Blade camber angle at inlet | KICR |
| Blade camber angle at outlet | KOCR |
| Transition location/chord | T |
| Maximum thickness location/chord | ZM |
| Inlet/outlet turning rate ratio | P |
| Blade maximum thickness/chord | TMX |
| Leading edge radius/chord | THLE |
| Trailing edge radius/chord | THTE |

These geometry parameters are illustrated graphically in Figure 6. For more details about the geometry of these classes of blade shapes, we refer the reader to Reference 16. In the BLDOPT program, any arbitrary combination up to six of the above parameters may be used in the optimization analysis.

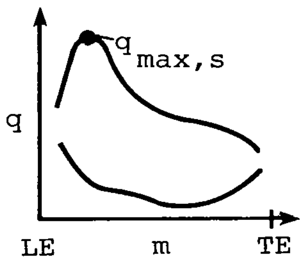
The sample optimization problem that has been examined to verify the combined procedure employs, as a design objective, the minimization of the velocity diffusion on the blade suction surface, i.e.,

$$\mathrm{OBJ} = \frac{q_{\mathrm{max,suction}}}{q_{\mathrm{avg,exit}}} \tag{16}$$

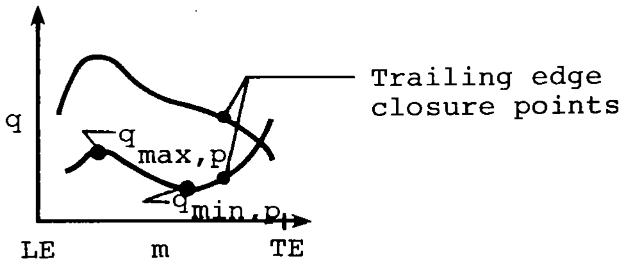
where $q_{\mathrm{max,suction}}$ is the maximum surface velocity on the blade suction surface and $q_{\mathrm{avg,exit}}$ is the average exit velocity in the freestream. Six of the eight design variables described above are employed: blade outlet camber angle, KOCR; transition location between fore and aft circular arc sections, T; maximum thickness location, ZM; inlet to outlet turning rate ratio, P; maximum thickness, TMX; and radius of the leading edge circle, THLE. During the optimization process, each of the design variables was constrained to remain within certain prescribed bounds in order to prevent a physically-unrealistic blade design from occurring. Furthermore, several active side constraints were additionally imposed both to insure design of a physically-realistic blade and also to achieve certain desirable flow characteristics on the blade. The active side constraints employed were:

1. Maintenance of nonzero local blade thickness
2. Maintenance of low velocity diffusion on the blade pressure surface
3. Trailing edge closure via an effective Kutta condition

The basis of the first constraint is self-evident and is necessary since various combinations of the basic circular-arc blade geometry parameters can easily result in the upper and lower blade surface arcs crossing and thus lead to negative thickness. To understand the basis of the second and third constraints, it is helpful to examine the typical blade surface velocity plot as determined by the TSONIC solver. As sketched below in the plot on the left,



**Baseline profile**



**During optimization**

the baseline profile has a large peak suction velocity which is desired to be reduced. It is also desirable to maintain on the pressure surface as uniform a velocity distribution as possible and, furthermore, to avoid a large mismatch in the upper and lower surface velocities at the trailing edge. During the optimization process, it is sometimes found that the lower surface velocity can develop peaks, such as shown in the plot on the right, and that the velocity distributions may cross ahead of the trailing edge. The constraints constructed to alleviate these occurrences are as follows. In order to keep large differences between the pressure surface velocity maxima and minima from occurring, we enforce the condition

$$0.0 < \frac{q_{max,press}}{q_{min,press}} < 1.3 \quad .$$

where $q_{max,pres}$ is the maximum blade pressure surface velocity over the front half of the blade and $q_{min,press}$ is the minimum blade pressure surface velocity over the last two-thirds of the blade. Restricting the maximum velocity considered to the front half of the blade and the minimum velocity to the rear of the blade prevents the maximum from moving rearward and the minimum from moving forward and thereby defeating the constraint. To maintain an effective Kutta condition at the rear of the blade, we enforce the condition

$$-1 < \frac{q_{ITE-2,suction} - q_{ITE-2,press}}{25} < 1$$

Here, $q_{ITE-2,suction}$ and $q_{ITE-2,press}$ are the third last surface velocities on the flow field grid near the trailing edge on the suction and pressure surfaces, respectively. Additional constraints, or constraints different from the above, can easily be implemented into the optimization analysis with the BLDOPT code. Details for carrying this out are provided in the user's manual.

We have successfully completed a verification series of calculations of the new combined PERTURB/TSONIC/BLADE/COPES-CONMIN procedure in which the accuracy and sensitivity of the perturbation method was tested as a function of choice of the initial calibration solution matrix. The initial or base values of the design variables for the baseline blade profile, and the upper and lower bounds of the design variables that were specified for this test problem were:

| Design Variable Number | Description | Lower Bound | Upper Bound | Initial Value |
|---|---|---|---|---|
| 1 | Outlet blade camber angle - KOCR | -15.0° | 0.0° | -10.0° |
| 2 | Transition location/chord - T | 0.20 | 0.60 | 0.25 |
| 4 | Maximum thickness location/ chord - ZM | 0.20 | 0.55 | 0.45 |
| 5 | Inlet/outlet turning/chord - P | 0.50 | 4.00 | 1.50 |
| 6 | Maximum thickness/chord - TMX | 0.03 | 0.10 | 0.05 |
| 7 | Leading edge radius/chord - THLE | 0.003 | 0.012 | 0.005 |

The results of these calculations are summarized in Table 1. There we have provided comparisons of the final design variables and objective function predicted when employing full nonlinear TSONIC solutions throughout the optimization process with corresponding results when using the perturbation method. For the perturbation results, different choices of the calibration solution matrix were made and are noted in the table. All the results represent converged solutions, with each calculation employing 10 optimization search cycles or less if no change in objective function should occur in three successive itermations.

The result indicated for the case when the perturbation method is not employed and TSONIC solutions are used throughout (IOPT = 1) provide the benchmark solution for comparison with the perturbation results. We note that similar full nonlinear benchmark results reported in Reference 3 for a related problem demonstrated the sensitivity of this class of optimization problems to the choice of the maximum velocity diffusion as an objective function. Identical benchmark results were obtained on the Ames Research Center CDC 7600 and the Lewis Research Center IBM 3033. The differences between those two results, which were of the same order as the differences between the various perturbation results, were due solely to the number of significant figures maintained in the respective calculations, i.e., eight for the IBM 3033 and 14 for the CDC 7600. This illustrates a common characteristic of many nonlinear multiple-parameter optimization problems, i.e., the existence of many local minimums. Furthermore, it also emphasizes the sensitivity of certain classes of optimization problems to both choice of objective function and design variables.

We observe from the perturbation results indicated in Table 1 that, with the exception of only one design variable (T) in certain instances of a deliberately made poor choice of calibration solution matrix, the final design variables predicted by the perturbation method for both IOPT=2 or 3 options trend in the same direction from the baseline value as the full nonlinear (IOPT=1) result and consistently improve the objective function. Under the IOPT=2 option, case 1 displays the results for a choice of calibration solution matrix which is very close to the final design result reached using the full nonlinear IOPT=1 option. The final perturbation-predicted design result for case 1 is slightly removed from the nonlinear result, but the objective function is quite close to the nonlinear result, indicating the presence of nearby alternative local optimization minimums. For case 2, the calibration matrix was determined by using the option ICALB=0 and selecting a constant-value calibration stepsize for each design variable of PSTEP=0.10. This implies that the value for each design variable for the calibration solution matrix is found by incrementing by 10 percent its base value. This manner of selecting the calibration matrix design variables is relatively crude since, on average, half of the perturbation flow solutions for the optimization searches will involve design variable interpolation and half will require extrapolation. Furthermore, a certain fixed percentage increment on some design variables may be far too much in range in that large solution interpolations may be required, while that same percentage increment may be far too small for other design variables which would then require large extrapolations. Nevertheless, in the face of no a priori information regarding the direction and range that the optimization search will proceed over, the use of the ICALB=0 option provides a convenient and inexpensive way of obtaining a preliminary optimization result. Additionally, as the results for case 2 indicate, the ICALB=0 results are often quite good. Analogous results using ICALB=0 and PSTEP=-0.10, which implies a decrement of 10 percent from the base design variable values for the calibration design variables, are given in case 3. As can be seen, these results are inferior to those of case 2, and illustrate the relative importance of chosing calibration matrix design variable values that result in modest interpolations/extrapolations, since for case 3 larger interpolations/extrapolations are required. The results of both cases 4 and 5 further illustrate this point. For case 4, the calibration design variables were chosen so as to result exclusively in modest perturbation solution extrapolations during the optimization searches. In case 5, similar choices were made so as to result exclusively in modest solution interpolations. Both results in terms of final design variable values and objective function are quite good. The final IOPT=2 result shown in case 6 illustrates the effect of an intentional bad selection for the calibration solution design variables in that large perturbation solution extrapolations/ interpolations are required during optimization. Although the final design result for the objective function is the least satisfactory of the six IOPT=2 cases, the majority of the design variables have trended in the appropriate direction. Consequently, even in for this situation involving deliberate poor choices of the calibration matrix, the perturbation method does not break down and yield spurious results, but provides instead a reasonable preliminary result. The final perturbation result shown in Table 1 is for the IOPT=3 option. For a slightly higher computational cost, that result provides a very good comparison between the final IOPT 1 nonlinear result.

The computational time needed to obtain the perturbation results in cases 1 to 6 under the IOPT=2 option were 76-78 secs. of CDC 7600 CPU time per case. The corresponding time for the IOPT=3 option was 97 secs. The benchmark IOPT=1 full nonlinear CDC 7600 result shown in Table 1 required 644 secs. Thus, the perturbation method provides a savings of (644 - 78)/ 644 = 88% of the computational time for the IOPT=2 option and (644 - 97)/644 = 85% for the IOPT=3 option for this example.

The significant conclusions to be drawn from this study are that the perturbation method can work accurately in multiple-parameter design environments even for very sensitive optimization problems and provide both meaningful final design results and large computational savings over not using the method. The choice of objective function such as was made for this case study, namely a point quantity located in a high-gradient region, requires careful user attention to the initial calibration matrix choice if IOPT=2 is employed in order to avoid large extrapolations, whereas if the IOPT=3 option is employed and the program allowed to automatically determine the calibration matrix, no exceptional difficulties are observed.

Additional optimization computations were made to try to determine whether an alternative choice of objective function would remove the sensitivity observed in the current problem. For example, computations were made employing objective functions defined as:(1) the sum of the maximum surface velocity on the blade suction surface plus the surface velocities on either side of that point, and (2) the sum of the first five surface velocities near the leading edge on the blade suction surface. The design variables and side constraints were kept the same as those of the original problem. The hope was that by spreading the objective function over a wider region on the blade surface, that the extreme sensitivity of the problem would be reduced. The results of these calculations, however, were disappointing in that they provided uniformily inferior results to the original choice of the objective function as a point quantity [Eq. (16)]. Our conclusion with regard to improving the posing of this particular optimization problem is that two issues must be addressed that were beyond the scope of this investigation. The first concerns the definition of the flow solution in the vicinity of the peak suction pressure. A detailed examination should be made of the accuracy and reliability of the flow solver (TSONIC) in that region. The second issue concerns the reliability of the basic CONMIN optimizer itself. In many of the optimization calculations undertaken in this study, a notable characteristic of the CONMIN optimizer was its penchant to move to a shallow objective function minimum in the near vicinity of the baseline configuration and to remain there. Alteration of stepsizes, design variable scalings, and certain tolerances did not change this characteristic. This behavior of CONMIN has been noted by others (Ref. 18) who have concluded that the conjugate gradient algorithm has serious convergence deficiencies when applied to the class of aerodynamic optimization problems being considered in this study. An attractive alternative method based on a quasi-Newton algorithm has demonstrated significantly superior performance characteristics over COPES/CONMIN for these same classes of problems (Ref. 18). The CONMIN procedure was originally developed for structural design problems with large numbers of variables and constraints, rather than for the relatively new aerodynamic optimization problem which involves a relatively limited number of design variables and constraints. Consequently, it is not surprising that superior procedures are now being discovered and developed. In future work, an investigation should be made of the desirability of replacing the COPES/ CONMIN optimization procedure embodied in the present BLDOPT program developed here.

## 4. CONCLUSIONS AND RECOMMENDATIONS

An investigation was conducted to complete the preliminary development of a combined perturbation/optimization procedure and associated computational code for designing optimized blade-to-blade profiles of turbomachinery blades. The overall purpose of the procedures developed in this study is to provide demonstration of the utility of a rapid nonlinear perturbation method for minimizing the computational requirements associated with optimized design studies of turbomachinery flows. The nonlinear perturbation method employed has been successfully developed in previous phases of this study and employs coordinate straining concepts together with unit perturbations determined from a special calibration matrix of nonlinear base solutions to predict families of related nonlinear solutions without further need of the computational nonlinear flow field solver. The solutions predicted can be either continuous or discontinuous.

The results reported here relate to the combination of the perturbation method, configured to predict simultaneous multiple-parameter changes, with the NASA/Lewis Research Center TSONIC code for predicting blade-to-blade flow solutions, the NASA/Lewis Research Center BLADE code for generating NASA blade-to-blade double circular arc blade shapes, and the NASA COPES-CONMIN code for performing optimization searches in multiple-parameter design space. The combined PERTURB/TSONIC/BLADE/COPES-CONMIN code, called BLDOPT, has been configured to perform optimization studies employing one, all, or any combination of the following eight blade geometry parameters used to characterize NASA double circular arc blade profiles: inlet blade camber angle, outlet blade camber angle, transition location between the inlet and outlet circular arc sections, maximum thickness location, inlet to outlet turning rate ratio, blade maximum thickness, leading edge radius, and trailing edge radius. Redefinition of the objective function and active side constraints for other case studies have been made simple and straightforward by confining their definition to one subroutine. The sample objective function and constraint definitions included in the version of the code reported here employ the velocity diffusion on the blade suction surface as objective function and three active side constraints related to maintenance of nonzero local blade thickness, low velocity diffusion on the blade pressure surface, and an effective trailing edge Kutta condition. The combined BLDOPT code has been made user-friendly and has been documented in a user's manual included as part of this report. An option has been included to allow the user to bypass use of the perturbation method altogether and employ TSONIC solutions throughout the optimization process in order to establish selected benchmark calculations. Options are also available to allow the user to employ the perturbation method in an automatic hands-off fashion. This is accomplished at the modest computational expense of one additional nonlinear

TSONIC-solution only optimization cycle over the alternative option of employing the perturbation method with the user supplying information regarding the initial calibration solution matrix.

Results of a series of calculations of the combined BLDOPT code have verified the code, demonstrated the accuracy of the perturbation-predicted results, and established benchmark guidelines of the potential for computational savings of the method under the various options included in the code. In general, the perturbation method is capable of providing an order of magnitude reduction in computational work in these applications.

Based on these results, we conclude that perturbation methods formulated on these ideas are both accurate and extremely workable in design environments. They clearly can provide the means for substantially reducing the computational work required in such applications. We suggest the further testing of the perturbation method with the combined BLDOPT code in order to test the limits of the method in such important preliminary design applications. Forthermore, we recommend the combination of these same procedures with supercritical flow solvers so as to accomplish both subcritical and supercritical blade optimization design.

# APPENDIX A

## USER'S MANUAL FOR COMPUTER PROGRAM BLDOPT

### A.1 INTRODUCTION

The purpose of this appendix is to describe the operation of the computer code that was developed in conjunction with the theoretical work presented in this report, and to provide sufficient detail to permit convenient use and change of the program. The program determines an optimized blade shape, with respect to certain blade surface geometry parameters (Ref. 16) and based on TSONIC blade-to-blade flow solutions (Ref. 15), by employing a modified version of the COPES-CONMIN optimization search program (Ref. 13). The typically large computational demands of such optimization procedures caused by the need for numerous blade-to-blade flow solutions during the optimum search process is substantially reduced by incorporation of a novel, recently-developed, rapid, nonlinear, strained-coordinate perturbation method (Refs. 2 and 3) as discussed in the main text.

A description of the general operating procedure of the combined program is given, together with complete description of both input and output. The program is written in FORTRAN IV and has been developed on the Ames Research Center CDC 7600 computer facility. Approximate program run times for an optimization problem involving six design variables and 10 optimization search cycles when not employing or employing the perturbation method under the various program options are:

| CPU Run Time | Program Option, IOPT |
|---|---|
| 800 secs. | 1 (TSONIC solutions only) |
| 100 secs. | 2 (Perturbation method) |
| 180 secs. | 3 (1 TSONIC solutions only cycle followed by perturbation method) |

The storage requirements are $141K_8$ for small core memory and $77K_8$ for large core memory.

## A.2 PROGRAM DESCRIPTION

The combined blade optimization program BLDOPT consists of the following main elements:

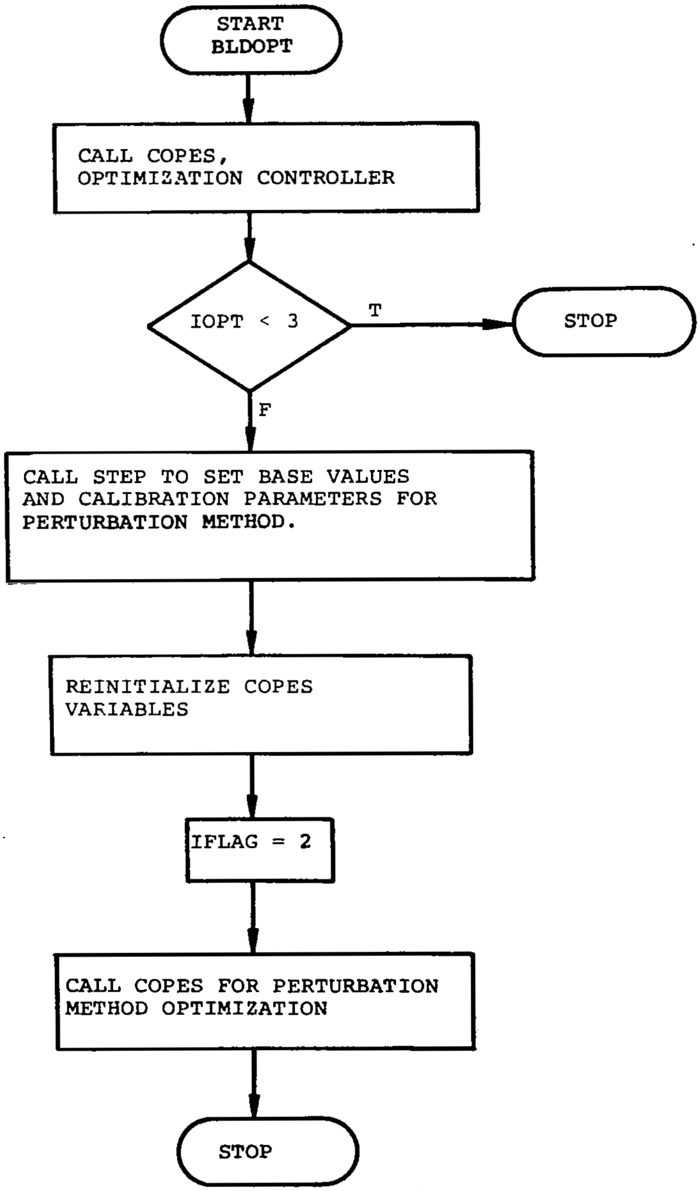
| Code Element | Function |
|---|---|
| COPES-CONMIN[13] | Optimization procedure |
| TSONIC[15] | Turbomachinery blade-to-blade flow solver |
| BLADE[16] | Blade geometry description |
| PERTRB[3] | Nonlinear perturbation method |

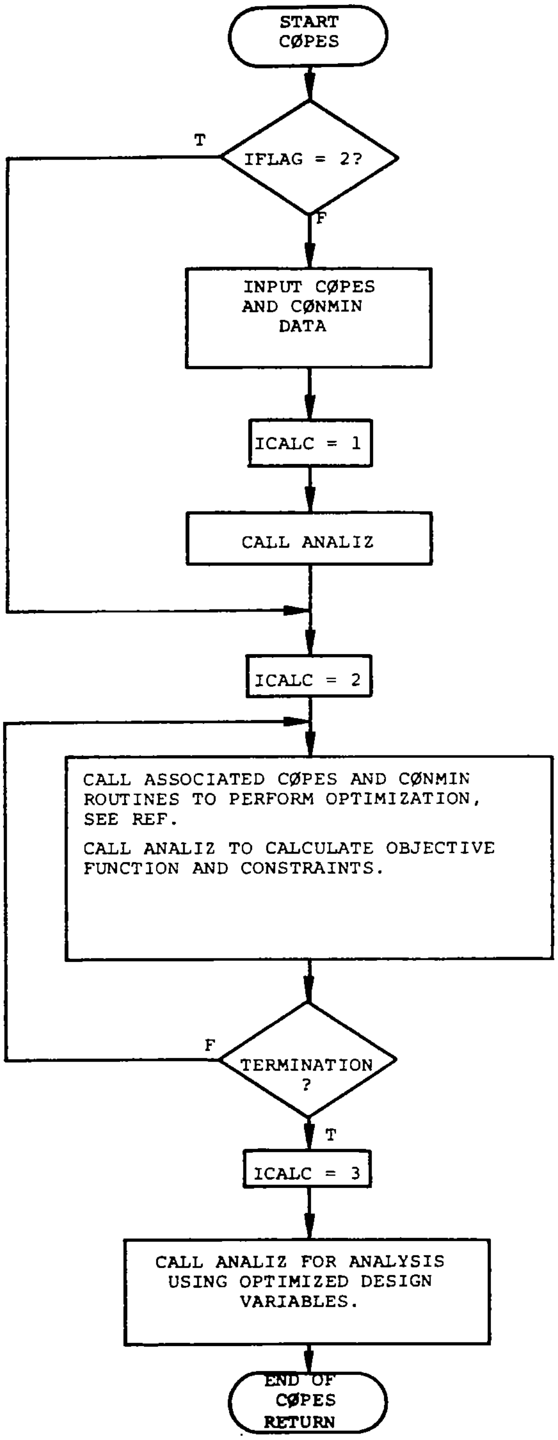
The program is configured to perform the optimization of a blade element as described geometrically in Reference 16. The optimization is based upon the following design variables which are geometric parameters describing the blade element:

| Design Variable Number | Geometric Parameter | Program Name |
|---|---|---|
| 1 | Blade camber angle at inlet | KICR |
| 2 | Blade camber angle at outlet | KOCR |
| 3 | Transition location/chord | T |
| 4 | Maximum thickness location/chord | ZM |
| 5 | Inlet/outlet turning rate ratio | P |
| 6 | Blade maximum thickness/chord | TMX |
| 7 | Leading edge radius/chord | THLE |
| 8 | Trailing edge radius/chord | THTE |

At the user's option, the optimization problem can be specified to employ any arbitrary combination up to six of the above design variables. Additionally, the user has the ability to construct readily particular objective functions and side constraints to be used in new optimization problems. Ease of definition and implementation of optimization problems with regard to objective function, side constraints, and design variable bounding were the primary reasons for selection of the COPES-CONMIN optimization driver. All information regarding definition of objective function and side constraints is contained in the subroutine OBJCON. In the program version listed here, the objective function is defined as the maximum velocity diffusion on the blade suction surface, and three side constraints are imposed to maintain (1) nonzero blade thickness, (2) low velocity diffusion on the blade pressure surface, and (3) trailing edge closure. Details of how these constraints are defined are provided in the main text, and their implementation in the code is straightforward and self-explanatory when viewing the program listing.

## A.3 PROGRAM FLOW CHART

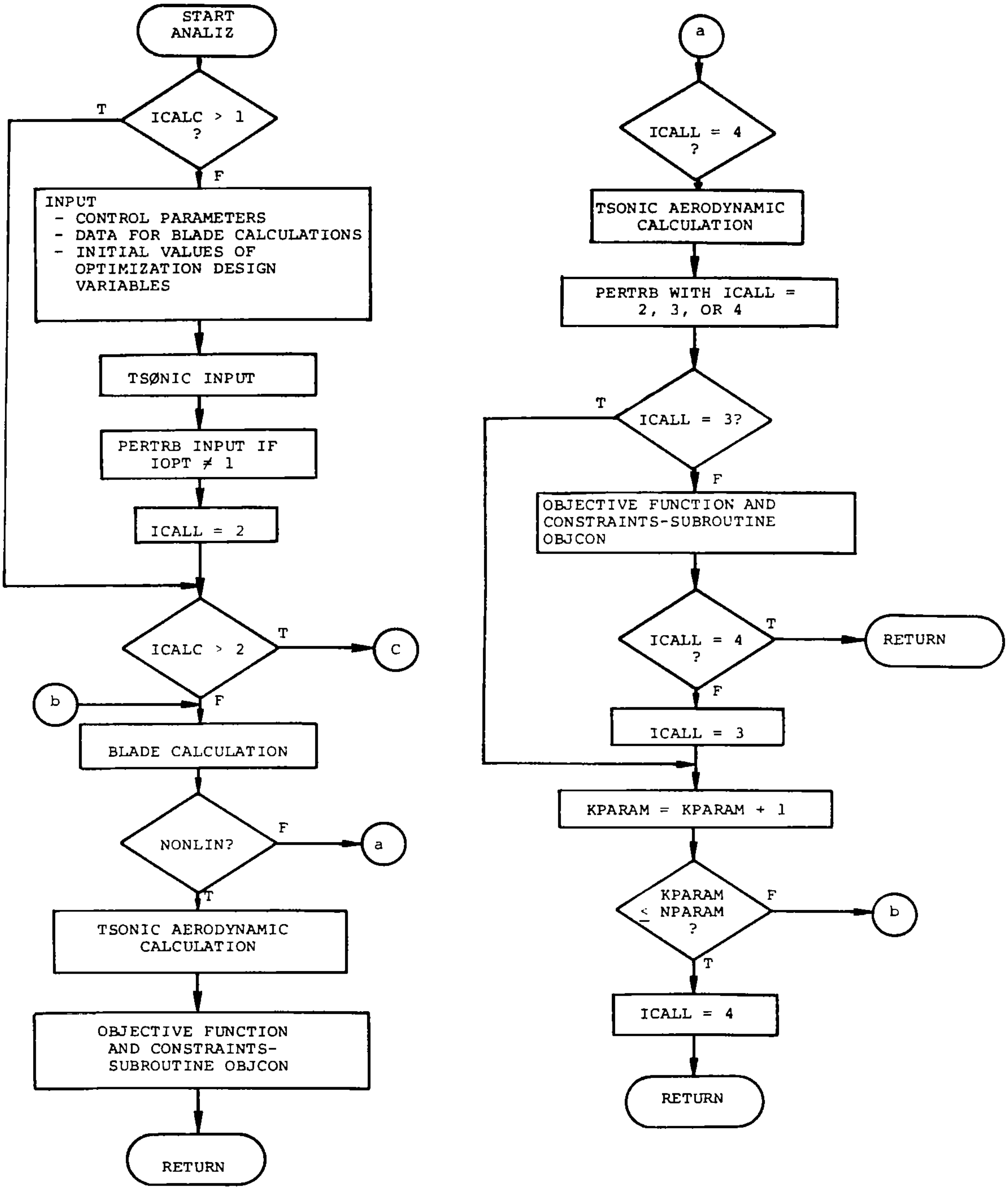

START BLDOPT
CALL COPES, OPTIMIZATION CONTROLLER
IOPT < 3
T
STOP
F
CALL STEP TO SET BASE VALUES AND CALIBRATION PARAMETERS FOR PERTURBATION METHOD.
REINITIALIZE COPES VARIABLES
IFLAG = 2
CALL COPES FOR PERTURBATION METHOD OPTIMIZATION
STOP

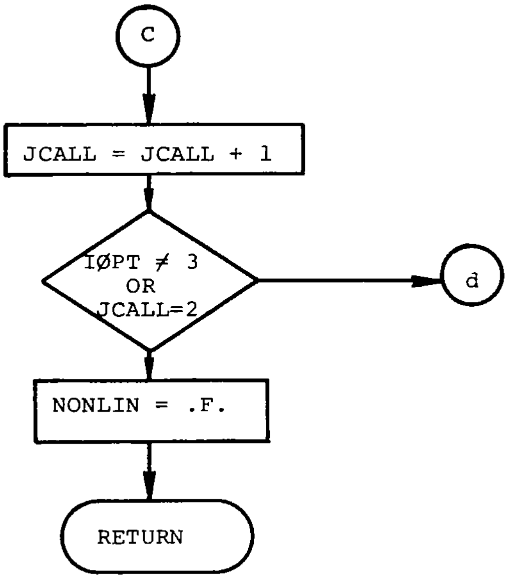


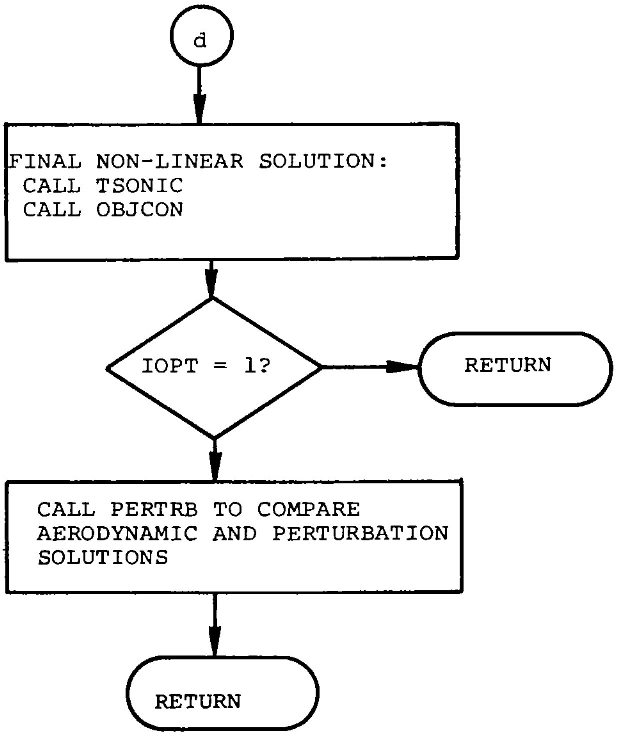
INPUT AND INITIALIZATION

OPTIMIZATION ANALYSIS

FINAL ANALYSIS; PRINT RESULTS


START ANALIZ
ICALC > 1 ?
T
F
INPUT
- CONTROL PARAMETERS
- DATA FOR BLADE CALCULATIONS
- INITIAL VALUES OF OPTIMIZATION DESIGN VARIABLES
TSØNIC INPUT
PERTRB INPUT IF IOPT ≠ 1
ICALL = 2
ICALC > 2
T
C
b
F
BLADE CALCULATION
NONLIN?
F
a
T
TSONIC AERODYNAMIC CALCULATION
OBJECTIVE FUNCTION AND CONSTRAINTS-SUBROUTINE OBJCON
RETURN
a
ICALL = 4 ?
TSONIC AERODYNAMIC CALCULATION
PERTRB WITH ICALL = 2, 3, OR 4
ICALL = 3?
T
F
OBJECTIVE FUNCTION AND CONSTRAINTS-SUBROUTINE OBJCON
ICALL = 4 ?
T
RETURN
F
ICALL = 3
KPARAM = KPARAM + 1
KPARAM ≤ NPARAM ?
F
b
T
ICALL = 4
RETURN


c
JCALL = JCALL + 1
IØPT ≠ 3
OR
JCALL=2
d
NONLIN = .F.
RETURN


d
FINAL NON-LINEAR SOLUTION:
CALL TSONIC
CALL OBJCON
IOPT = 1?
RETURN
CALL PERTRB TO COMPARE
AERODYNAMIC AND PERTURBATION
SOLUTIONS
RETURN

## A.4 DICTIONARY OF INPUT VARIABLES

This section provides a dictionary of all input variables. The variables are divided into four sections corresponding to the four major parts of the program (see A.2).

### A.4.1 Dictionary of Input Variables for Subroutine COPES (Ref. 13)

All COPES variables are defined in Section A.5.3.

### A.4.2 Dictionary of Input Variables for Subroutine ANALIZ

ALP — Blade-element layout-cone half angle, degrees; see Reference 16.

DVCALB(I) — Array of dimension NDV, specifying the calibration parameters used in the perturbation method optimization

ICALB — Integer parameter which controls input of the array DVCALB:

ICALB = 0, do not input DVCALB
ICALB = 1, input DVCALB

IDV(I) — Array of integers, of dimension NDV, which is used to select a subset of variable blade parameters as design variables in the optimization. If IDV(I) = K, the I*th* design variable is VV(K).

IOPT — Integer parameter which controls which method of analysis is to be used in optimization:

IOPT = 1, nonlinear aerodynamic solution
IOPT = 2, perturbation method
IOPT = 3, nonlinear optimization for one iteration to predict calibration stepsizes, followed by perturbation method.

ITMAX3 — Maximum number of optimization iterations allowed for the perturbation solution when IOPT = 3. Not used if IOPT = 1 or 2.

KICR — Centerline blade inlet angle on layout cone, degrees; see Reference 16.

KOCR — Centerline blade outlet angle on layout cone, degrees; see Reference 16.

NB Number of blades

NCN Number of constraint sets in the optimization problem; this value must be the same as that for NCONS in COPES input. NCN $\leq$ 5.

NDV Number of independent design variables used in the optimization problem. This value must be the same as NDV in COPES input. NDV $\leq$ 8.

P Ratio of inlet-segment turning ratio to outlet-segment turning rate for a blade element; see Reference 16.

PSTEP Constant-value calibration stepsize, which may be used in the perturbation method optimization. If ICALB = 0, the value of the K*th* calibration parameter DVCALB(K) = (1.+PSTEP)*QO(K), where QO(K) is the value of the K*th* base solution parameter.

R Inlet radius, length unit; see Reference 16.

SOLID Blade tip solidity (chord/circumferential spacing); see Reference 16.

T Blade centerline transition point location, made non-dimensional by the chord; see Reference 16.

THLE Blade-element leading-edge circle radius, made non-dimensional by the chord; see Reference 16.

THTE Blade-element trailing-edge circle radius, made non-dimensional by the chord; see Reference 16.

TMX Blade-element maximum thickness, made non-dimensional by the chord; see Reference 16.

VNAME(I) Array of dimension NDV, containing 10-character strings which identify, for printed output, the independent design variables used in optimization.

VV(I) Array of dimension 8 which is equivalent to the list of input variable blade parameters:

| | |
|---|---|
| VV(1) = KICR | VV(5) = P |
| VV(2) = KOCR | VV(6) = TMX |
| VV(3) = T | VV(7) = THLE |
| VV(4) = ZM | VV(8) = THTE |

ZM Blade centerline maximum thickness location, made non-dimensional by the chord; see Reference 16.

### A.4.3 Dictionary of Input Variables for Subroutine TSONIC

This section presents definitions of the input variables required for the TSONIC flow analysis. For a complete description of the variables and their usage see Reference 15.

AR Gas constant, J/(kg)(K)

BESP Array of stream-channel normal thicknesses corresponding to the MR and RMSP arrays, meters, see Figure 12, Reference 15.

BETAI Inlet flow angle $\beta_{1e}$ along BG with respect to m-direction, deg, see Figure 11, Reference 15.

BETAO Outlet flow angle $\beta_{te}$ along CF with respect to m-direction, deg, see Figure 11, Reference 15.

DENTOL Tolerance on density change per iteration for reduced weight flow (DENTOL may be left blank, and the value 0.01 will be used. If trouble is experienced in obtaining convergence (i.e., the maximum relative change in density (Item 14 of output, Ref. 15) does not get small enough, then a larger value of DENTOL may be used, or a smaller value of REDFAC may be used. (The value of 0.001 for DENTOL would be a tight tolerance, 0.01 is a medium tolerance, and 0.1 would be a loose tolerance.)

FSMI m-coordinate corresponding to BETAI (it is assumed that FSMI $\leq$ 0); if not specified, FSMI = 0.

FSMO m-coordinate corresponding to BETAO (it is assumed that FSMO $\geq$ chord); if not specified, FSMO = chord.

GAM Specific heat ratio

LAMBDA Upstream whirl, $rV_\theta$, meters$^2$/sec.

LOPT Integer variable which controls input of PLOSS array:

LOPT = 0, PLOSS array is not given as input
LOPT = 1, read in PLOSS array

LRVB Integer variable which controls input:

LRVB = 0, BETAI and BETAO are input
LRVB = 1, LAMBDA and RVTHO are input

MBI Number of vertical mesh lines from AH to BG inclusive, see Figure 13, Reference 15.

MBO  Number of vertical mesh lines from AH to CF inclusive, see Figure 13, Reference 15.

MM  Total number of vertical mesh lines in m-direction from AH to DE, maximum of 100, see Figure 13, Reference 15.

MOPT  Integer control variable:

MOPT = 0, use only when REDFAC = 1, no correction is made to the BESP array for the reduced mass flow solution.

MOPT = 1, read in the WOWCR array to use for calculating the reduced mass flow BESP array.

MOPT = 2, the reduced BESP array will be calculated by the program using average blade angles and using SSM1 and SSM2 values to determine whether flow is subsonic or supersonic.

MR  Array of m-coordinates of spline points for stream-channel radii and stream-channel thickness, meters, see Figure 12, Reference 15 (MR is measured from the leading edge of the blade. These coordinates should cover the entire distance from AH to DE, and may extend beyond these bounds. The total number of points is NRSP.).

NBBI  Number of mesh spaces in θ-direction between AB and GH, maximum of 50, see Figure 13, Reference 15.

NBL  Number of blades.

MRSP  Number of spline points for stream-channel radius (RMSP) and thickness (BESP) coordinates, maximum of 50, see Figure 12, Reference 15.

OMEGA  Rotational speed, ω, rad/sec (note that ω is negative if rotation is in the opposite direction of that shown in Fig. 12, Ref. 15).

ORF  Value of overrelaxation factor to be used in the solution of the inner iteration simultaneous equations (if ORF = 0, the program calculates an estimated value for the overrelaxation factor. See page 25, Ref. 15 for discussion.).

PLOSS  array of fractional total pressure loss, $1 - \frac{P'}{P'_{ideal}}$, corresponding to the MR, RMSP, and BESP arrays.

REDFAC Factor by which weight flow (WTFL) must be reduced in order to assure subsonic flow throughout passage (REDFAC is usually between 0.5 and 0.9).

RHOIP Inlet stagnation density, kg/meter$^3$

RMSP Array of r-coordinates of spline points for the stream-channel radii, corresponding to the MR array, meters, see Figure 12, Reference 15.

RVTHO Downstream whirl, $(rV_r)_o$, meters$^2$/sec.

SPLNO(1), SPLNO(2) Number of blade spline points given for each surface as input, maximum of 50 [these include the first and last points (dummies) that are tangent to the leading- and trailing-edge radii (Fig. 11, Ref. 15)].

SSM1 m-coordinate where supersonic solution is to start.

SSM2 m-coordinate where supersonic solution is to end. (Note: If SSM1 and SSM2 are both left blank, there will be no supersonic region).

TIP Inlet stagnation temperature, K

WOWCR Array of $W/W_{cr}$ values at mid-channel, corresponding to the MR, RMSP, and BESP arrays. Used to calculate the reduced mass flow BESP array.

WTFL Mass flow per blade for stream channel, kg/sec.

The remaining variables, starting with BLDAT, are used to indicate what output is desired. A value of 0 for any of these variables will cause the output associated with that variable to be omitted. A value of 1 will cause the corresponding output to be printed for the final iteration only; 2, for the first and final iterations; and 3, for all iterations. Case should be used not to call for more output than is really useful. The following list gives the output associated with each of these variables:

BLDAT All geometrical information which does not change from iteration to iteration (i.e., coordinates and first and second derivatives of all blade surface spline points; blade coordinates, blade slopes, and blade curvatures where vertical mesh lines meet each blade surface; radii and stream-channel thickness corresponding to each vertical mesh line; m-coordinate, stream-channel radius and thickness, and blade surface angles and slopes where horizontal mesh lines intersect each blade; and ITV and IV arrays, internal variables describing the location of the blade surfaces with respect to the finite difference grid).

AANDK Coefficient array, constant vector, and indexes of all adjacent points for each point in finite-difference mesh (this information is needed for debugging the program only).

ERSOR Maximum change in stream function at any point for each iteration of SOR equation [Eq. (A8), Ref. 17].

STRFN Value of stream function at each unknown mesh point in region.

SLCRD Streamline θ-cordinates at each vertical mesh line, and streamline plot.

INTVL Velocity and flow angle at each interior mesh point for both reduced and actual weight flow.

SURVL m-coordinate, surface velocity, flow angle, distance along surface, and $W/W_{cr}$ based on meridional velocity components where each vertical mesh line meets each blade surface; m-coordinate, surface velocity, flow angle, distance along surface, and $W/W_{cr}$ based on tangential velocity components where each horizontal mesh line meets each blade surface, plot of blade surface velocities against meridional streamline distance, meters.

### A.4.4 Dictionary of Input Variables for Subroutine PERTRB

This section presents definitions of the input variables required for the perturbation method. For a complete description of the variables and their usage see Reference 3.

A Scaling parameter in straining procedure. A = -x(1), where x(1) is x-location of first data point on lower surface (see PROGRAM DESCRIPTION, Ref. 3).

B Scaling parameter in straining procedure. B = -x(N), where x(N) is location of last data point on upper surface (see PROGRAM DESCRIPTION, Ref. 3).

LPLOT Specifies whether or not an additional plot by a peripheral device is to be made. Software must be supplied by user in subroutine DRVPLT.

LPLOT = 0 ... no peripheral plot
LPLOT = 1 ... peripheral plot

LSELCT(I) Array of length 6 of which NSELCT elements are read in; specifies nature of points to be held invariant according to the code:

1 ... minimum point held invariant
2 ... maximum point held invariant
3 ... 1st critical point held invariant
4 ... 2nd critical point held invariant
5 ... 3rd critical point held invariant
6 ... 4th critical point held invariant

Note that critical point ordering is determined from order of occurrence starting at the lower surface at the point furthest from the leading edge and proceeding clockwise around the surface (see PROGRAM DESCRIPTION, Ref. 3).

Note that the code numbers can be assigned in any order, e.g.,

```
LSELCT(1) = 1              LSELCT(1) = 4
LSELCT(2) = 3      and     LSELCT(2) = 1
LSELCT(3) = 4              LSELCT(3) = 3
```

Are equivalent, both corresponding to NSELCT = 3, with the minimum, and first and second critical points held invariant.

LUNIT Controls whether or not unit coordinate strainings and unit perturbation(s) are printed.

LUNIT = 0 ... no output
LUNIT = 1 ... output

NSELCT Number of points (in addition to end points) to be held invariant in straining; note: $1 \le \text{NSELCT} \le 6$.

PARNAM(K) Array of 8-character strings which identify the parameters varied. NPARAM element of the array are read in.

TITLE Character string of length 80; identifies job. First nine characters are used to identify peripheral plot.

VNAM Character string of length 2 which symbolizes dependent variables, e.g., "CP" for pressure coefficient.

## A.5 PREPARATION OF INPUT DATA

This section describes the preparation of the card input data for the program. A description of each input item is presented, followed by a description of the card format.

### A.5.1 Description of Input

The data are divided into four sections corresponding to the four major parts of the program.

#### A.5.1.1 COPES Input

Item 1.1 To end of COPES input. Input for the COPES optimization control subroutines is described in Section A.5.3. The user should take particular note of variable ITMAX in Block C and the array X in Block R. If IOPT = 3, ITMAX should be set equal to 1, and all values of the array X should be set to zero.

#### A.5.1.2 ANALIZ Input

Item 2.1 One card, containing text which identifies the ANALIZ input block; may contain up to 80 characters.

Item 2.2 One card, containing the control parameters IOPT, NDV, NCN, ITMAX3.

Item 2.3 One card, containing the constant blade parameters NB, R, ALP, and SOLID.

Item 2.4 One card, containing the variable blade parameters KICR, KOCR, T, ZM, P, TMX, THLE, THTE. The initial values of the design variables used in optimization are contained in this set.

Item 2.5 One card, containing the character strings VNAME(I), I = 1, NDV.

Item 2.6 One card, containing the integer array IDV(I), I = 1, NDV.

Item 2.7 One card, containing parameters ICALB and PSTEP.

Item 2.9 One card, optional, containing perturbation parameters. DVCALB(I), I = 1, NDV. Omit this item if ICALB = 0.

#### A.5.1.3 TSONIC Input

Item 3.1 One card, containing text identifying the TSONIC input block; may contain up to 80 characters.

Item 3.2 One card, containing values for GAM, AR, TIP, RHOIP, WTFL, OMEGA, and ORF.

Item 3.3 One card, containing values for geometric parameters BETAI, BETAO, FSMI, and FSMO.
Optional: LAMBDA and RVTHO may be specified instead of BETAI and BETAO. In this case, specify LRVB = 1. FSMI and FSMO are not needed.

Item 3.4 One card, containing values for REDFAC, DENTOL, SSM1, SSM2.

Item 3.5 One card, containing integral MBI, MBO, MM, NBBI, NBL, NRSP, MOPT, LOPT, LRVB.

Item 3.6 One card, containing SPLNO(1).

Item 3.7 One card, containing SPLNO(2).

Item 3.8 Set of cards, eight values per card, containing array MR(I), I = 1, NRSP.

Item 3.9 Set of cards, eight values per card, containing array RMSP(I), I = 1, NRSP.

Item 3.10 Set of cards, eight values per card, containing array BESP(I), I = 1, NRSP.

Item 3.11 Set of cards, optional, eight values per card, containing array WOWCR(I), I = 1, NRSP. This item is required only when MOPT = 1.

Item 3.12 Set of cards, optional, eight values per card, containarray PLOSS(I), I = 1, MRSP. Omit this item if LOPT = 0.

Item 3.13 One card, containing the integer print control variables BLDAT, AANDK, ERSOR, STRFN, SLCRD, INTVL, and survl.

Item 3.14 One card, containing the character string $END in columns 1-4. This identifies the end of TSONIC input.

### A.5.1.4 PERTRB Input

Item 4.1 One card of text, identifying the PERTRB input block. This item may contain up to 80 characters.

Item 4.2 One card, containing TITLE for job identification. This item may contain up to 80 characters. The first 9 characters are used to identify peripheral plot, if LPLOT = 1.

Item 4.3 One card, containing the integer control parameters NSELCT, LUNIT, and LPLOT.

Item 4.4 One card, containing NSELCT values of the integer array LSELCT.

Item 4.5 One card, containing the character string VNAM.

Item 4.6 One card, containing the character strings PARNAM(I), I = 1, NDV.

Item 4.7 One card, containing the scaling parameters A and B.

## A.5.2 Format of Input Data

A.5.2. Format of Input Data

Item 1.1 - end of COPES input see Section A.5.3

Item no.2.1 1 card (8A10)

| | |
|---|---|
| Variable | Text |
| Card column | 80 |
| Format type | A |

Item no.2.2 1 card (10I5)

| | | | | |
|---|---|---|---|---|
| Variable | IØPT | NDV | NCN | ITMAX3 |
| Card column | 5 | 10 | 15 | 20 |
| Format type | I | I | I | I |

Item no.2.3 1 card (I10,3F10.6)

| | | | | |
|---|---|---|---|---|
| Variable | NB | R | ALP | SØLID |
| Card column | 10 | 20 | 30 | 40 |
| | I | F | F | F |

Item no. 2.4 1 card (8F10.0)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | KICR | KØCR | T | ZM | P | TMX | THLE | THTE |
| Card column | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Format type | F | F | F | F | F | F | F | F |

Item no. 2.5 1 card (8A10)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | VNAME(1) | VNAME(2) | --- | --- | VNAME(NDV) | | | |
| Card column | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Format type | A | A | A | A | A | A | A | A |

Item no. 2.6 1 card (10I5)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | IDV(1) | IDV(2) | --- | --- | IDV(NDV) | | | |
| Card column | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 |
| Format type | I | I | I | I | I | I | I | I |

Item no. 2.7 1 card (I10, 3F10.6)

| | | |
|---|---|---|
| Variable | ICALB | PSTEP |
| Card column | 10 | 20 |
| Format type | | |

Item no. 2.8 1 card (8F10) Read only when ICALB not zero.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | DVCALB(1) | DVCALB(2) | ---- | --- | DVCALB(NDV) | | | |
| Card column | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Format type | F | F | F | F | F | F | F | F |

Item no. 3.1 1 card (8A10)

| | |
|---|---|
| Variable | Text |
| Card column | 80 |
| Format type | A |

Item no. 3.2 1 card (8F10.5)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | GAM | AR | TIP | RHØIP | WTFL | | ØMEGA | ØRF |
| Card column | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Format type | F | F | F | F | F | F | F | F |

Item no. 3.3 1 card (8F10.5)

| | | | | | | |
|---|---|---|---|---|---|---|
| Variable | BETAI | BETAØ | | | FSMI | FSMØ |
| Card column | 10 | 20 | 30 | 40 | 50 | 60 |
| Format type | F | F | F | K | F | F |

Item no. 3.4 1 card (8F10.5)

| | | | | |
|---|---|---|---|---|
| Variable | REDFAC | DENTØL | SSM1 | SSM2 |
| Card column | 10 | 20 | 30 | |
| Format type | F | F | F | F |

Item no. 3.5 1 card (16I5)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | MBI | MBØ | | | MM | NBBI | NBL | NRSP | MØPT | LØPT | LRVB |
| Card column | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| Format type | I | I | I | I | I | I | I | I | I | I | I |

Item no. 3.6 1 card (8F10.5)

| | | | | | |
|---|---|---|---|---|---|
| Variable | | | | | SPLNØ(1) |
| Card column | 10 | 20 | 30 | 40 | 50 |
| Format type | | | | | F |

Item no. 3.7 1 card (8F10.5)

| | | | | | |
|---|---|---|---|---|---|
| Variable | | | | | SPLNØ(2) |
| Card column | 10 | 20 | 30 | 40 | 50 |
| Format type | | | | | F |

Item no. 3.8 J cards, J=INT((NRSP-1)/8)+1, 8 values per card (8F10.5)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | MR(1) | MR(2) | ---- | ---- | MR(NRSP) | | | |
| Card column | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Format type | F | F | F | F | F | F | F | F |

Item no. 3.9 J cards, J as above, 8 values per card (8F10.5)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | RMSP(1) | RMSP(2) | ---- | ---- | RMSP(NRSP) | | | |
| Card column | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Format type | F | F | F | F | F | F | F | F |

Item no.3.10 J cards, J as above, 8 values per card (8F10.5)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | BESP(1) | BESP(2) | ---- | ---- | BESP(NRSP) | | | |
| Card column | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Format type | F | F | F | F | F | F | F | F |

Item no.3.11 (If MØPT=1) J cards, J as above,8 values per card (8F10.5)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | WØWCR(1) | WØWCR(2) | ---- | ---- | WØWCR(NRSP) | | | |
| Card column | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Format type | F | F | F | F | F | F | F | F |

Item no.3.12 (If LØPT≠0) J cards, J as above,8 values per card (8F10.5)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | PLØSS(1) | PLØSS(2) | ---- | ---- | PLØSS(NRSP) | | | |
| Card column | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Format type | F | F | F | F | F | F | F | F |

Item no.3.13 1 card (16I5)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Variable | BLDAT | AANDK | ERSØR | STRFN | SLCRD | INTVL | SURVL |
| Card column | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
| Format type | I | I | I | I | I | I | I |

Item no.3.14 1 card (8A10)

| | |
|---|---|
| Variable | $END |
| Card column | 10 |
| Format type | A |

Item no. 4.1 1 card (8A10)

| | |
|---|---|
| Variable | TEXT |
| Card column | 80 |
| Format type | A |

Item no. 4.2 1 card (8A10)

| | |
|---|---|
| Variable | TITLE |
| Card column | 80 |
| Format type | A |

Item no. 4.3 1 card (16I5)

| | | | |
|---|---|---|---|
| Variable | NSELCT | LUNIT | LPLØT |
| Card column | 5 | 10 | 15 |
| Format type | I | I | I |

Item no. 4.4 1 card (16I5)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | LSELCT(1) | LSELCT(2) | ----- | ----- | LSELCT(NSELCT) | | | |
| Card column | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 |
| Format type | I | I | I | I | I | I | I | I |

Item no. 4.5 1 card (2A1)

| | |
|---|---|
| Variable | VNAM |
| Card column | 2 |
| Format type | A |

Item no. 4.6 1 card (10A8)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | PARNAM(1) | PARNAM(2 | --- | ---- | PARNAM(NDV) | | | |
| Card column | 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 |
| Format type | A | A | A | A | A | A | A | A |

Item no. 4.7 1 card (8F10.6)

| | | |
|---|---|---|
| Variable | A | B |
| Card column | 10 | 20 |
| Format type | F | F |

## A.5.3 Format of COPES Input Data.

DATA BLOCK A

DESCRIPTION: Title card.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| TITLE | | | | | | | | 20A4 |
| CANTILEVERED BEAM DESIGN | | | | | | | | |

| FIELD | CONTENTS |
|---|---|
| 1-8 | Any 80 character title may be given on this card. |

DATA BLOCK B

DESCRIPTION: Program Control Parameters.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | | FORMAT |
|---|---|---|---|---|---|---|---|---|
| NCALC | NDV | NSV | N2VAR | NXAPRX | IPNPUT | IPDBG | | 7I10 |
| 2 | 2 | 3 | 5 | 2 | 0 | 0 | | |

FIELD CONTENTS

1 NCALC: Calculation Control

0 - Read input and stop. Data of blocks A, B and V is required. Remaining data is optional.

1 - One cycle through program. The same as executing ANALIZ stand-alone. Data of blocks A, B and V is required. Remaining data is optional.

2 - Optimization. Data of blocks A-I and V is required. Remaining data is optional.

3 - Sensitivity analysis. Data of blocks A, B, P, Q and V is required. Remaining data is optional.

4 - Two variable function space. Data of blocks A, B, and R-V is required. Remaining data is optional.

FIELD CONTENTS

1 - cont. NCALC:

5 - Optimum Sensitivity. Data of blocks A-K and V is required. Remaining data is optional.

6 - Optimization using approximation techniques. Data of blocks A-O and V is required. Remaining data is optional.

2 NDV: Number of independent design variables in optimization.

3 NSV: Number of variables on which sensitivity analysis will be performed.

4 N2VAR: Number of objective functions in a two variable function space study.

5 NXAPRX: Number of X-variables for approximate analysis/optimization.

6 IPNPUT: Input print control.
0 - Print card images of data plus formatted print of input data.
1 - Formatted print only of input data.
2 - No print of input data.

7 IPDBG: Debug print control.

DATA BLOCK C OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Integer optimization control parameters.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| IPRINT | ITMAX | ICNDIR | NSCAL | ITRM | LINOBJ | NACMX1 | NFDG | 8I10 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

FIELD CONTENTS

1 IPRINT: Print control used in the optimization program CONMIN.

0 - No print during optimization.

1 - Print initial and final optimization information.

2 - Print above plus objective function value and design variable values at each iteration.

3 - Print above plus constraint values, direction vector and move parameter at each iteration.

4 - Print above plus gradient information.

5 - Print above plus each proposed design vector, objective function and constraint values during the one-dimensional search.

| FIELD | CONTENTS |
|---|---|
| 2 | ITMAX: Maximum number of optimization iterations allowed. DEFAULT = 20. |
| 3 | ICNDIR: Conjugate direction restart parameter. DEFAULT = NDV + 1. |
| 4 | NSCAL: Scaling parameter. GT.0 - Scale design variables to order of magnitude one every NSCAL iterations. LT.0 - Scal design variables according to user-input scaling values. |
| 5 | ITRM: Number of consecutive iterations which must satisfy relative or absolute convergence criterion before optimization process is terminated. DEFAULT = 3. |
| 6 | LINOBJ: Linear objective function identifier. If the optimization objective is known to be a linear function of the design variables, set LINOBJ = 1. DEFAULT = Non-linear. |
| 7 | NACMX1; One plus the maximum number of active constraints anticipated. DEFAULT = NDV + 2. |
| 8 | NFDG: Finite difference gradient identifier.<br>0 - All gradient information is computed by finite difference within CONMIN.<br>1 - All gradient information is computed analytically by the user-supplied code.<br>2 - Gradient of objective is computed analytically. Gradients of constraints are computed by finite difference within CONMIN. |

REMARKS

1) Currently NFDG must be zero in COPES.

DATA BLOCK D OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Floating point optimization program parameters.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |  | FORMAT |
|---|---|---|---|---|---|---|---|---|
| FDCH | FDCHM | CT | CTMIN | CTL | CTLMIN | THETA |  | 7F10 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |  |  |
| DELFUN | DABFUN | ALPHAX | ABOBJ1 |  |  |  |  | 4F10 |
| 0.0 | 0.0 | 0.0 | 0.0 |  |  |  |  |  |

NOTE: TWO CARDS ARE READ HERE.

| FIELD | | CONTENTS |
|---|---|---|
| 1 | FDCH: | Relative change in design variables in calculating finite difference gradients. DEFAULT = 0.01. |
| 2 | FDCHM: | Minimum absolute step in finite difference gradient calculations. DEFAULT = 0.001. |

| FIELD | CONTENTS |
|---|---|
| 3 | CT: Constraint thickness parameter. DEFAULT = -0.05. |
| 4 | CTMIN: Minimum absolute value of CT considered in the optimization process. DEFAULT = 0.004. |
| 5 | CTL: Constraint thickness parameter for linear constraints. DEFAULT = -0.01. |
| 6 | CTLMIN: Minimum absolute value of CTL considered in the optimization process. DEFAULT = 0.001. |
| 7 | THETA: Mean value of push-off factor in the method of feasible directions. DEFAULT = 1.0. |
| 1 | DELFUN: Minimum relative change in objective function to indicate convergence of the optimization process. DEFAULT = 0.001. |
| 2 | DABFUN: Minimum absolute change in objective function to indicate convergence of the optimization process. DEFAULT = 0.001 times the initial objective value. |
| 3 | ALPHAX: Maximum fractional change in any any design variable for first estimate of the step.in the one-dimensional search. DEFAULT = 0.1. |
| 4 | ABOBJ1: Expected fractional change in the objective function for first estimate of the step in the one-dimensional search. DEFAULT = 0.1. |

REMARKS

1) The DEFAULT values for these parameters usually work well.

DATA BLOCK E OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Total number of design variables, design objective identification and sign.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | | FORMAT |
|---|---|---|---|---|
| NDVTOT | IOBJ | SGNOPT | | 2I10,F10 |
| 0 | 3 | -1.0 | | |

FIELD CONTENTS

1 NDVTOT: Total number of variables linked to the design variables. This option allows two or more parameters to be assigned to a single design variable. The value of each parameter is the value of the design variable times a multiplier, which may be different for each parameter. DEFAULT = NDV.

2 IOBJ: Global variable location associated with the objective function in optimization.

3 SGNOPT: Sign used to identify whether function is to be maximized or minimized. +1.0 indicates maximization. -1.0 indicates minimization. If SGNOPT is not unity in magnitude, it acts as a multiplier as well, to scale the magnitude of the objective.

DATA BLOCK F OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Design variable bounds, initial values and scaling factors.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | | FORMAT |
|---|---|---|---|---|---|
| VLB | VUB | X | SCAL | | 4F10 |
| .5 | 5. | 0.0 | 0.0 | | |

NOTE: READ ONE CARD FOR EACH OF THE NDV INDEPENDENT DESIGN VARIABLES.

FIELD CONTENTS

1 VLB: Lower bound on the design variable. If VLB.LT.-1.0E+15, no lower bound.

2 VUB: Upper bound on the design variable. If VUB.GT.10.E+15, no upper bound.

3 X: Initial value of the design variable. If X is non-zero, this will supercede the value initialized by the user-supplied subroutine ANALIZ.

4 SCAL: Design variable scale factor. Not used if NSCAL.GE.0 in BLOCK C.

DATA BLOCK G OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Design variable identification.

FORMAT AND EXAMPLE

| 1 | 2 | 3 |  | FORMAT |
|---|---|---|---|---|
| NDSGN | IDSGN | AMULT |  | 2I10,F10 |
| 1 | 1 | 1.0 |  |  |

NOTE: READ ONE CARD FOR EACH OF THE NDVTOT DESIGN VARIABLES.

FIELD CONTENTS

1 NDSGN: Design variable number associated with this variable.

2 IDSGN: Global variable number associated with this variable.

3 AMULT: Constant multiplier on this variable. The value of the variable will be the value of the design variable, NDSGN, times AMULT. DEFAULT = 1.0.

DATA BLOCK H OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Number of constrained parameters.

FORMAT AND EXAMPLE

| 1 | | FORMAT |
|---|---|---|
| NCONS | | I10 |
| 4 | | |

FIELD CONTENTS

1 NCONS: Number of constraint sets in the optimization problem.

REMARKS

1) If two or more adjacent parameters in the global common block have the same limits imposed, these are part of the same constraint set.

DATA BLOCK I OMIT IF NDV = 0 IN BLOCK B, OR NCONS = 0 IN BLOCK H

DESCRIPTION: Constraint identification and constraint bounds.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 |  | FORMAT |
|---|---|---|---|---|---|
| ICON | JCON | LCON |  |  | 3I10 |
| 4 | 0 | 0 |  |  |  |
| BL | SCAL1 | BU | SCAL2 |  |  |
| -1.0 +20 | 0.0 | 20000. | 0.0 |  |  |

NOTE: READ TWO CARDS FOR EACH OF THE NCONS CONSTRAINT SETS.

FIELD CONTENTS

1 ICON: First global number corresponding to the constraint set.

2 ICON: Last global number corresponding to the constraint set. DEFAULT = ICON.

3 LCON: Linear constraint identifier for this constraint set. LCON = 1 indicates linear constraints.

| FIELD | CONTENTS | |
|---|---|---|
| 1 | BL: | Lower bound on the constrained variables. If BL.LT.-1.0E+15, no lower bound. |
| 2 | SCAL1: | Normalization factor on lower bound. DEFAULT = MAX of ABS(BL), 0.1. |
| 3 | BU: | Upper bound on the constrained variables. If BU.GT.1.0E+15, no upper bound. |
| 4 | SCAL2: | Normalization factor on upper bound. DEFAULT = MAX of ABS(BU), 0.1. |

REMARKS

1) The normalization factor should usually be defaulted.

2) The constraint functions sent to CONMIN are of the form;
(BL - VALUE)/SCAL1 .LE. 0.0 and (VALUE - BU)/SCAL2 .LE. 0.0.

3) Each constrained parameter is converted to two constraints in CONMIN unless ABS(BL) or ABS(BU) exceeds 1.0E+15, in which case no constraint is created for that bound.

DATA BLOCK J OMIT IF NXAPRX = 0 IN BLOCK B

DESCRIPTION: Approximate analysis/optimization control parameters.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| NF | NXS | NXFS | NXA | INOM | ISCRX | ISCRXF | IPAPRX | 8I10 |
| 5 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | |
| KMIN | KMAX | NPMAX | JNOM | INXLOC | INFLOC | | | 6I10 |
| 0 | 0 | 0 | 0 | 0 | 0 | | | |

FIELD CONTENTS

1 NF: Number of functions to be approximated. Default = number of optimization objective and constraint functions.

2 NXS: Number of X-vectors read as data.

3 NXFS: Number of X-F pairs read as data.

4 NXA: If non-zero, the design variables read by SUBROUTINE ANALIZ form an X-vector.

5 INOM: Nominal X-vector. Default = bost available.

| FIELD | CONTENTS |
|---|---|
| 6 | ISCRX: File from which NXS X-vectors are read. Default = 5. |
| 7 | ISCRXF: File from which NXFS X-F pairs of data are read. Default = 5. |
| 1 | KMIN: Minimum number of approximation iterations. |
| 2 | KMAX: Maximum number of approximation iterations. |
| 3 | NPMAX: Maximum number of designs retained for Tayler series expansion. |
| 4 | JNOM: Number of iterations after which the best design is picked as nominal. |
| 5 | INXLOC: X-variable global location identifier. If INXLOC = 0, the Tayler series expansion is on the design variables listed in BLOCK G. |
| 6 | INFLOC: Function global location identifier. If INFLOC = 0, the Objective and constraint functions identified in BLOCKS E and I are the functions on which the Tayler series expansion is performed. |

REMARKS

1) If ISCRX and/or ISCRXF file number is other than 5, the data read from that file is assumed to be binary data.

2) If NXS = NXFS = 0, NXA is defaulted to NXA = 1, even is it is read as zero. Also, a second vector of design variables is automatically defined by COPES to yield two independent designs to start the optimization.

DATA BLOCK K OMIT IF NDV = 0 IN BLOCK B, OR NXAPRX = 0 IN BLOCK B

DESCRIPTION: Bounds and multipliers for approximate optimization.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| DX1 | DX2 | DX3 | DX4 | DX5 | ... | ... | ... | 8F10 |
| .5 | 2. | | | | | | | |
| XFACT1 | XFACT2 | | | | | | | 2F10 |
| 0. | 0. | | | | | | | |

NOTE: TWO OR MORE CARDS ARE READ HERE.

FIELD CONTENTS

1-8 DXI: Allowable change (in magnitude) of the Ith design variable during each approximate optimization.

1 XFACT1: Multiplier on DXI when the diagonal elements of the H matrix are available. Default = 1.5.

2 XFACT2: Multiplier on DXI when all elements of the H matrix are available. Default = 2.0.

## DATA BLOCK L OMIT IF NXAPRX = 0 IN BLOCK B OR INXLOC = 0 IN BLOCK J

DESCRIPTION: Global locations of approximating variables.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| LOCX1 | LOCX2 | LOCX3 | LOCX4 | ..... | ..... | ..... | ..... | 8I10 |
| 1 | 2 | | | | | | | |

NOTE: MORE THAN ONE CARD MAY BE READ HERE.

| FIELD | CONTENTS |
|---|---|
| 1-8 | LOCI: Global location of Ith approximating variable. |

REMARKS

1) If INXLOC = 0 in BLOCK J, this data is not read. In this case, the data is defaulted to be the global locations of the design variables (IDSGN values in BLOCK G).

DATA BLOCK M OMIT IF NXAPRX = 0 IN BLOCK B OR INFLOC = 0 IN BLOCK J

DESCRIPTION: Global locations of functions to be approximated.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| LOCF1 | LOCF2 | LOCF3 | LOCF4 | ..... | ..... | ..... | ..... | 8I10 |
| 3 | 5 | 6 | 4 |  |  |  |  |  |

NOTE: MORE THAN ONE CARD MAY BE READ HERE.

| FIELD | CONTENTS |
|---|---|
| 1-8 | LOCI: Global location of Ith function to be approximated. |

REMARKS

1) If INFLOC = 0 in BLOCK J, this data is not read. In this case, the data is defaulted to be the global locations of the objective function (IOBJ in BLOCK E) followed by the global locations of the constrained parameters (ICON, JCON in BLOCK I).

DATA BLOCK N OMIT IF NXS = 0 IN BLOCK J

DESCRIPTION: X-Vectors for approximate optimization.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| XI1 | XI2 | XI3 | XI4 | ... | ... | ... | ... | 8F10 |
| 4. | 15. | | | | | | | |

NOTE: NXS SETS OF DATA ARE READ HERE.

NOTE: MORE THAN ONE CARD MAY BE READ FOR EACH SET OF DATA.

| FIELD | CONTENTS |
|---|---|
| 1-8 | XIJ: Jth value of Ith X-vector, J = 1,NXAPRX. |

## DATA BLOCK O OMIT IF NXFS = 0 IN BLOCK J

DESCRIPTION: X-F pairs of information for approximate optimization.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| X1 | X2 | X3 | X4 | ... | ... | ... | ... | 8F10 |
| 2. | 18. | | | | | | | |
| Y1 | Y2 | Y3 | Y4 | Y5 | ... | ... | ... | |
| 7200. | 416.667 | .914495 | 18518.519 | | | | | |

NOTE: NXFS SETS OF DATA ARE READ HERE.

NOTE: MORE THAN ONE CARD MAY BE REQUIRED FOR XI OR YI.

NOTE: NXAPRX VALUES OF X AND NF VALUES OF Y ARE READ FOR EACH SET OF DATA.

| FIELD | CONTENTS |
|---|---|
| 1-8 | XI: Ith value of X, I = 1,NXAPRX. |
| 1-8 | YI: Ith value of Y, I = 1,NF. |

DATA BLOCK P OMIT IF NSV = 0 IN BLOCK B

DESCRIPTION: Sensitivity objectives.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| NSOBJ | IPSENS | | | | | | | 2I10 |
| 5 | 0 | | | | | | | |
| NSN1 | NSN2 | NSN3 | NSN4 | NSN5 | ... | ... | ... | 8I10 |
| 3 | 4 | 5 | 6 | 7 | | | | |

NOTE: TWO OR MORE CARDS ARE READ HERE.

| FIELD | | CONTENTS |
|---|---|---|
| 1 | NSOBJ: | Number of seperate objective functions to be calculated as functions of the sensitivity variables. |
| 2 | IPSENS: | Print control. If IPSENS.GT.0, detailed print will be called at each step in the sensitivity analysis. DEFAULT = No print. |
| 1-8 | NSNI: | Global variable number associated with the sensitivity objective functions. |

REMARKS

1) More than eight sensitivity objectives are allowed. Add data cards as required to contain data.

## DATA BLOCK Q OMIT IF NSV = 0 IN BLOCK B

DESCRIPTION: Sensitivity variables.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 -- | FORMAT |
|---|---|---|---|---|---|---|---|---|
| ISENS | NSENS | | | | | | | 2I10 |
| 9 | 4 | | | | | | | |
| SNS1 | SNS2 | SNS3 | SNS4 | .... | .... | .... | .... | 8F10 |
| 200. | 100. | 150. | 250. | | | | | |

NOTE: READ ONE SET OF DATA FOR EACH OF THE NSV SENSITIVITY VARIABLES.

NOTE: TWO OR MORE CARDS ARE READ FOR EACH SET OF DATA.

| FIELD | | CONTENTS |
|---|---|---|
| 1 | ISENS: | Global variable number associated with the sensitivity variable. |
| 2 | NSENS: | Number of values of this sensitivity variable to be read on the next card. |
| 1-8 | SENSI; | Values of the sensitivity variable. I = 1,NSENS. I = 1 corresponds to the nominal value. |

REMARKS

1) More than eight values of the sensitivity variable are allowed. Add data cards as required to contain the data.

DATA BLOCK R OMIT IF N2VAR = 0 IN BLOCK B

DESCRIPTION: Two variable function space control parameters.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | | FORMAT |
|---|---|---|---|---|---|---|
| N2VX | M2VX | N2VY | M2VY | IP2VAR | | 5I10 |
| 1 | 4 | 2 | 5 | 0 | | |

FIELD CONTENTS

1 N2VX: Global location of the X-variable in the two variable function space.

2 M2VX: Number of values of X to be considered.

3 N2VY: Global location of the Y-variable in the two variable function space.

4 M2VY: Number of values of Y to be considered.

5 IP2VAR: Print control. If IP2VAR.GT.0, detailed print will be called at each step (each X-Y combination). DEFAULT = No print.

## DATA BLOCK S OMIT IF N2VAR = 0 IN BLOCK B

DESCRIPTION: Objective functions of the two variable function space study.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| NZ1 | NZ2 | NZ3 | NZ4 | NZ5 | ... | ... | ... | 8I10 |
| 3 | 4 | 5 | 6 | 7 | | | | |

FIELD CONTENTS

1-8 NZI: Global location corresponding to the Ith function of X and Y to be calculated. N2VAR values are read here.

REMARKS

1) More than eight objective functions are allowed. Add data cards as required to contain the data.

DATA BLOCK T OMIT IF N2VAR = 0 IN BLOCK B

DESCRIPTION: Values of the X-variable in a two variable function space study.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| X1 | X2 | X3 | X4 | ... | ... | ... | ... | 8F10 |
| 0.5 | 1.0 | 1.5 | 2.0 |  |  |  |  |  |

FIELD CONTENTS

1-8 XI: Values of the X-variable in the two variable function space. M2VX values are read here.

REMARKS

1) More than eight values are allowed. Add data cards as requirèd to contain the data.

DATA BLOCK U OMIT IF N2VAR = 0 IN BLOCK B

DESCRIPTION: Values of the Y-variable in a two variable function space study.

FORMAT AND EXAMPLE

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | FORMAT |
|---|---|---|---|---|---|---|---|---|
| Y1 | Y2 | Y3 | Y4 | Y5 | ... | ... | ... | 8F10 |
| 4.0 | 8.0 | 12.0 | 16.0 | 20.0 | | | | |

FIELD CONTENTS

1-8 YI: Values of the Y-variable in the two variable function space. M2VY values are read here.

REMARKS

1) More than eight values are allowed. Add data cards as required to contain the data.

DATA BLOCK V

DESCRIPTION: COPES data 'END' card.

FORMAT AND EXAMPLE

| 1 | | FORMAT |
|---|---|---|
| END | | 3A1 |
| END | | |

| FIELD | CONTENTS |
|---|---|
| 1 | The word 'END' in columns 1-3. |

REMARKS

1) This card MUST appear at the end of the COPES data.

2) This ends the COPES input data.

3) Data for the user-supplied routine, ANALIZ, follows this.

## A.6 DESCRIPTION OF OUTPUT

The first output item consists of a banner page related to the COPES control program and followed by card images of the COPES input data. The next output items contain COPES optimization information which will be employed by the optimization program. This is followed by a display of input information required by the ANALIZ subroutine and related to the control parameters, constant blade properties, variable blade properties, active design variables, and input information for the calibration solution matrix. Next, is a display of input information required by the TSONIC blade-to-blade flow solver. Finally, a display is provided of the input information needed by the perturbation method.

The next items of output are related to the TSONIC solution for the baseline blade profile. The first item consists of the input information on design variables and constant blade properties that is provided to the blade element program which then performs the computation necessary to determine blade property characteristics required as input to the TSONIC code. The next items are the input to the TSONIC code and the output generated by the code for the flow solution. This is followed by output from OBJCON related to the objective function and active constraints. The next item is the banner page of information that will initiate the CONMIN minimization procedure. The optimization search cycles are then begun. The output that follows depends upon which IOPT option was specified. However, regardless of the IOPT option selected, each time a TSONIC flow solution is required by the optimization package, the following segment of output is produced: the input information regarding design variables and constant blade properties that is provided to the blade element program is displayed, followed by the input to the TSONIC code, the output from TSONIC, and finally, output from OBJCON related to the current objective function and active side constraint values for the TSONIC solution just calculated. Consequently, for IOPT = 1, for which TSONIC solutions are used throughout the optimization process, the above segment of information is displayed for each TSONIC solution for the gradient and search calculations. At the end of each iteration cycle, CONMIN provides output regarding the ending values of the design variables and side constraints. This continues until the ITMAX limit is reached, or the objective function has not changed within the last three iterations, at which point the final optimization results are printed, followed by a final TSONIC calculation at the design point. For the IOPT = 2 option, after the base solution is computed, the calibration solution matrix is determined based on user-supplied information. The optimization cycles then proceed using perturbation-predicted solutions for the blade surface velocities. When the optimization process is complete, a final TSONIC solution is calculated at the design point and a printer plot provided exhibiting a comparison of the perturbation-predicted surface velocity distribution with the TSONIC result. For the IOPT = 3 option, the optimization process is allowed to proceed with TSONIC solutions only as with IOPT = 1, but only for one search cycle. Then, based on the new base design point reached, design variable values for a calibration solution matrix are determined. Next, each of the TSONIC solutions for the new base and calibration solutions are separately determined, with output provided after each solution regarding number of critical points, and strained coordinate and surface pressure arrays. Following the final calibration solution, summary output is provided regarding the base coordinates, the strained coordinate arrays for each calibration solution, and the corresponding surface velocity arrays. Next, the CONMIN optimization search cycles are entered using the perturbation method to predict all flow solutions required in the gradient and search calculations. The search cycles are continued to the ITMAX3 limit or until the objective function does not change for three successive iterations, at which point the final optimization results are printed, followed by a final TSONIC calculation at the design point, and a printer plot illustrating comparisons between the perturbation method predicted surface velocities distribution and the nonlinear TSONIC result.

## A.7 ERROR MESSAGES

```
NUMBER OF CRITICAL POINTS IN
BASE AND CALIBRATION SOLUTIONS
ARE UNEQUAL - CALCULATION ENDED
```

This message will be printed if critical points are specified in straining (LSPEC = 0) and the number of critical points in base and calibration solutions are unequal. The remedy is to avoid use of critical points in straining, or to use base and calibration solutions having equal numbers of critical points.

```
NUMBER OF CRITICAL POINTS
SELECTED EXCEEDS NUMBER
ACTUALLY LOCATED - CALCULATION
ENDED
```

This message will be printed if more critical points are specified in straining (LSPEC = 0) than the number located by the program. The remedy is to specify a number of points less than or equal to the actual number.

```
ORDER OF SPECIFIED POINTS IN
BASE AND CALIBRATION SOLUTIONS
DOES NOT CORRESPOND - CALCULATION
ENDED
```

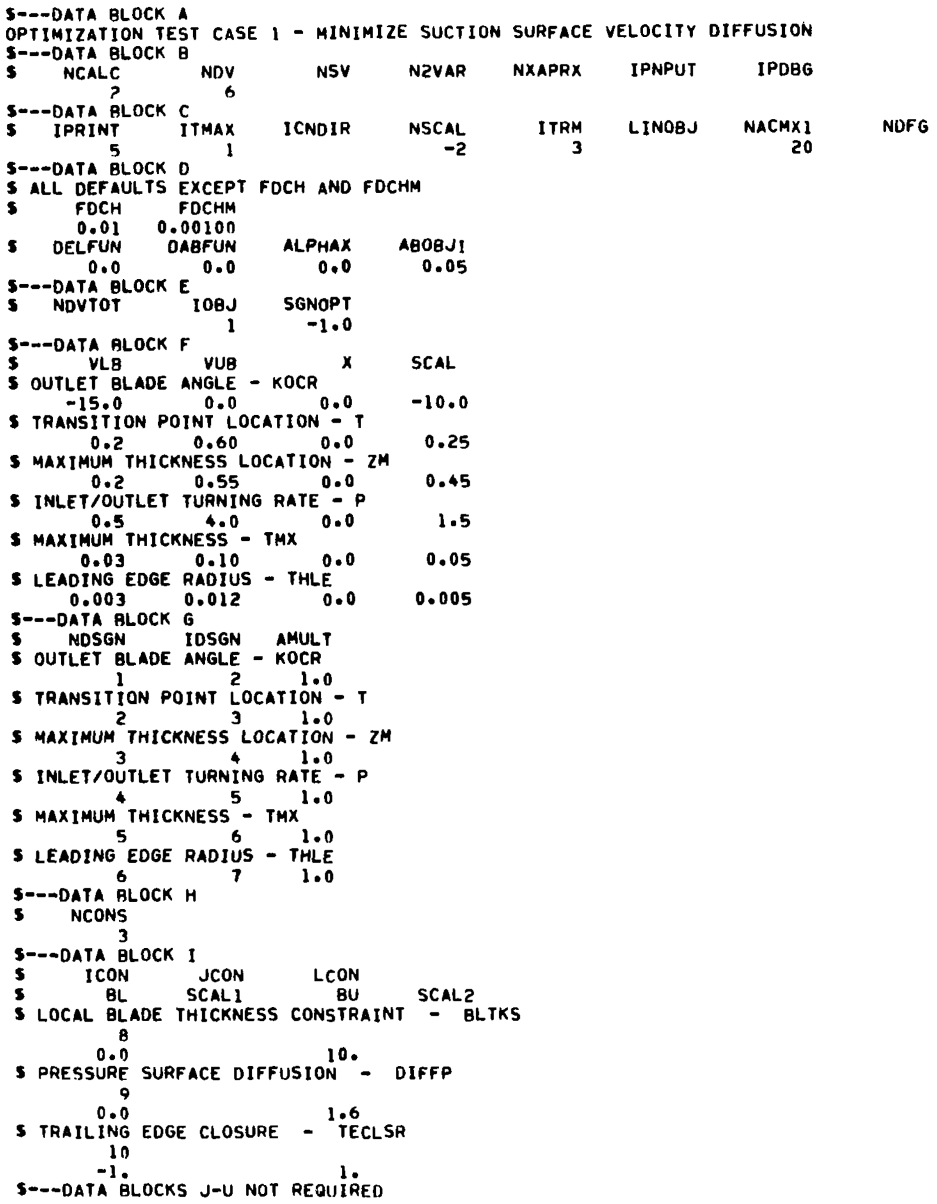
This message will be printed if the fixed points specified (LSPEC = 0) occur in a different sequence in the base and calibration solutions. The remedy is to use base and calibration solutions having the same qualitative features.

## A.8 SAMPLE CASE

The sample case presented in this section provides example results of the perturbation method for the blade design optimization problem described in Section 3 of the main text. The calculation is for the simultaneous six design variable (KOCR, T, ZM, P, TMX, THLE) optimization of full potential turbomachinery flows past compressor blades having NASA double circular arc blade profiles with the following initial values, lower, and upper bounds, respectively, of these parameters: (-10.0, 0.25, 0.45, 1.5, 0.05, 0.005), (-15.0, 0.20, 0.50, 0.03, 0.003), (0.00, 0.60, 0.55, 4.00, 0.10, 0.012).

The input data is tabulated in Figure A.1 with the COPES data appearing first, followed by the inputs for subroutine ANALIZ, subroutine TSONIC, and subroutine PERTURB. We note that in the input for subroutine PERTURB, the number of invariant points to be held invariant for this calculation were chosen to be one (NSELCT = 1), and that particular point was chosen as the maximum point (LSELCT(1) = 2, i.e.), the stagnation point, and that the dependent variable for print output will be symbolized by 'WM' denoting the surface speed. Examination of the sample input and comparison with the description of input data provided in Sections A.5.1 to A.5.3 provides a convenient, self-explanatory menu of how to prepare typical input data sets for future case studies.

Finally, Figure A.2 provides an abbreviated print output for this sample case. That output, together, with the information contained in Appendix A, provides a benchmark result that can be employed to completely verify the BLDOPT code on any user facility.



```
$---DATA BLOCK A
OPTIMIZATION TEST CASE 1 - MINIMIZE SUCTION SURFACE VELOCITY DIFFUSION
$---DATA BLOCK B
$    NCALC       NDV       NSV     N2VAR    NXAPRX     IPNPUT     IPDBG
         2         6
$---DATA BLOCK C
$   IPRINT     ITMAX    ICNDIR     NSCAL       ITRM     LINOBJ    NACMX1       NDFG
         5         1                  -2          3                   20
$---DATA BLOCK D
$ ALL DEFAULTS EXCEPT FDCH AND FDCHM
$     FDCH      FDCHM
      0.01   0.00100
$   DELFUN    DABFUN    ALPHAX    ABOBJ1
       0.0       0.0       0.0      0.05
$---DATA BLOCK E
$   NDVTOT     IOBJ     SGNOPT
                  1       -1.0
$---DATA BLOCK F
$      VLB       VUB         X      SCAL
     -15.0       0.0       0.0     -10.0
$ TRANSITION POINT LOCATION - T
       0.2      0.60       0.0      0.25
$ MAXIMUM THICKNESS LOCATION - ZM
       0.2      0.55       0.0      0.45
$ INLET/OUTLET TURNING RATE - P
       0.5       4.0       0.0       1.5
$ MAXIMUM THICKNESS - TMX
      0.03      0.10       0.0      0.05
$ LEADING EDGE RADIUS - THLE
     0.003     0.012       0.0     0.005
$---DATA BLOCK G
$    NDSGN      IDSGN    AMULT
$ OUTLET BLADE ANGLE - KOCR
         1         2     1.0
$ TRANSITION POINT LOCATION - T
         2         3     1.0
$ MAXIMUM THICKNESS LOCATION - ZM
         3         4     1.0
$ INLET/OUTLET TURNING RATE - P
         4         5     1.0
$ MAXIMUM THICKNESS - TMX
         5         6     1.0
$ LEADING EDGE RADIUS - THLE
         6         7     1.0
$---DATA BLOCK H
$    NCONS
         3
$---DATA BLOCK I
$      ICON       JCON       LCON
$       BL      SCAL1        BU      SCAL2
$ LOCAL BLADE THICKNESS CONSTRAINT  -  BLTKS
         8
       0.0                  10.
$ PRESSURE SURFACE DIFFUSION  -  DIFFP
         9
       0.0                  1.6
$ TRAILING EDGE CLOSURE  -  TECLSR
        10
       -1.                   1.
$---DATA BLOCKS J-U NOT REQUIRED
```

Figure A.1.- Card input for sample case.

```
$---DATA BLOCK V
END
     ***  INPUT FOR SUBROUTINE ANALIZ  ***
    3    6    3    6
        34  0.454     6.664     2.252
  52.0     -10.0       0.25      0.45      1.5       0.05      0.005     0.005
KOCR      T         ZM        P         TMX       THLE
    2    3    4    5    6    7
         0   0.0
     ***  INPUT FOR SUBROUTINE TSONIC  ***
1.400     1716.48   599.76    .00334586 .00570000           0.0       1.910
48.2      0.0       0.0       0.0       0.0       0.0
1.0       0.001     0.0       0.0
   24   56              72   15   34   13    0    1    0
                                        13.0
                                        13.0
-.13      -.005     .005      .02003    .04003    .08003    ,10003    .12503
.15004    .17526    .18526    .22500    .27
.4540     .4540     .4540     .4540     .4540     .4540     .4540     .4540
.4540     .4540     .4540     .4540     .4540
,05       ,05       ,0499     .0496     .04925    .0485     .04815    .04770
.04720    .04675    .04661    .04661    .04661
0.        0.        .0015     .0059     .0110     .0215     .0300     .0335
.0400     .0470     .048      .048      .048
    0    0    0    0    0    0    1
$END
     ***  INPUT FOR SUBROUTINE PERTRB  ***
OPTIMIZATION TEST CASE 1 - MINIMIZE SUCTION SURFACE VELOCITY DIFFUSION
    1    1    0
    2
WM
  KOCR       T      ZM        P      TMX    THLE
      -1.0       1.0
```

Figure A.1.- Concluded.

```
CCCCCCC   0000000   PPPPPPP   EEEEEEE   SSSSSSS
C         0     0   P     P   E         S
C         0     0   P     P   E         S
C         0     0   PPPPPPP   EEEE      SSSSSSS
C         0     0   P         E               S
C         0     0   P         E               S
CCCCCCC   0000000   P         EEEEEEE   SSSSSSS



         C O N T R O L   P R O G R A M

                     F O R

   E N G I N E E R I N G   S Y N T H E S I S



                   T I T L F

OPTIMIZATION TEST CASE 1 - MINIMIZE SUCTION SURFACE VELOCITY DIFFUSION
```

Figure A.2.- Abbreviated print output for sample case.

```
CARD IMAGES OF CONTROL DATA


CARD                    IMAGE


  1)  $---DATA BLOCK A
  2)  OPTIMIZATION TEST CASE 1 - MINIMIZE SUCTION SURFACE VELOCITY DIFFUSION
  3)  $---DATA BLOCK B
  4)  $    NCALC       NDV       NSV     N2VAR    NXAPRX    IPNPUT     IPDBG
  5)           2         6
  6)  $---DATA BLOCK C
  7)  $   IPRINT     ITMAX    ICNDIR     NSCAL      ITRM    LINOBJ    NACMX1      NDFG
  8)           5         1                  -2         3                  20
  9)  $---DATA BLOCK D
 10)  $ ALL DEFAULTS EXCEPT FDCH AND FDCHM
 11)  $     FDCH     FDCHM
 12)        0.01   0.00100
 13)  $   DELFUN    DABFUN    ALPHAX    ABOBJ1
 14)         0.0       0.0       0.0      0.05
 15)  $---DATA BLOCK E
 16)  $   NDVTOT      IOBJ    SGNOPT
 17)                     1      -1.0
 18)  $---DATA BLOCK F
 19)  $      VLB       VUB         X     SCAL
 20)  $ OUTLET BLADE ANGLE - KOCR
 21)       -15.0       0.0       0.0     -10.0
 22)  $ TRANSITION POINT LOCATION - T
 23)         0.2      0.60       0.0      0.25
 24)  $ MAXIMUM THICKNESS LOCATION - ZM
 25)         0.2      0.55       0.0      0.45
 26)  $ INLET/OUTLET TURNING RATE - P
 27)         0.5       4.0       0.0       1.5
 28)  $ MAXIMUM THICKNESS - TMX
 29)        0.03      0.10       0.0      0.05
 30)  $ LEADING EDGE RADIUS - THLE
 31)       0.003     0.012       0.0     0.005
 32)  $---DATA BLOCK G
 33)  $    NDSGN     IDSGN   AMULT
 34)  $ OUTLET BLADE ANGLE - KOCR
 35)           1         2     1.0
 36)  $ TRANSITION POINT LOCATION - T
 37)           2         3     1.0
 38)  $ MAXIMUM THICKNESS LOCATION - ZM
 39)           3         4     1.0
 40)  $ INLET/OUTLET TURNING RATE - P
 41)           4         5     1.0
 42)  $ MAXIMUM THICKNESS - TMX
 43)           5         6     1.0
 44)  $ LEADING EDGE RADIUS - THLE
 45)           6         7     1.0
 46)  $---DATA BLOCK H
 47)  $    NCONS
 48)           3
 49)  $---DATA BLOCK I
 50)  $     ICON      JCON      LCON
 51)  $       BL     SCAL1        BU     SCAL2
 52)  $ LOCAL BLADE THICKNESS CONSTRAINT  -  BLTKS
 53)           8
 54)         0.0                 10.
 55)  $ PRESSURE SURFACE DIFFUSION  -  DIFFP
 56)           9
```

Figure A.2.- Continued.

```
       0.0                  1.6
$ TRAILING EDGE CLOSURE  -  TECLSR
        10
       -1.                  1.
$---DATA BLOCKS J-U NOT REQUIRED
$---DATA BLOCK V
END
```

Figure A.2.- Continued.

```
TITLE:
OPTIMIZATION TEST CASE 1 - MINIMIZE SUCTION SURFACE VELOCITY DIFFUSION


CONTROL PARAMETERS:
CALCULATION CONTROL,                   NCALC =    2
NUMBER OF GLOBAL DESIGN VARIABLES,       NDV =    6
NUMBER OF SENSITIVITY VARIABLES.         NSV =    0
NUMBER OF FUNCTIONS IN TWO-SPACE,      N2VAR =    0
NUMBER OF APPROXIMATING VAR.          NXAPRX =    0
INPUT INFORMATION PRINT CODE,         IPNPUT =    0
DEBUG PRINT CODE,                      IPDBG =    0


CALCULATION CONTROL, NCALC
VALUE   MEANING
  1     SINGLE ANALYSIS
  2     OPTIMIZATION
  3     SENSITIVITY
  4     TWO-VARIABLE FUNCTION SPACE
  5     OPTIMUM SENSITIVITY
  6     APPROXIMATE OPTIMIZATION



• • OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE          =    1
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) =  -.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT  ITMAX   ICNDIR   NSCAL    ITRM   LINOBJ   NACMX1   NFDG
  5       1       0       -2       3       0       20       0

 FDCH            FDCHM            CT               CTMIN
 .10000E-01       .10000E-02      0.               0.

 CTL             CTLMIN           THETA            PHI
 0.              0.               0.               0.

 DELFUN          DABFUN           ALPHAX           ABOBJ1
 0.              0.               0.                .50000E-01

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
D. V.      LOWER          UPPER          INITIAL
NO.        BOUND          BOUND          VALUE            SCALE
  1      -.15000E+02    0.              0.              -.10000E+02
  2       .20000E+00     .60000E+00     0.               .25000E+00
  3       .20000E+00     .55000E+00     0.               .45000E+00
  4       .50000E+00     .40000E+01     0.               .15000E+01
  5       .30000E-01     .10000E+00     0.               .50000E-01
  6       .30000E-02     .12000E-01     0.               .50000E-02


DESIGN VARIABLES
      D. V.     GLOBAL     MULTIPLYING
ID     NO.     VAR. NO.      FACTOR
 1      1         2        .10000E+01
```

Figure A.2.- Continued.

```
 2      2           3          .10000E+01
 3      3           4          .10000E+01
 4      4           5          .10000E+01
 5      5           6          .10000E+01
 6      6           7          .10000E+01


CONSTRAINT INFORMATION

THERE ARE  3 CONSTRAINT SETS
      GLOBAL  GLOBAL  LINEAR      LOWER       NORMALIZATION      UPPER      NORMALIZATION
 ID   VAR. 1  VAR. 2    ID        BOUND          FACTOR          BOUND         FACTOR
  1     8       0       0      0.             .10000E+00     .10000E+02     .10000E+02
  3     9       0       0      0.             .10000E+00     .16000E+01     .16000E+01
  5    10       0       0      -.10000E+01    .10000E+01     .10000E+01     .10000E+01

TOTAL NUMBER OF CONSTRAINED PARAMETERS =    3



● ● ESTIMATED DATA STORAGE REQUIREMENTS

           REAL                               INTEGER
INPUT  EXECUTION  AVAILABLE       INPUT  EXECUTION  AVAILABLE
  57       779       5000           34       112       1000
```

Figure A.2.- Continued.

```
                         --- INPUT FOR CONTROL SUBROUTINE ANALIZ ---


CONTROL PARAMETERS

     IOPT =  3          NDV ■  6          NCN =  3          ITMAX3 =  6


CONSTANT BLADE PARAMETERS

     NB        R       ALP       SOLID
     34      .4540    6.6640    2.2520


VARIABLE BLADE PARAMETERS

     KICR       KOCR         T          ZM          P          TMX        THLE       THTE
   52.0000   -10.0000     .2500      .4500      1.5000      .0500      .0050      .0050


ACTIVE DESIGN VARIABLES

     KOCR        T          ZM          P          TMX        THLE
  -10.0000     .2500      .4500      1.5000      .0500      .0050


ICALB = 0      PSTEP ■ 0.000
```

Figure A.2.- Continued.

```
                                --- INPUT FOR TSONIC BLADE-TO-BLADE FLOW SOLVER ---

   GAM              AR             TIP             RHOIP            WTFL                           OMEGA             ORF
 1.400000        1716.480        599.7600        .3345860E-02    .5700000E-02    0.              0.              1.910000
  BETAI           BETAO           CHORDF           STGRF            FSMI            FSMO
 48.20000        0.              0.              0.              0.              0.
  REDFAC           DENTOL           SSM1             SSM2
 1.000000        .1000000E-02    0.              0.

MBI    MBO                     MM    NBBI    NBL    NRSP    MOPT    LOPT    LRVB
  24     56      0      0      72     15      34     13       0       1       0

 BLADE SURFACE 1  --  UPPER SURFACE
   RI1             RO1             BETI1           BETO1            SPLNO1
0.              0.              0.              0.              13.00000
   MSP1  ARRAY
0.              0.              0.              0.              0.              0.              0.              0.
0.              0.              0.              0.              0.
   THSP1  ARRAY
0.              0.              0.              0.              0.              0.              0.              0.
0.              0.              0.              0.              0.

 BLADE SURFACE 2  --  LOWER SURFACE
   RI2             RO2             BETI2           BETO2            SPLNO2
0.              0.              0.              0.              13.00000
   MSP2  ARRAY
0.              0.              0.              0.              0.              0.              0.              0.
0.              0.              0.              0.              0.
   THSP2  ARRAY
0.              0.              0.              0.              0.              0.              0.              0.
0.              0.              0.              0.              0.

   MR  ARRAY
-.1300000       -.5000000E-02    .5000000E-02    .2003000E-01    .4003000E-01    .8003000E-01    .1000300        .1250300
 .1500400        .1752600        .1852600        .2250000        .2700000
   RMSP  ARRAY
 .4540000        .4540000        .4540000        .4540000        .4540000        .4540000        .4540000        .4540000
 .4540000        .4540000        .4540000        .4540000        .4540000
   BESP  ARRAY
 .5000000E-01    .5000000E-01    .4990000E-01    .4960000E-01    .4925000E-01    .4850000E-01    .4815000E-01    .4770000E-01
 .4720000E-01    .4675000E-01    .4661000E-01    .4661000E-01    .4661000E-01
   PLOSS ARRAY
0.              0.               .1500000E-02    .5900000E-02    .1100000E-01    .2150000E-01    .3000000E-01    .3350000E-01
 .4000000E-01    .4700000E-01    .4800000E-01    .4800000E-01    .4800000E-01

 BLDAT  AANDK  ERSOR  STRFN  SLCRD  INTVL  SURVL
   0      0      0      0      0      0      1
```

Figure A.2.- Continued.

```
                              --- INPUT FOR PERTURBATION METHOD ---

*********************************************************************************************************
*                         OPTIMIZATION TEST CASE 1 - MINIMIZE SUCTION SURFACE VELOCITY DIFFUSION        *
*********************************************************************************************************


.....LIST OF INPUT PARAMETERS

     N =  62

     A = -1.0    B =  1.0

     NPARAM = 6


.....STRAINING OPTIONS

     NUMBER OF FIXED POINTS: 3

     FIXED POINTS WILL BE AUTOMATICALLY DETERMINED
     BY THE PROGRAM FOR ALL SOLUTIONS AS FOLLOWS:

          TWO END POINTS
          POINT OF MAXIMUM WM
```

Figure A.2.- Continued.

```
                                       *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                              INLET    OUTLET    TRANS.   MAX.TH.   IN/OUT    MAX.     L.E.     T.E.
  NO.     INLET     CONE     SOLIDITY      BLADE     BLADE     LOC.     LOC.     TURNING   THICK.   RAD.     RAD.
 BLADES   RADIUS    ANGLE                  ANGLE     ANGLE    /CHORD   /CHORD     RATE    /CHORD   /CHORD   /CHORD
            (L)     (DEG)                  (DEG)     (DEG)

   34     .45400   6.66400   2.25200      52.000  -10.0000    .25000   .45000   1.50000   .05000   .00500   .00500
```

Figure A.2.- Continued.

```
                         --- INPUT FOR TSONIC BLADE-TO-BLADE FLOW SOLVER ---

   GAM              AR              TIP             RHOIP           WTFL                                            OMEGA           ORF
 1.400000        1716.480        599.7600        .3345860E-02    .5700000E-02    0.              0.              1.910000
  BETAI            BETAO           CHORDF          STGRF           FSMI             FSMO
 48.20000        0.              .1834184        .1311528        0.              0.
  REDFAC           DENTOL           SSM1            SSM2
 1.000000        .1000000E-02    0.              0.

MBI    MBO                        MM    NBBI    NBL    NRSP   MOPT    LOPT   LRVB
  24     56      0        0       72     15      34     13      0       1      0

 BLADE SURFACE 1  --  UPPER SURFACE
   RI1              RO1             BETI1           BETO1           SPLNO1
 .9668364E-03    .9668364E-03    57.62951        -13.13649       13.00000
   MSP1  ARRAY
 .1503113E-03    .5980107E-02    .1529854E-01    .2744253E-01    .4447412E-01    .6273379E-01    .8187670E-01    .1016760
 .1218970        .1423000        .1585911        .1727172        .1826858
   THSP1  ARRAY
 .1140045E-02    .1958139E-01    .4336945E-01    .6726818E-01    .9178661E-01    .1116067        .1269242        .1375985
 .1435478        .1447487        .1423112        .1377348        .1330935

 BLADE SURFACE 2  --  LOWER SURFACE
   RI2              RO2             BETI2           BETO2           SPLNO2
 .9668364E-03    .9668364E-03    46.20771        -5.047831       13.00000
   MSP2  ARRAY
 .1664865E-02    .8669538E-02    .1911677E-01    .3189241E-01    .4893131E-01    .6676995E-01    .8523057E-01    .1041871
 .1235102        .1430679        .1587932        .1725519        .1823521
   THSP2  ARRAY
-.1473028E-02    .1370723E-01    .3337744E-01    .5345856E-01    .7484201E-01    .9279699E-01    .1074271        .1186613
 .1264542        .1307850        .1317585        .1308042        .1290985

   MR  ARRAY
-.1300000       -.5000000E-02    .5000000E-02    .2003000E-01    .4003000E-01    .8003000E-01    .1000300        .1250300
 .1500400        .1752600        .1852600        .2250000        .2700000
   RMSP  ARRAY
 .4540000        .4540000        .4540000        .4540000        .4540000        .4540000        .4540000        .4540000
 .4540000        .4540000        .4540000        .4540000        .4540000
   BESP  ARRAY
 .5000000E-01    .5000000E-01    .4990000E-01    .4960000E-01    .4925000E-01    .4850000E-01    .4815000E-01    .4770000E-01
 .4720000E-01    .4675000E-01    .4661000E-01    .4661000E-01    .4661000E-01
   PLOSS ARRAY
0.              0.               .1500000E-02    .5900000E-02    .1100000E-01    .2150000E-01    .3000000E-01    .3350000E-01
 .4000000E-01    .4700000E-01    .4800000E-01    .4800000E-01    .4800000E-01

 BLDAT  AANDK  ERSOR  STRFN  SLCRD  INTVL  SURVL
   0      0      0      0      0      0      1
```

Figure A.2.- Continued.

```
            RELATIVE             MERIDIONAL            CRITICAL            REL. FLOW
            VELOCITY              VELOCITY             VELOCITY              ANGLE
          AT M = FSMI           AT M = FSMI           AT M = FSMI       AT UPSTREAM BDY.
            745.90                497.17               1095.9              48.237
          AT M = FSMO           AT M = FSMO           AT M = FSMO      AT DOWNSTREAM BDY.
            499.45                499.45               1095.9              0.

          FSMI =   0.
          FSMO =    .18342

   CALCULATED PROGRAM CONSTANTS

      PITCH              HT              HM1
      .1847996        .1231997E-01     .5731826E-02

      ITMIN           ITMAX
        0               25

      LAMBDA               DOWNSTREAM WHIRL (RVTHO)
      252.4466                    0.

      REDUCED WEIGHT FLOW =     .5700000E-02

      NUMBER OF INTERIOR MESH POINTS =  1035

  CALCULATED VELOCITY DIAGRAM INFORMATION
                          IM          W                    W/WCR                BETA
  UPSTREAM BOUNDARY        1           745.47                .68022               48.237
  LEADING EDGE            24           745.90                .68061               48.200
  TRAILING EDGE           56           499.45                .45573              0.
  DOWNSTREAM BOUNDARY     72           500.06                .45629              0.
```

Figure A.2.- Continued.

```
     ITERATION  NO.   1
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3059       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1105
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  86


     ITERATION  NO.   2
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2681       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2909E-01
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  86


     ITERATION  NO.   3
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .4396       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1291E-01
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  85


     ITERATION  NO.   4
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  3.182       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3816E-01
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  53
 DENSTY CALL NO.  9
 NER(1) =  1
 RHO*W IS  1.2430 TIMES THE MAXIMUM VALUE FOR RHO*W


     ITERATION  NO.   5
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .8418       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1041E-01
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  22


     ITERATION  NO.   6
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3818       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .4669E-02
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  12


     ITERATION  NO.   7
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  1.655       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1857E-01
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =   8
 DENSTY CALL NO.  9
 NER(1) =  2
 RHO*W IS  1.2455 TIMES THE MAXIMUM VALUE FOR RHO*W


     ITFRATION  NO.   8
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .7274       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .8167E-02
```

Figure A.2.- Continued.

```
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =    1


     ITERATION  NO.   9
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3803       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .4269E-02
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =    1


     ITERATION  NO.  10
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  1.635       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1820E-01
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =    1
DENSTY CALL NO.  9
NER(1) =  3
RHO*W IS  1.2472 TIMES THE MAXIMUM VALUE FOR RHO*W


     ITERATION  NO.  11
     MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .7251       AT IM =  0,   IT = 11,   SURF = 1,   M =  .1779
     AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .8072E-02
     NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =    1
```

Figure A.2.- Continued.

```
           *               SURFACE VELOCITIES BASED ON MERIDIONAL COMPONENTS - REDUCED WEIGHT FLOW     *
           *                                             *                                             *
           *               BLADF SURFACE 1               *                 BLADE SURFACE 2             *
   M       *  VELOCITY ANGLE(DEG) SURF. LENGTH W/WCR     *  VELOCITY ANGLE(DEG) SURF. LENGTH  W/WCR    *
0.         * 0.          90.00   0.           0.         * 0.         -90.00    0.           0.        *
 .5732F-02 *  871.6      52.87    .1030E-01    .7953     *  608.5      44.24     .6680E-02    .5552    *
 .1146E-01 *  909.2      48.47    .1935E-01    .8296     *  579.5      41.58     .1451E-01    .5287    *
 .1720E-01 *  919.0      44.47    .2767E-01    .8385     *  554.2      39.02     .2202E-01    .5057    *
 .2293E-01 *  910.1      40.64    .3545E-01    .8304     *  536.5      36.57     .2927E-01    .4895    *
 .2866E-01 *  884.7      36.99    .4281E-01    .8073     *  524.8      34.15     .3630E-01    .4789    *
 .3439E-01 *  848.7      33.70    .4984E-01    .7744     *  515.5      31.78     .4313E-01    .4704    *
 .4012E-01 *  811.1      30.94    .5661E-01    .7401     *  509.7      29.64     .4980E-01    .4651    *
 .4585F-01 *  782.6      28.82    .6322E-01    .7141     *  506.7      27.78     .5633E-01    .4623    *
 .5159E-01 *  760.0      26.89    .6971E-01    .6935     *  502.7      26.21     .6277E-01    .4587    *
 .5732E-01 *  743.6      24.95    .7608E-01    .6785     *  498.7      24.68     .6911E-01    .4550    *
 .6305E-01 *  727.9      23.02    .8235E-01    .6642     *  493.4      23.16     .7538E-01    .4502    *
 .6878E-01 *  716.3      21.09    .8854E-01    .6536     *  489.6      21.65     .8158E-01    .4468    *
 .7451E-01 *  705.9      19.20    .9464E-01    .6441     *  485.1      20.15     .8772E-01    .4426    *
 .8025E-01 *  694.6      17.36    .1007        .6338     *  482.3      18.68     .9380E-01    .4401    *
 .8598E-01 *  687.5      15.55    .1067        .6273     *  479.9      17.23     .9982E-01    .4379    *
 .9171E-01 *  680.8      13.75    .1126        .6212     *  476.3      15.79     .1058        .4346    *
 .9744E-01 *  672.8      11.97    .1185        .6139     *  474.2      14.37     .1117        .4327    *
 .1032     *  666.8      10.22    .1243        .6085     *  471.9      12.96     .1176        .4306    *
 .1089     *  660.3       8.47    .1301        .6025     *  469.8      11.56     .1235        .4287    *
 .1146     *  653.6       6.73    .1359        .5964     *  466.0      10.17     .1293        .4252    *
 .1204     *  646.4       5.01    .1417        .5898     *  465.3       8.80     .1351        .4246    *
 .1261     *  639.3       3.30    .1474        .5834     *  464.7       7.45     .1409        .4241    *
 .1318     *  632.1       1.60    .1531        .5768     *  464.7       6.09     .1467        .4240    *
 .1376     *  624.4       -.09    .1589        .5698     *  465.8       4.72     .1525        .4250    *
 .1433     *  616.1      -1.76    .1646        .5622     *  468.3       3.36     .1582        .4273    *
 .1490     *  606.4      -3.45    .1703        .5534     *  472.3       2.02     .1640        .4310    *
 .1548     *  594.3      -5.17    .1761        .5423     *  477.9        .75     .1697        .4360    *
 .1605     *  578.3      -6.92    .1819        .5277     *  485.3       -.48     .1754        .4428    *
 .1662     *  557.6      -8.56    .1876        .5088     *  496.7      -1.89     .1812        .4532    *
 .1720     *  531.8     -10.05    .1934        .4853     *  521.7      -3.55     .1869        .4760    *
 .1777     *  499.1     -11.58    .1993        .4554     *  600.4      -4.87     .1926        .5478    *
 .1834     * 0.         -90.00    .2054       0.         * 0.          90.00     .1984       0.        *
```

Figure A.2.- Continued.

```
SURFACE VELOCITIES BASED ON TANGENTIAL COMPONENTS
             REDUCED WEIGHT FLOW


                  BLADE SURFACE  1
   M             VELOCITY   ANGLE(DEG)    W/WCR
 0.              522.7         90.00      .4769
  .3555E-02      914.3         54.65      .8343
  .7776E-02      880.0         51.28      .8030
  .1256E-01      911.6         47.67      .8318
  .1800E-01      919.8         43.93      .8393
  .2424E-01      909.4         39.79      .8298
  .3152E-01      879.6         35.29      .8026
  .4012E-01      833.8         30.94      .7608
  .5018E-01      777.0         27.36      .7090
  .6197E-01      743.7         23.38      .6786
  .7657E-01      708.7         18.53      .6466
  .9699E-01      694.0         12.11      .6333
  .1779          1096.        -11.65      1.000


                  BLADE SURFACE  2
   M             VELOCITY   ANGLE(DEG)    W/WCR
  .2310E-02      660.1         45.89      .6023
  .7995E-02      592.4         43.18      .5406
  .1426E-01      560.6         40.32      .5115
  .2122E-01      538.8         37.30      .4916
  .2901E-01      517.8         34.00      .4725
  .3790E-01      509.2         30.44      .4647
  .4811E-01      502.4         27.13      .4585
  .5979E-01      492.8         24.03      .4496
  .7348E-01      484.4         20.42      .4420
  .9043E-01      474.9         16.11      .4334
  .1143          465.4         10.25      .4247
```

Figure A.2.- Continued.

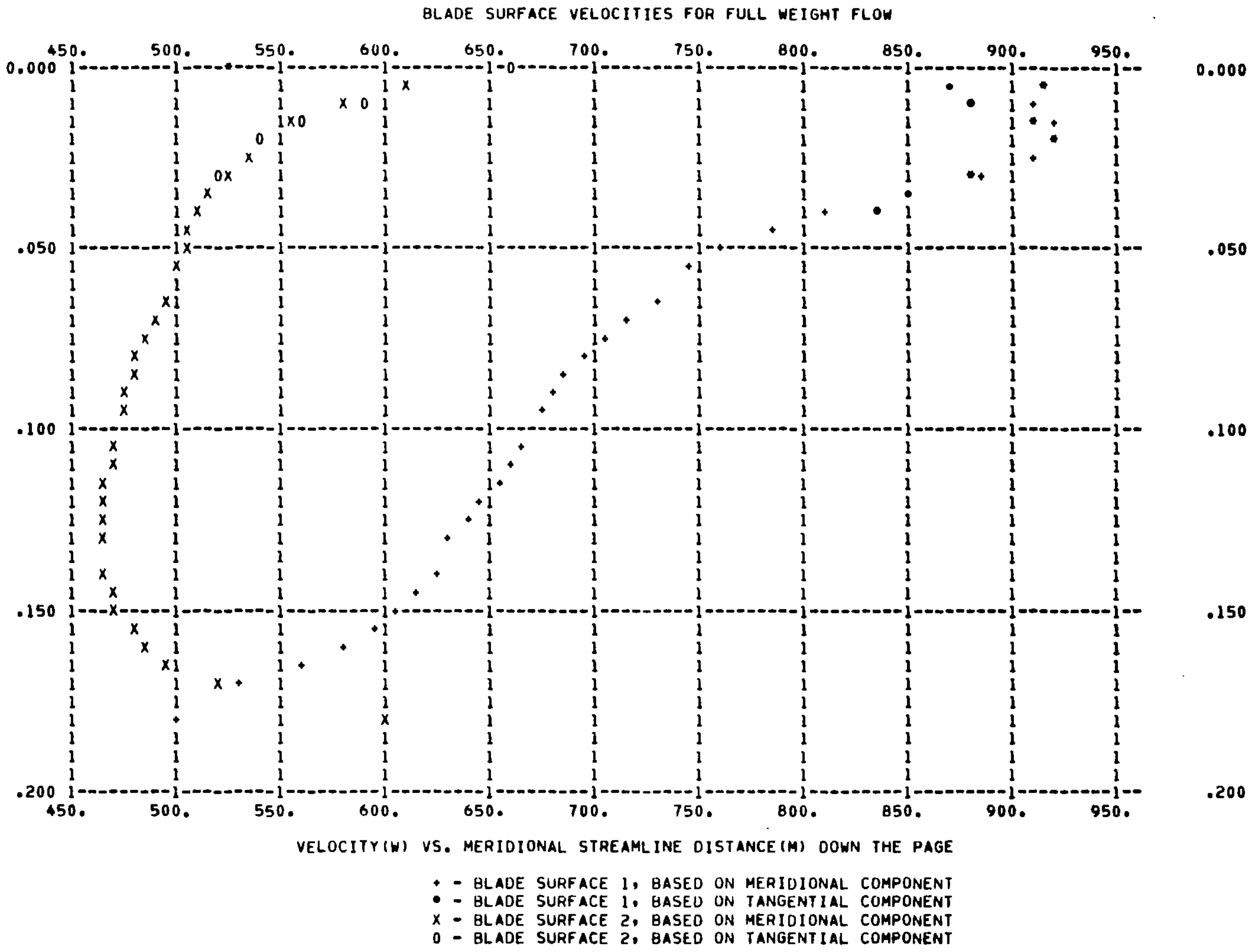


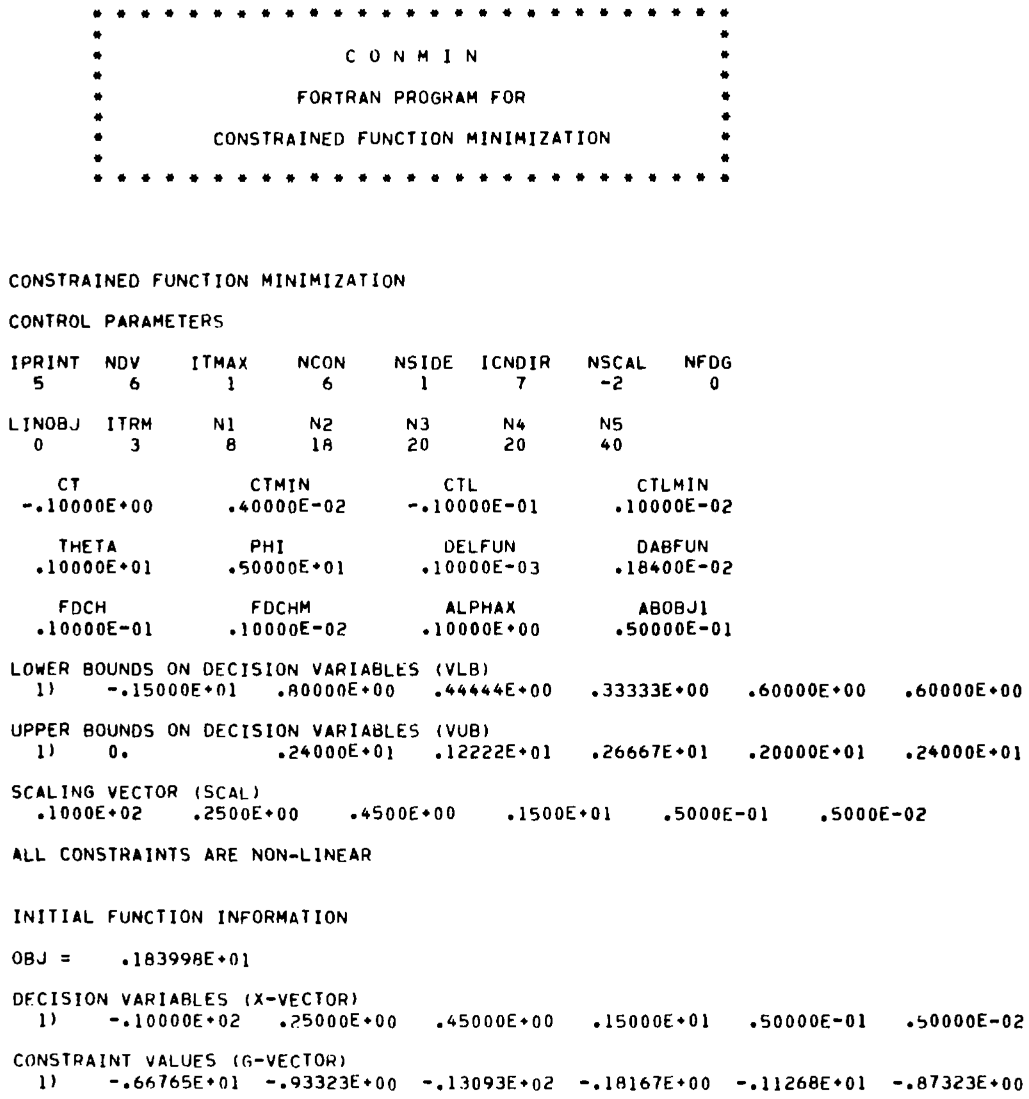
Figure A.2.- Continued.

```
                                        BLADE SURFACE PRESSURES FOR FULL WEIGHT FLOW

 IM          M                M/MC             P(1)/PT          P(2)/PT          CPT(1)            CPT(2)

 24      0.               0.                  .9994            .9994          -.6204E-03        -.6204E-03
 25       .5732E-02        .3125E-01          .6760            .8301          -.3240            -.1699
 26       .1146E-01        .6250E-01          .6507            .8435          -.3493            -.1565
 27       .1720E-01        .9375E-01          .6432            .8543          -.3568            -.1457
 28       .2293E-01        .1250              .6479            .8612          -.3521            -.1388
 29       .2866E-01        .1563              .6631            .8652          -.3369            -.1348
 30       .3439E-01        .1875              .6850            .8682          -.3150            -.1318
 31       .4012F-01        .2188              .7074            .8697          -.2926            -.1303
 32       .4585E-01        .2500              .7239            .8700          -.2761            -.1300
 33       .5159E-01        .2813              .7365            .8707          -.2635            -.1293
 34       .5732E-01        .3125              .7452            .8714          -.2548            -.1286
 35       .6305E-01        .3438              .7533            .8725          -.2467            -.1275
 36       .6878E-01        .3750              .7587            .8728          -.2413            -.1272
 37       .7451E-01        .4063              .7631            .8731          -.2369            -.1269
 38       .8025E-01        .4375              .7677            .8722          -.2323            -.1278
 39       .8598E-01        .4688              .7696            .8710          -.2304            -.1290
 40       .9171E-01        .5000              .7712            .8701          -.2288            -.1299
 41       .9744E-01        .5313              .7736            .8689          -.2264            -.1311
 42       .1032            .5625              .7755            .8684          -.2245            -.1316
 43       .1089            .5938              .7782            .8683          -.2218            -.1317
 44       .1146            .6250              .7813            .8693          -.2187            -.1307
 45       .1204            .6563              .7846            .8691          -.2154            -.1309
 46       .1261            .6875              .7877            .8687          -.2123            -.1313
 47       .1318            .7188              .7906            .8677          -.2094            -.1323
 48       .1376            .7500              .7933            .8660          -.2067            -.1340
 49       .1433            .7813              .7961            .8635          -.2039            -.1365
 50       .1490            .8125              .7995            .8602          -.2005            -.1398
 51       .1548            .8438              .8039            .8563          -.1961            -.1437
 52       .1605            .8750              .8101            .8516          -.1899            -.1484
 53       .1662            .9063              .8184            .8453          -.1816            -.1547
 54       .1720            .9375              .8289            .8334          -.1711            -.1666
 55       .1777            .9688              .8423            .7961          -.1577            -.2039
 56       .1834           1.000               .9521            .9521          -.4788E-01        -.4788E-01


X ARRAY
           .968750      .937500      .906250      .875000      .843750
           .812500      .781250      .750000      .718750      .687500
           .656250      .625000      .593750      .562500      .531250
           .500000      .468750      .437500      .406250      .375000
           .343750      .312500      .281250      .250000      .218750
           .187500      .156250      .125000      .093750      .062500
           .031250      .031250      .062500      .093750      .125000
           .156250      .187500      .218750      .250000      .281250
           .312500      .343750      .375000      .406250      .437500
           .468750      .500000      .531250      .562500      .593750
           .625000      .656250      .687500      .718750      .750000
           .781250      .812500      .843750      .875000      .906250
           .937500      .968750

 Y ARRAY
           600.354      521.669      496.727      485.325      477.873
           472.312      468.339      465.802      464.706      464.733
           465.289      466.016      469.834      471.882      474.222
           476.253      479.869      482.348      485.093      489.643
           493.390      498.688      502.725      506.666      509.703
```

Figure A.2.- Continued.

```
   515.508     524.794     536.506     554.157     579.455
   608.451     871.598     909.197     918.981     910.061
   884.702     848.724     811.096     782.606     760.025
   743.617     727.894     716.322     705.924     694.579
   687.479     680.820     672.815     666.824     660.302
   653.568     646.379     639.342     632.094     624.435
   616.098     606.446     594.286     578.274     557.598
   531.810     499.051


OUTPUT FROM OBJCON

   OBJECTIVE FUNCTION   DIFFS     =  .91898E+03
                        WO        =  .49945E+03
                        DIFFS/WO  =  .18400E+01

   CONSTRAINT 1         BLTKS     =  .66765E+00

   CONSTRAINT 2         YMAX      =  .60845E+03
                        YMIN      =  .46471E+03
                        DIFFP     =  .13093E+01

   CONSTRAINT 3     WMB(MBO-2,1)  =  .53181E+03
                    WMB(MBO-2,2)  =  .52167E+03
                        TECLSR    =  .12677E+00
```

Figure A.2.- Continued.



```
          * * * * * * * * * * * * * * * * * * * * * * * * * * *
          *                                                   *
          *                     C O N M I N                   *
          *                                                   *
          *                 FORTRAN PROGRAM FOR               *
          *                                                   *
          *          CONSTRAINED FUNCTION MINIMIZATION        *
          *                                                   *
          * * * * * * * * * * * * * * * * * * * * * * * * * * *


CONSTRAINED FUNCTION MINIMIZATION

CONTROL PARAMETERS

IPRINT  NDV    ITMAX    NCON    NSIDE  ICNDIR   NSCAL    NFDG
  5      6       1       6        1      7       -2        0

LINOBJ  ITRM     N1      N2       N3     N4      N5
  0      3       8       18       20     20      40

    CT              CTMIN           CTL              CTLMIN
 -.10000E+00     .40000E-02     -.10000E-01      .10000E-02

   THETA             PHI            DELFUN           DABFUN
  .10000E+01     .50000E+01      .10000E-03      .18400E-02

    FDCH            FDCHM           ALPHAX           ABOBJ1
  .10000E-01     .10000E-02      .10000E+00      .50000E-01

LOWER BOUNDS ON DECISION VARIABLES (VLB)
  1)    -.15000E+01   .80000E+00   .44444E+00   .33333E+00   .60000E+00   .60000E+00

UPPER BOUNDS ON DECISION VARIABLES (VUB)
  1)    0.            .24000E+01   .12222E+01   .26667E+01   .20000E+01   .24000E+01

SCALING VECTOR (SCAL)
  .1000E+02    .2500E+00    .4500E+00    .1500E+01    .5000E-01    .5000E-02

ALL CONSTRAINTS ARE NON-LINEAR


INITIAL FUNCTION INFORMATION

OBJ =     .183998E+01

DECISION VARIABLES (X-VECTOR)
  1)    -.10000E+02   .25000E+00   .45000E+00   .15000E+01   .50000E-01   .50000E-02

CONSTRAINT VALUES (G-VECTOR)
  1)    -.66765E+01  -.93323E+00  -.13093E+02  -.18167E+00  -.11268E+01  -.87323E+00
```

Figure A.2.- Continued.

```
BEGIN ITERATION NUMBER    1

CT =    -.10000E+00     CTL =    -.10000E-01     PHI =     .50000E+01


                                     *** INPUT FOR BLADE ELEMENT PROGRAM ***


                                                INLET    OUTLET    TRANS.   MAX.TH.   IN/OUT     MAX.      L.E.      T.E.
    NO.      INLET      CONE     SOLIDITY       BLADE     BLADE     LOC.     LOC.     TURNING   THICK.     RAD.      RAD.
  BLADES    RADIUS     ANGLE                    ANGLE     ANGLE    /CHORD   /CHORD     RATE    /CHORD    /CHORD    /CHORD
              (L)      (DEG)                    (DEG)     (DEG)

    34      .45400    6.66400    2.25200      52.000   -9.9000    .25000    .45000   1.50000    .05000    .00500    .00500
```

Figure A.2.- Continued.

```
                                --- INPUT FOR TSONIC BLADE-TO-BLADE FLOW SOLVER ---

   GAM              AR             TIP            RHOIP           WTFL                       OMEGA            ORF
 1.400000        1716.480        599.7600        .3345860E-02    .5700000E-02   0.              0.                1.910000
  BETAI           BETAO           CHORDF          STGRF           FSMI            FSMO
 48.20000       0.              .1833593        .1315224       0.              0.
  REDFAC          DENTOL           SSM1            SSM2
 1.000000        .1000000E-02   0.              0.

MBI    MBO                  MM   NBBI    NBL   NRSP   MOPT   LOPT   LRVB
  24     56      0      0     72     15     34     13      0      1      0

 BLADE SURFACE 1  --  UPPER SURFACE
   RI1             RO1             BETI1           BETO1           SPLNO1
 .9668292E-03    .9668292E-03    57.63155        -13.03485       13.00000
   MSP1  ARRAY
 .1502917E-03    .5978272E-02    .1529266E-01    .2743032E-01    .4445239E-01    .6270190E-01    .8183494E-01    .1016254
 .1218393        .1422379        .1585276        .1726546        .1826251
   THSP1  ARRAY
 .1139973E-02    .1957908E-01    .4336726E-01    .6727171E-01    .9180706E-01    .1116533        .1270053        .1377225
 .1437228        .1449823        .1425966        .1380689        .1334640

 BLADE SURFACE 2  --  LOWER SURFACE
   RI2             RO2             BETI2           BETO2           SPLNO2
 .9668292E-03    .9668292E-03    46.20589       -4.944609        13.00000
   MSP2  ARRAY
 .1664831E-02    .8668414E-02    .1911275E-01    .3188349E-01    .4891460E-01    .6674475E-01    .8519690E-01    .1041455
 .1234617        .1430141        .1587367        .1724944        .1822947
   THSP2  ARRAY
-.1473066E-02    .1370572E-01    .3337749E-01    .5346616E-01    .7486838E-01    .9285030E-01    .1075148        .1187910
 .1266333        .1310207        .1320445        .1311376        .1294676

   MR  ARRAY
-.1300000       -.5000000E-02    .5000000E-02    .2003000E-01    .4003000E-01    .8003000E-01    .1000300        .1250300
 .1500400        .1752600        .1852600        .2250000        .2700000
   RMSP  ARRAY
 .4540000        .4540000        .4540000        .4540000        .4540000        .4540000        .4540000        .4540000
 .4540000        .4540000        .4540000        .4540000        .4540000
   BESP  ARRAY
 .5000000E-01    .5000000E-01    .4990000E-01    .4960000E-01    .4925000E-01    .4850000E-01    .4815000E-01    .4770000E-01
 .4720000E-01    .4675000E-01    .4661000E-01    .4661000E-01    .4661000E-01
   PLOSS ARRAY
0.              0.               .1500000E-02    .5900000E-02    .1100000E-01    .2150000E-01    .3000000E-01    .3350000E-01
 .4000000E-01    .4700000E-01    .4800000E-01    .4800000E-01    .4800000E-01

 BLDAT  AANDK  ERSOR  STRFN  SLCRD  INTVL  SURVL
    0      0      0      0      0      0      1
```

Figure A.2.- Continued.

```
        RELATIVE            MERIDIONAL           CRITICAL            REL. FLOW
        VELOCITY             VELOCITY            VELOCITY              ANGLE
       AT M = FSMI          AT M = FSMI         AT M = FSMI        AT UPSTREAM BDY.
        745.90               497.17              1095.9               48.237
       AT M = FSMO          AT M = FSMO         AT M = FSMO       AT DOWNSTREAM BDY.
        499.44               499.44              1095.9                0.

       FSMI =   0.
       FSMO =    .18336


CALCULATED PROGRAM CONSTANTS

   PITCH            HT              HMI
   .1847996        .1231997E-01    .5729979E-02

   ITMIN          ITMAX
      0              25

   LAMBDA              DOWNSTREAM WHIRL (RVTHO)
   252.4466                   0.

   REDUCED WEIGHT FLOW =    .5700000E-02

   NUMBER OF INTERIOR MESH POINTS =  1035

CALCULATED VELOCITY DIAGRAM INFORMATION
                        IM          W                  W/WCR               BETA
UPSTREAM BOUNDARY        1        745.47               .68022             48.237
LEADING EDGE            24        745.90               .68061             48.200
TRAILING EDGE           56        499.44               .45572              0.
DOWNSTREAM BOUNDARY     72        500.06               .45629              0.
```

Figure A.2.- Continued.

```
    ITERATION  NO.   1
    MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3084        AT IM =  0,    IT = 11,    SURF = 1,    M =  .1786
    AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1106
    NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  86


    ITERATION  NO.   2
    MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2718        AT IM =  0,    IT = 11,    SURF = 1,    M =  .1786
    AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2915E-01
    NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  86


    ITERATION  NO.   3
    MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .4543        AT IM =  0,    IT = 11,    SURF = 1,    M =  .1786
    AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1308E-01
    NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  85


    ITERATION  NO.   4
    MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  3.728        AT IM =  0,    IT = 11,    SURF = 1,    M =  .1786
    AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .4423E-01
    NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  53
DENSTY CALL NO.  9
NER(1) =  1
RHO*W IS  1.2462 TIMES THE MAXIMUM VALUE FOR RHO*W


    ITERATION  NO.   5
    MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .8621        AT IM =  0,    IT = 11,    SURF = 1,    M =  .1786
    AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1063E-01
    NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  23


    ITERATION  NO.   6
    MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3878        AT IM =  0,    IT = 11,    SURF = 1,    M =  .1786
    AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .4736E-02
    NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  13


    ITERATION  NO.   7
    MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  1.740        AT IM =  0,    IT = 11,    SURF = 1,    M =  .1786
    AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1951E-01
    NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =   8
DENSTY CALL NO.  9
NER(1) =  2
RHO*W IS  1.2487 TIMES THE MAXIMUM VALUE FOR RHO*W


    ITERATION  NO.   8
    MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .7370        AT IM =  0,    IT = 11,    SURF = 1,    M =  .1786
    AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .8272E-02
```

Figure A.2.- Continued.

```
      NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =    1


      ITERATION  NO.   9
      MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3891      AT IM =  0,   IT = 11,   SURF = 1,   M =  .1786
      AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .4369E-02
      NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =    1


      ITERATION  NO.  10
      MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  1.757      AT IM =  0,   IT = 11,   SURF = 1,   M =  .1786
      AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1955E-01
      NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =    1
  DENSTY CALL NO.  9
  NER(1) =  3
  RHO*W IS  1.2486 TIMES THE MAXIMUM VALUE FOR RHO*W


      ITERATION  NO.  11
      MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .7389      AT IM =  0,   IT = 11,   SURF = 1,   M =  .1786
      AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .8235E-02
      NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =    1
```

Figure A.2.- Continued.

```
               *           SURFACE VELOCITIES BASED ON MERIDIONAL COMPONENTS - REDUCED WEIGHT FLOW           *
               *                                                   *                                            *
               *                 BLADE SURFACE 1                   *                 BLADE SURFACE 2            *
      M        *  VELOCITY   ANGLE(DEG) SURF. LENGTH     W/WCR     *  VELOCITY   ANGLE(DEG) SURF. LENGTH     W/WCR     *
 0.            * 0.            90.00    0.              0.         * 0.           -90.00    0.              0.         *
  .5730E-02    *  871.3        52.88     .1030E-01       .7950     *  608.9        44.25     .6677E-02       .5556     *
  .1146E-01    *  909.0        48.49     .1935E-01       .8294     *  579.9        41.59     .1450E-01       .5292     *
  .1719E-01    *  918.8        44.49     .2767E-01       .8384     *  554.6        39.03     .2202E-01       .5061     *
  .2292E-01    *  910.0        40.66     .3545E-01       .8304     *  537.0        36.59     .2927E-01       .4900     *
  .2865E-01    *  884.7        37.02     .4281E-01       .8073     *  525.2        34.17     .3630E-01       .4793     *
  .3438E-01    *  849.2        33.73     .4983E-01       .7749     *  516.0        31.81     .4313E-01       .4708     *
  .4011E-01    *  811.3        30.97     .5661E-01       .7402     *  510.1        29.67     .4979E-01       .4655     *
  .4584E-01    *  782.8        28.85     .6322E-01       .7143     *  507.1        27.82     .5633E-01       .4627     *
  .5157E-01    *  760.2        26.93     .6970E-01       .6937     *  503.1        26.25     .6276E-01       .4591     *
  .5730E-01    *  743.9        25.00     .7608E-01       .6787     *  499.1        24.73     .6911E-01       .4554     *
  .6303E-01    *  728.1        23.06     .8235E-01       .6644     *  493.7        23.21     .7538E-01       .4505     *
  .6876E-01    *  716.5        21.14     .8853E-01       .6538     *  490.0        21.70     .8158E-01       .4471     *
  .7449E-01    *  706.1        19.25     .9464E-01       .6443     *  485.4        20.20     .8771E-01       .4429     *
  .8022E-01    *  694.8        17.40     .1007           .6339     *  482.6        18.73     .9379E-01       .4404     *
  .8595E-01    *  687.6        15.60     .1067           .6274     *  480.2        17.28     .9982E-01       .4382     *
  .9168E-01    *  681.0        13.81     .1126           .6214     *  476.6        15.85     .1058           .4349     *
  .9741E-01    *  672.9        12.03     .1185           .6140     *  474.4        14.43     .1117           .4329     *
  .1031        *  666.9        10.27     .1243           .6085     *  472.2        13.02     .1176           .4309     *
  .1089        *  660.5         8.53     .1301           .6027     *  470.0        11.62     .1235           .4288     *
  .1146        *  653.6         6.80     .1359           .5964     *  467.2        10.24     .1293           .4263     *
  .1203        *  646.5         5.07     .1416           .5899     *  465.4         8.87     .1351           .4247     *
  .1261        *  639.3         3.37     .1474           .5834     *  464.7         7.52     .1409           .4240     *
  .1318        *  632.2         1.67     .1531           .5769     *  464.8         6.16     .1467           .4241     *
  .1375        *  624.6         -.01     .1589           .5699     *  465.9         4.80     .1525           .4252     *
  .1432        *  616.2        -1.68     .1646           .5623     *  468.3         3.43     .1582           .4273     *
  .1490        *  606.5        -3.37     .1703           .5534     *  472.3         2.10     .1639           .4310     *
  .1547        *  594.4        -5.09     .1761           .5424     *  477.9          .83     .1697           .4361     *
  .1604        *  578.6        -6.83     .1818           .5280     *  485.2         -.40     .1754           .4427     *
  .1662        *  558.0        -8.47     .1876           .5091     *  496.4        -1.80     .1811           .4530     *
  .1719        *  532.3        -9.97     .1934           .4857     *  521.3        -3.46     .1869           .4757     *
  .1776        *  499.8       -11.49     .1992           .4561     *  598.6        -4.77     .1926           .5462     *
  .1834        * 0.           -90.00     .2053          0.         * 0.            90.00     .1984          0.         *
```

Figure A.2.- Continued.

```
SURFACE VELOCITIES BASED ON TANGENTIAL COMPONENTS
                 REDUCED WEIGHT FLOW


                       BLADE SURFACE  1
     M             VELOCITY    ANGLE(DEG)     W/WCR
  0.               522.3         90.00        .4766
   .3554E-02       913.9         54.66        .8339
   .7774E-02       879.7         51.29        .8027
   .1255E-01       911.4         47.68        .8316
   .1799E-01       919.7         43.95        .8392
   .2423E-01       909.4         39.81        .8298
   .3150E-01       879.6         35.33        .8027
   .4009E-01       833.0         30.98        .7601
   .5013E-01       777.3         27.41        .7092
   .6189E-01       744.0         23.44        .6788
   .7644E-01       708.7         18.62        .6467
   .9671E-01       693.5         12.25        .6328
   .1786           1096.        -11.78        1.000


                       BLADE SURFACE  2
     M             VELOCITY    ANGLE(DEG)     W/WCR
   .2310E-02       660.6         45.89        .6028
   .7994E-02       592.9         43.18        .5410
   .1426E-01       561.1         40.33        .5120
   .2121E-01       539.3         37.31        .4921
   .2900E-01       518.3         34.02        .4729
   .3788E-01       509.7         30.47        .4651
   .4807E-01       502.8         27.18        .4588
   .5973E-01       493.1         24.08        .4499
   .7337E-01       484.7         20.49        .4423
   .9024E-01       475.2         16.21        .4336
   .1139           466.1         10.41        .4253
```

Figure A.2.- Continued.

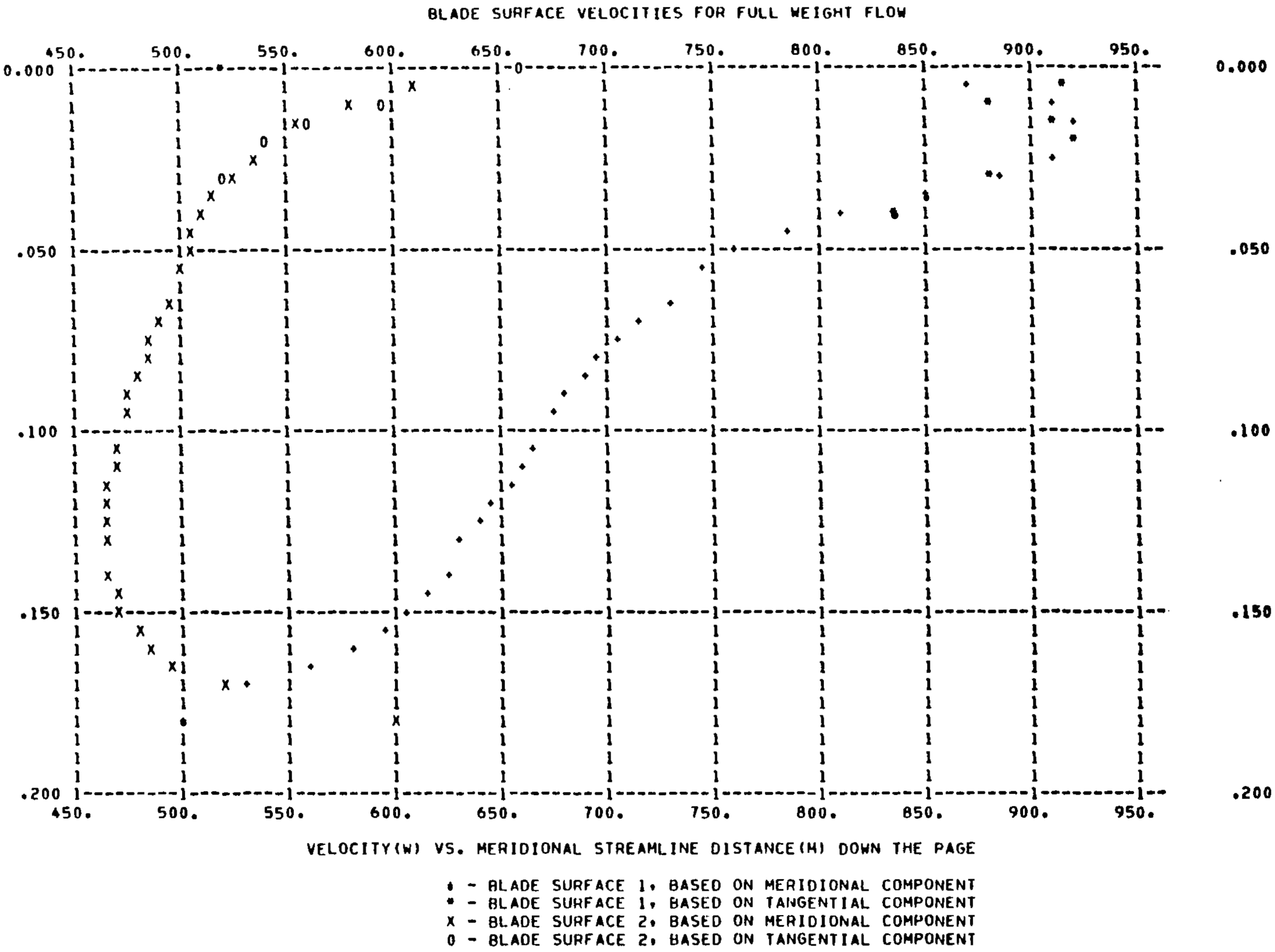


Figure A.2.- Continued.

```
                                   BLADE SURFACE PRESSURES FOR FULL WEIGHT FLOW

  IM        M              H/HC           P(1)/PT        P(2)/PT        CPT(1)          CPT(2)

  24     0.             0.               .9994          .9994         -.6204E-03      -.6204E-03
  25      .5730E-02      .3125E-01       .6762          .8298         -.3238          -.1702
  26      .1146E-01      .6250E-01       .6509          .8432         -.3491          -.1568
  27      .1719E-01      .9375E-01       .6433          .8541         -.3567          -.1459
  28      .2292E-01      .1250           .6479          .8610         -.3521          -.1390
  29      .2865E-01      .1563           .6631          .8650         -.3369          -.1350
  30      .3438E-01      .1875           .6847          .8680         -.3153          -.1320
  31      .4011E-01      .2188           .7073          .8695         -.2927          -.1305
  32      .4584E-01      .2500           .7238          .8699         -.2762          -.1301
  33      .5157E-01      .2813           .7363          .8706         -.2637          -.1294
  34      .5730E-01      .3125           .7450          .8713         -.2550          -.1287
  35      .6303E-01      .3438           .7531          .8724         -.2469          -.1276
  36      .6876E-01      .3750           .7585          .8726         -.2415          -.1274
  37      .7449E-01      .4063           .7630          .8729         -.2370          -.1271
  38      .8022E-01      .4375           .7676          .8721         -.2324          -.1279
  39      .8595E-01      .4688           .7695          .8708         -.2305          -.1292
  40      .9168E-01      .5000           .7711          .8700         -.2289          -.1300
  41      .9741E-01      .5313           .7736          .8688         -.2264          -.1312
  42      .1031          .5625           .7755          .8682         -.2245          -.1318
  43      .1089          .5938           .7781          .8682         -.2219          -.1318
  44      .1146          .6250           .7813          .8688         -.2187          -.1312
  45      .1203          .6563           .7845          .8691         -.2155          -.1309
  46      .1261          .6875           .7877          .8687         -.2123          -.1313
  47      .1318          .7188           .7905          .8677         -.2095          -.1323
  48      .1375          .7500           .7932          .8660         -.2068          -.1340
  49      .1432          .7813           .7961          .8635         -.2039          -.1365
  50      .1490          .8125           .7995          .8603         -.2005          -.1397
  51      .1547          .8438           .8038          .8563         -.1962          -.1437
  52      .1604          .8750           .8099          .8516         -.1901          -.1484
  53      .1662          .9062           .8182          .8455         -.1818          -.1545
  54      .1719          .9375           .8287          .8336         -.1713          -.1664
  55      .1776          .9688           .8420          .7969         -.1580          -.2031
  56      .1834         1.000            .9521          .9521         -.4788E-01      -.4788E-01


X ARRAY
          .968750     .937500     .906250     .875000     .843750
          .812500     .781250     .750000     .718750     .687500
          .656250     .625000     .593750     .562500     .531250
          .500000     .468750     .437500     .406250     .375000
          .343750     .312500     .281250     .250000     .218750
          .187500     .156250     .125000     .093750     .062500
          .031250     .031250     .062500     .093750     .125000
          .156250     .187500     .218750     .250000     .281250
          .312500     .343750     .375000     .406250     .437500
          .468750     .500000     .531250     .562500     .593750
          .625000     .656250     .687500     .718750     .750000
          .781250     .812500     .843750     .875000     .906250
          .937500     .968750

 Y ARRAY
          598.622     521.326     496.430     485.191     477.892
          472.296     468.296     465.933     464.826     464.715
          465.422     467.225     469.987     472.202     474.379
          476.622     480.225     482.606     485.388     489.992
          493.694     499.052     503.092     507.060     510.120
```

Figure A.2.- Continued.

```
          515.956     525.246     536.981     554.624     579.933
          608.917     871.309     908.986     918.846     910.016
          884.741     849.202     811.259     782.794     760.231
          743.855     728.095     716.532     706.124     694.759
          687.633     680.982     672.940     666.912     660.502
          653.560     646.538     639.326     632.201     624.598
          616.196     606.488     594.393     578.629     557.971
          532.289     499.834


 OUTPUT FROM OBJCON

    OBJECTIVE FUNCTION  DIFFS      =  .91885E+03
                        WO         =  .49944E+03
                        DIFFS/WO   =  .18398E+01

    CONSTRAINT 1        BLTKS      =  .66766E+00

    CONSTRAINT 2        YMAX       =  .60892E+03
                        YMIN       =  .46472E+03
                        DIFFP      =  .13103E+01

    CONSTRAINT 3     WMB(MBO-2,1)  =  .53229E+03
                     WMB(MBO-2,2)  =  .52133E+03
                        TECLSR     =  .13704E+00
```

Figure A.2.- Continued.

```
FINAL OPTIMIZATION INFORMATION

 OBJ =     .170765E+01

 DECISION VARIABLES (X-VECTOR)
   1)    -.93094E+01   .29650E+00   .55000E+00   .95806E+00   .32891E-01   .51525E-02

 CONSTRAINT VALUFS (G-VECTOR)
   1)    -.28002E+01  -.97200E+00  -.14455E+02  -.96575E-01  -.15965E+01  -.40346E+00

 THERE ARE    1 ACTIVE CONSTRAINTS
 CONSTRAINT NUMBERS ARE
     4

 THERE ARE    0 VIOLATED CONSTRAINTS

 THERE ARE    1 ACTIVE SIDE CONSTRAINTS
 DECISION VARIABLES AT LOWER OR UPPER BOUNDS (MINUS INDICATES LOWER BOUND)
     3

 TERMINATION CRITERION
      ITER EQUALS ITMAX

 NUMBER OF ITERATIONS =    1

 OBJECTIVE FUNCTION WAS EVALUATED           12  TIMES

 CONSTRAINT FUNCTIONS WERE EVALUATED        12  TIMES
```

Figure A.2.- Continued.

```
OPTIMIZATION RESULTS


OBJECTIVE FUNCTION
GLOBAL LOCATION    1     FUNCTION VALUE  .17077E+01


DESIGN VARIABLES

        D. V.     GLOBAL       LOWER                        UPPER
  ID     NO.     VAR. NO.      BOUND           VALUE         BOUND
   1      1          2      -.15000E+02   -.93094E+01   0.
   2      2          3       .20000E+00    .29650E+00    .60000E+00
   3      3          4       .20000E+00    .55000E+00    .55000E+00
   4      4          5       .50000E+00    .95806E+00    .40000E+01
   5      5          6       .30000E-01    .32891E-01    .10000E+00
   6      6          7       .30000E-02    .51525E-02    .12000E-01


DESIGN CONSTRAINTS

        GLOBAL       LOWER                          UPPER
  ID   VAR. NO.      BOUND           VALUE           BOUND
   1       8      0.             .28002E+00     .10000E+02
   3       9      0.             .14455E+01     .16000E+01
   5      10     -.10000E+01     .59654E+00     .10000E+01
```

Figure A.2.- Continued.

```
                                        *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                      INLET    OUTLET    TRANS.   MAX.TH.   IN/OUT     MAX.      L.E.      T.E.
   NO.      INLET      CONE    SOLIDITY              BLADE     BLADE     LOC.      LOC.    TURNING    THICK.     RAD.      RAD.
 BLADES     RADIUS     ANGLE                          ANGLE     ANGLE    /CHORD    /CHORD    RATE     /CHORD    /CHORD    /CHORD
              (L)      (DEG)                          (DEG)     (DEG)

   34       .45400    6.66400   2.25200    52.000   -9.3094    .29650    .55000    .95806    .03289    .00515    .00500
```

Figure A.2.- Continued.

```
                         --- INPUT FOR TSONIC BLADE-TO-BLADE FLOW SOLVER ---

  GAM             AR              TIP             RHOIP           WTFL                                            OMEGA           ORF
1.400000        1716.480        599.7600        .3345860E-02    .5700000E-02    0.              0.              1.910000
 BETAI           BETAO           CHORDF          STGRF           FSMI            FSMO
48.20000        0.              .1795132        .1534563        0.              0.
 REDFAC          DENTOL          SSM1            SSM2
1.000000        .1000000E-02    0.              0.

MBI    MBO                   MM   NBRI    NBL   NRSP   MOPT   LOPT   LRVB
 24     56     0      0      72     15     34     13      0      1      0

 BLADE SURFACE 1  --  UPPER SURFACE
  RI1             RO1             BETI1           BETO1           SPLNO1
.9958413E-03    .9663591E-03    53.17187        -11.06885       13.00000
  MSP1  ARRAY
.1988241E-03    .6491482E-02    .1596615E-01    .2768746E-01    .4356364E-01    .6073413E-01    .7906837E-01    .9830693E-01
.1181776        .1383991        .1546368        .1687631        .1787495
  THSP1  ARRAY
.1314862E-02    .1885167E-01    .4212224E-01    .6675356E-01    .9436997E-01    .1178990        .1367454        .1506814
.1595550        .1632900        .1625744        .1592733        .1554091

 BLADE SURFACE 2  --  LOWER SURFACE
  RI2             RO2             BETI2           BETO2           SPLNO2
.9958413E-03    .9663591E-03    50.81841        -5.477123       13.00000
  MSP2  ARRAY
.1767866E-02    .8225985E-02    .1791505E-01    .2985114E-01    .4593955E-01    .6312073E-01    .8117985E-01    .9994522E-01
.1192385        .1388764        .1547094        .1685705        .1784377
  THSP2  ARRAY
-.1385046E-02   .1513937E-01    .3691847E-01    .5973983E-01    .8493909E-01    .1063483        .1239432        .1375884
.1471895        .1526932        .1541361        .1532488        .1513964

  MR  ARRAY
-.1300000       -.5000000E-02   .5000000E-02    .2003000E-01    .4003000E-01    .8003000E-01    .1000300        .1250300
.1500400        .1752600        .1852600        .2250000        .2700000
  RMSP  ARRAY
.4540000        .4540000        .4540000        .4540000        .4540000        .4540000        .4540000        .4540000
.4540000        .4540000        .4540000        .4540000        .4540000
  BESP  ARRAY
.5000000E-01    .5000000E-01    .4990000E-01    .4960000E-01    .4925000E-01    .4850000E-01    .4815000E-01    .4770000E-01
.4720000E-01    .4675000E-01    .4661000E-01    .4661000E-01    .4661000E-01
  PLOSS ARRAY
0.              0.              .1500000E-02    .5900000E-02    .1100000E-01    .2150000E-01    .3000000E-01    .3350000E-01
.4000000E-01    .4700000E-01    .4800000E-01    .4800000E-01    .4800000E-01

 BLDAT  AANDK  ERSOR  STRFN  SLCRD  INTVL  SURVL
   0      0      0      0      0      0      1
```

Figure A.2.- Continued.

```
          RELATIVE           MERIDIONAL           CRITICAL           REL. FLOW
          VELOCITY            VELOCITY            VELOCITY             ANGLE
        AT M = FSMI         AT M = FSMI         AT M = FSMI       AT UPSTREAM BDY.
          745.90              497.17              1095.9              48.257
        AT M = FSMO         AT M = FSMO         AT M = FSMO      AT DOWNSTREAM BDY.
          498.55              498.55              1095.9             0.

        FSMI =   0.
        FSMO =    .17951

 CALCULATED PROGRAM CONSTANTS

    PITCH             HT             HM1
    .1847996        .1231997E-01    .5609788E-02

    ITMIN          ITMAX
       0             27

    LAMBDA              DOWNSTREAM WHIRL (RVTHO)
    252.4466                   0.

    REDUCED WEIGHT FLOW =     .5700000E-02

    NUMBER OF INTERIOR MESH POINTS =  1046

CALCULATED VELOCITY DIAGRAM INFORMATION
                       IM         W                  W/WCR                BETA
UPSTREAM BOUNDARY       1          745.23               .68000               48.257
LEADING EDGE           24          745.90               .68061               48.200
TRAILING EDGE          56          498.55               .45491              0.
DOWNSTREAM BOUNDARY    72          499.77               .45602              0.
```

Figure A.2.- Continued.

```
ITERATION  NO.   1
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1837        AT IM =  0,   IT =  4,   SURF = 1,   M =  .1918E-01
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1045
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  90


ITERATION  NO.   2
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .7501E-01   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4069E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2483E-01
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS.=  90


ITERATION  NO.   3
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3724E-01   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4069E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .7438E-02
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  89


ITERATION  NO.   4
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1933E-01   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4069E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2531E-02
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  49


ITERATION  NO.   5
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1019E-01   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4069E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .9376E-03
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  22


ITERATION  NO.   6
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .5275E-02   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4069E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3679E-03
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  14


ITERATION  NO.   7
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3104E-02   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4069E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1662E-03
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =   1


ITERATION  NO.   8
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1306E-02   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4069E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .5430E-04
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =   1


ITERATION  NO.   9
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .6819E-03   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4069E-02
```

Figure A.2.- Continued.

```
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2643E-04
NUMBER OF UNCONVERGFD BLADE SURFACE MESH POINTS =    0


ITERATION  NO.  10
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3138E-03   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4069E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2102E-04
NUMBER OF UNCONVERGFD BLADE SURFACE MESH POINTS =    0
```

Figure A.2.- Continued.

```
              *                SURFACE VELOCITIES BASED ON MERIDIONAL COMPONENTS - REDUCED WEIGHT FLOW                      *
              *                                                      *                                                      *
              *                BLADE SURFACE 1                       *                 BLADE SURFACE 2                      *
    M         *  VELOCITY    ANGLE(DEG) SURF. LENGTH      W/WCR      *  VELOCITY    ANGLE(DEG) SURF. LENGTH      W/WCR      *
0.            * 0.             90.00    0.               0.          * 0.            -90.00    0.               0.          *
 .5610E-02    *  836.7         50.59     .9360E-02        .7635      *  632.9         48.96     .6851E-02        .5775      *
 .1122E-01    *  848.1         48.08     .1797E-01        .7739      *  599.0         46.37     .1518E-01        .5466      *
 .1683E-01    *  851.3         45.66     .2618E-01        .7768      *  564.0         43.89     .2313E-01        .5147      *
 .2244E-01    *  846.2         43.35     .3404E-01        .7721      *  540.8         41.52     .3077E-01        .4935      *
 .2805E-01    *  834.5         41.16     .4162E-01        .7615      *  522.7         39.21     .3813E-01        .4769      *
 .3366E-01    *  820.3         39.02     .4895E-01        .7485      *  508.1         36.98     .4526E-01        .4636      *
 .3927E-01    *  805.2         36.85     .5607E-01        .7347      *  496.1         34.83     .5218E-01        .4527      *
 .4488E-01    *  788.7         34.68     .6298E-01        .7197      *  487.9         32.77     .5893E-01        .4452      *
 .5049E-01    *  770.7         32.50     .6972E-01        .7032      *  479.5         30.82     .6553E-01        .4375      *
 .5610E-01    *  754.2         30.30     .7629E-01        .6882      *  473.5         28.92     .7200E-01        .4320      *
 .6171E-01    *  739.3         28.11     .8272E-01        .6745      *  467.1         27.10     .7835E-01        .4263      *
 .6732E-01    *  723.5         25.94     .8901E-01        .6602      *  462.5         25.34     .8461E-01        .4220      *
 .7293E-01    *  710.8         23.83     .9520E-01        .6486      *  457.2         23.59     .9077E-01        .4172      *
 .7854E-01    *  697.6         21.78     .1013            .6365      *  453.8         21.87     .9685E-01        .4141      *
 .8415E-01    *  688.8         19.78     .1073            .6285      *  449.7         20.17     .1029            .4104      *
 .8976E-01    *  680.9         17.80     .1132            .6213      *  447.5         18.48     .1088            .4083      *
 .9537E-01    *  671.6         15.84     .1191            .6128      *  445.6         16.82     .1147            .4066      *
 .1010        *  665.3         13.91     .1249            .6070      *  442.6         15.19     .1205            .4039      *
 .1066        *  658.7         12.00     .1306            .6011      *  441.0         13.57     .1263            .4024      *
 .1122        *  652.0         10.10     .1363            .5949      *  439.8         11.97     .1321            .4013      *
 .1178        *  645.0          8.23     .1420            .5885      *  439.2         10.39     .1378            .4007      *
 .1234        *  635.7          6.38     .1477            .5801      *  437.8          8.82     .1435            .3995      *
 .1290        *  629.3          4.54     .1533            .5742      *  438.7          7.25     .1491            .4003      *
 .1346        *  622.6          2.71     .1589            .5681      *  440.7          5.69     .1548            .4021      *
 .1402        *  615.5           .90     .1646            .5616      *  444.0          4.12     .1604            .4052      *
 .1459        *  607.4          -.92     .1702            .5542      *  449.0          2.60     .1660            .4097      *
 .1515        *  597.2         -2.76     .1758            .5450      *  455.5          1.13     .1717            .4156      *
 .1571        *  584.1         -4.61     .1814            .5330      *  463.5          -.29     .1773            .4230      *
 .1627        *  567.1         -6.38     .1870            .5175      *  475.4         -1.92     .1829            .4338      *
 .1683        *  548.2         -8.06     .1927            .5003      *  500.5         -3.80     .1885            .4567      *
 .1739        *  533.5         -9.68     .1984            .4868      *  585.9         -5.24     .1941            .5347      *
 .1795        * 0.            -90.00     .2043           0.          * 0.             90.00     .1998           0.          *
```

Figure A.2.- Continued.

```
SURFACE VELOCITIES BASED ON TANGENTIAL COMPONENTS
                 REDUCED WEIGHT FLOW


                      BLADE. SURFACE   1
     M               VELOCITY   ANGLE(DEG)      W/WCR
 0.                  538.5        90.00         .4913
  .4069E-02          923.1        51.31         .8423
  .8721E-02          838.6        49.19         .7652
  .1374E-01          850.8        46.98         .7763
  .1918E-01          851.5        44.69         .7770
  .2507E-01          844.3        42.31         .7704
  .3149E-01          831.4        39.85         .7587
  .3852E-01          815.4        37.15         .7440
  .4631E-01          787.7        34.13         .7188
  .5512E-01          768.0        30.68         .7008
  .6534E-01          738.9        26.70         .6742
  .7768E-01          713.0        22.08         .6506
  .9369E-01          687.7        16.42         .6275
  .1202              656.6         7.45         .5992
  .1658              603.2        -7.33         .5504


                      BLADE SURFACE   2
     M               VELOCITY   ANGLE(DEG)      W/WCR
  .2283E-02          729.0        50.57         .6652
  .7074E-02          624.6        48.27         .5700
  .1227E-01          581.7        45.90         .5308
  .1793E-01          552.8        43.42         .5044
  .2412E-01          530.1        40.82         .4837
  .3092E-01          511.6        38.06         .4669
  .3845E-01          496.7        35.13         .4532
  .4688E-01          481.2        32.07         .4390
  .5639E-01          467.9        28.82         .4270
  .6734E-01          456.7        25.33         .4167
  .8031E-01          447.8        21.33         .4086
  .9666E-01          438.6        16.44         .4003
  .1210              432.7         9.51         .3948
```

Figure A.2.- Continued.

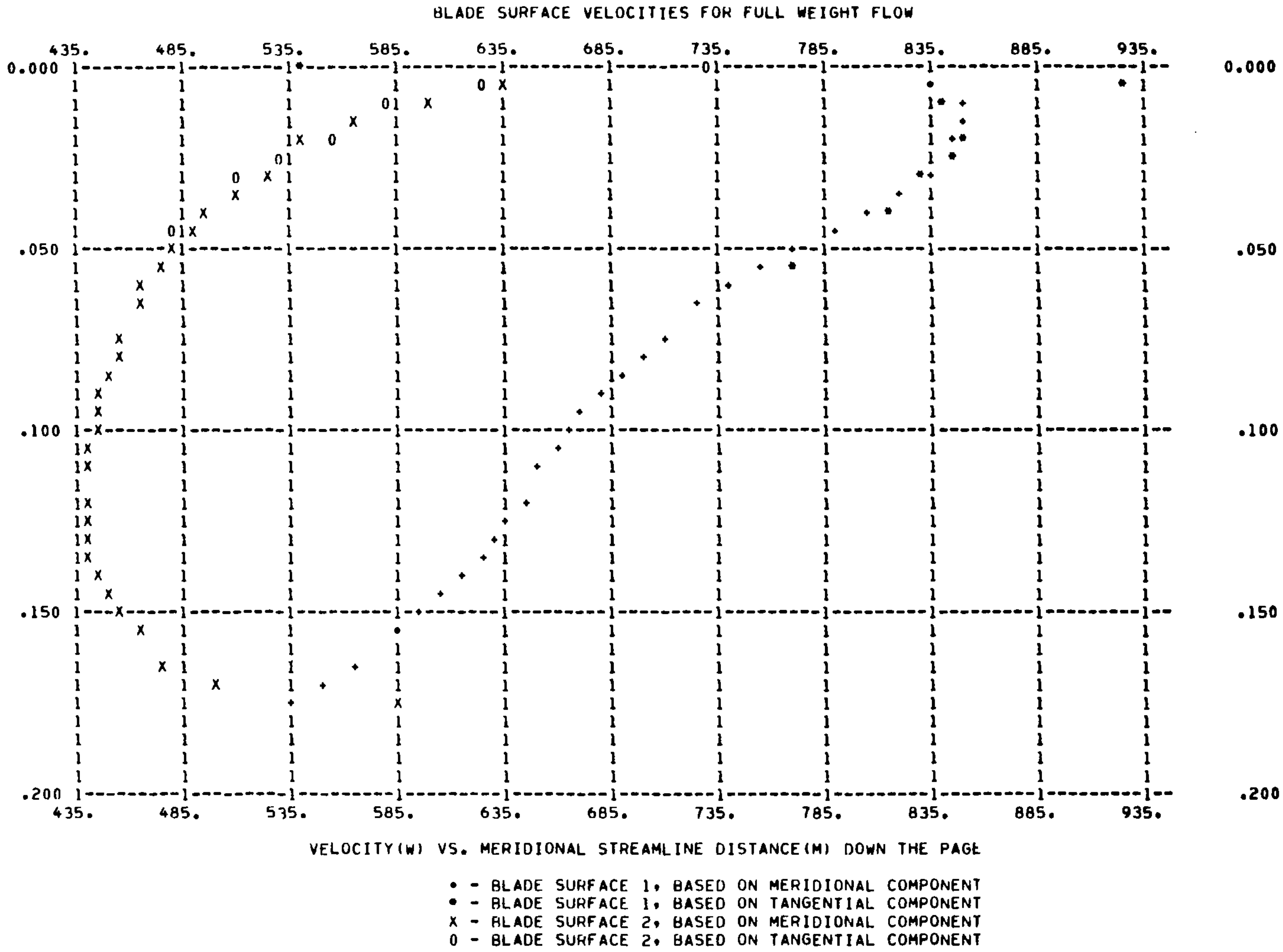


Figure A.2.- Continued.

```
                                    BLADE SURFACE PRESSURES FOR FULL WEIGHT FLOW

IM          M              M/MC           P(1)/PT        P(2)/PT        CPT(1)         CPT(2)

24      0.             0.                .9994          .9994          -.6204E-03     -.6204E-03
25       .5610F-02      .3125E-01        .6981          .8173          -.3019         -.1827
26       .1122F-01      .6250E-01        .6899          .8337          -.3101         -.1663
27       .1683F-01      .9375E-01        .6867          .8496          -.3133         -.1504
28       .2244F-01      .1250            .6887          .8593          -.3113         -.1407
29       .2805E-01      .1563            .6949          .8663          -.3051         -.1337
30       .3366E-01      .1875            .7028          .8717          -.2972         -.1283
31       .3927E-01      .2188            .7111          .8759          -.2889         -.1241
32       .4488E-01      .2500            .7203          .8784          -.2797         -.1216
33       .5049E-01      .2813            .7303          .8810          -.2697         -.1190
34       .5610E-01      .3125            .7392          .8825          -.2608         -.1175
35       .6171E-01      .3438            .7469          .8839          -.2531         -.1161
36       .6732E-01      .3750            .7549          .8845          -.2451         -.1155
37       .7293F-01      .4063            .7608          .8851          -.2392         -.1149
38       .7854E-01      .4375            .7666          .8846          -.2334         -.1154
39       .8415E-01      .4688            .7695          .8840          -.2305         -.1160
40       .8976E-01      .5000            .7718          .8826          -.2282         -.1174
41       .9537E-01      .5313            .7749          .8811          -.2251         -.1189
42       .1010          .5625            .7768          .8806          -.2232         -.1194
43       .1066          .5938            .7793          .8801          -.2207         -.1199
44       .1122          .6250            .7823          .8799          -.2177         -.1201
45       .1178          .6563            .7855          .8797          -.2145         -.1203
46       .1234          .6875            .7899          .8797          -.2101         -.1203
47       .1290          .7188            .7925          .8785          -.2075         -.1215
48       .1346          .7500            .7949          .8766          -.2051         -.1234
49       .1402          .7813            .7972          .8740          -.2028         -.1260
50       .1459          .8125            .7999          .8705          -.2001         -.1295
51       .1515          .8437            .8033          .8663          -.1967         -.1337
52       .1571          .8750            .8082          .8614          -.1918         -.1386
53       .1627          .9062            .8148          .8551          -.1852         -.1449
54       .1683          .9375            .8222          .8433          -.1778         -.1567
55       .1739          .9687            .8278          .8035          -.1722         -.1965
56       .1795         1.000             .9525          .9525          -.4755E-01     -.4755E-01
```

Figure A.2.- Continued.

```
RESULTS OF COMPUTATIONS ON BASE SOLUTION:


.....MACH NUMBER,
     VALUES OF PERTURBATION PARAMETERS,
     CRITICAL VALUE OF WM:

          M0 =  .1000

          Q0(1) =    -9.3094      (  KOCR  )

          Q0(2) =      .2965      (    T   )

          Q0(3) =      .5500      (   ZM   )

          Q0(4) =      .9581      (    P   )

          Q0(5) =      .0329      (   TMX  )

          Q0(6) =      .0052      (  THLE  )

          WMCRIT =-66.8587


.....LOCATIONS OF MIN., MAX., AND CRITICAL PTS.
  (* DENOTES POINT ON LOWER SURFACE)

     MINIMUM AT X =  .6875*    (POINT NO.  10)
     MAXIMUM AT X =  .0937     (POINT NO.  34)


.....LOCATION OF FIXED POINTS
  (* DENOTES POINT ON LOWER SURFACE)

          XFIX(1) = 1.0000*
          XFIX(2) =  .0937
          XFIX(3) = 1.0000



X ARRAY
         .968750     .937500     .906250     .875000     .843750
         .812500     .781250     .750000     .718750     .687500
         .656250     .625000     .593750     .562500     .531250
         .500000     .468750     .437500     .406250     .375000
         .343750     .312500     .281250     .250000     .218750
         .187500     .156250     .125000     .093750     .062500
         .031250     .031250     .062500     .093750     .125000
         .156250     .187500     .218750     .250000     .281250
         .312500     .343750     .375000     .406250     .437500
         .468750     .500000     .531250     .562500     .593750
         .625000     .656250     .687500     .718750     .750000
         .781250     .812500     .843750     .875000     .906250
         .937500     .968750

  Y ARRAY
         585.946     500.526     475.384     463.538     455.453
         448.954     444.034     440.692     438.692     437.817
```

Figure A.2.- Continued.

```
          439.170       439.833       441.032       442.598       445.557
          447.463       449.745       453.791       457.230       462.531
          467.147       473.460       479.521       487.914       496.105
          508.106       522.699       540.850       564.034       599.017
          632.856       836.747       848.134       851.345       846.151
          A34.503       820.308       805.229       788.747       770.703
          754.190       739.256       723.486       710.818       697.563
          688.798       680.850       671.634       665.267       658.725
          651.996       644.996       635.734       629.278       622.630
          615.503       607.355       597.245       584.097       567.118
          548.249       533.506


OUTPUT FROM OBJCON

   OBJECTIVE FUNCTION   DIFFS      =  .85135E+03
                        WO         =  .49A55E+03
                        DIFFS/WO   =  .17077E+01

   CONSTRAINT 1         BLTKS      =  .28002E+00

   CONSTRAINT 2         YMAX       =  .63286E+03
                        YMIN       =  .43782E+03
                        DIFFP      =  .14455E+01

   CONSTRAINT 3     WMB(MBO-2,1)   =  .54A25E+03
                    WMB(MBO-2,2)   =  .50053E+03
                        TECLSR     =  .59654E+00
```

Figure A.2.- Continued.

UNIT PERTURBATION OF WM AND UNIT STRAINING OF XBASE
FOR CALIBRATION SOLUTIONS 1 THROUGH 5

|  |  | • 1ST CALB SOLN • |  | • 2ND CALB SOLN • |  | • 3RD CALB SOLN • |  | • 4TH CALB SOLN • |  | • 5TH CALB SOLN • |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| POINT | XBASE | XSTRUNIT | WMUNIT | XSTRUNIT | WMUNIT | XSTRUNIT | WMUNIT | XSTRUNIT | WMUNIT | XSTRUNIT | WMUNIT |
| 1 | .9687 | .9687 | -20.0835 | .9687 | -12.3557 | .9687 | .7336 | .9679 | 49.8051 | .9687 | -134.3581 |
| 2 | .9375 | .9375 | -2.0339 | .9375 | .3504 | .9375 | 22.0747 | .9357 | 31.4676 | .9375 | 321.5647 |
| 3 | .9062 | .9062 | -1.5704 | .9062 | -1.8310 | .9062 | 32.2313 | .9036 | 32.5262 | .9062 | 553.3391 |
| 4 | .8750 | .8750 | -1.1541 | .8750 | -2.8760 | .8750 | 39.4171 | .8714 | 33.1910 | .8750 | 730.8362 |
| 5 | .8437 | .8437 | -.5654 | .8437 | -3.2252 | .8437 | 44.4573 | .8393 | 33.0680 | .8437 | 869.5636 |
| 6 | .8125 | .8125 | -.0083 | .8125 | -3.2979 | .8125 | 47.7861 | .8071 | 32.3865 | .8125 | 982.7536 |
| 7 | .7813 | .7813 | .4519 | .7813 | -3.2944 | .7813 | 49.9671 | .7750 | 31.2294 | .7813 | 1083.0267 |
| 8 | .7500 | .7500 | .8409 | .7500 | -3.2652 | .7500 | 51.3220 | .7429 | 29.7367 | .7500 | 1177.6278 |
| 9 | .7188 | .7188 | 1.1920 | .7188 | -3.1984 | .7188 | 51.9009 | .7107 | 27.8109 | .7188 | 1266.5219 |
| 10 | .6875 | .6875 | 1.5444 | .6875 | -3.0260 | .6875 | 51.5705 | .6786 | 24.0298 | .6875 | 1346.7744 |
| 11 | .6563 | .6563 | 1.7105 | .6563 | -2.7491 | .6563 | 50.4412 | .6464 | 22.6987 | .6563 | 1436.6945 |
| 12 | .6250 | .6250 | 1.9518 | .6250 | -2.5167 | .6250 | 48.7109 | .6143 | 20.1833 | .6250 | 1513.6100 |
| 13 | .5938 | .5938 | 2.1692 | .5938 | -2.2244 | .5938 | 45.8657 | .5821 | 17.5319 | .5938 | 1584.0968 |
| 14 | .5625 | .5625 | 2.3808 | .5625 | -1.8467 | .5625 | 41.5757 | .5500 | 12.3536 | .5625 | 1644.2614 |
| 15 | .5313 | .5313 | 2.4946 | .5313 | -1.4206 | .5313 | 34.7531 | .5179 | 9.6214 | .5313 | 1711.4227 |
| 16 | .5000 | .5000 | 2.6598 | .5000 | -.9420 | .5000 | 27.1473 | .4857 | 4.7197 | .5000 | 1760.2479 |
| 17 | .4688 | .4688 | 2.8328 | .4688 | -.3770 | .4688 | 18.3364 | .4536 | -3.8576 | .4688 | 1797.3748 |
| 18 | .4375 | .4375 | 2.9307 | .4375 | .3384 | .4375 | 8.5195 | .4214 | -8.7994 | .4375 | 1849.8007 |
| 19 | .4063 | .4063 | 2.8725 | .4063 | 1.1044 | .4063 | -2.1194 | .3893 | -19.8105 | .4063 | 1905.3349 |
| 20 | .3750 | .3750 | -1.1870 | .3750 | 1.6390 | .3750 | -18.8717 | .3571 | -28.8464 | .3750 | 2411.8914 |
| 21 | .3438 | .3438 | 3.4304 | .3438 | 1.2143 | .3438 | -42.9978 | .3250 | -49.4112 | .3438 | 1914.4488 |
| 22 | .3125 | .3125 | 3.4417 | .3125 | -.2424 | .3125 | -82.2106 | .2929 | -73.9244 | .3125 | 2377.3086 |
| 23 | .2813 | .2813 | 3.5360 | .2813 | 1.7374 | .2813 | -121.3626 | .2607 | -100.9777 | .2813 | 1799.7259 |
| 24 | .2500 | .2500 | 3.5962 | .2500 | 11.6855 | .2500 | -170.1902 | .2286 | -129.5244 | .2500 | 1750.2485 |
| 25 | .2188 | .2188 | 3.6615 | .2188 | 28.8759 | .2188 | -213.2488 | .1964 | -168.5015 | .2188 | 1673.8101 |
| 26 | .1875 | .1875 | 3.7119 | .1875 | 49.8522 | .1875 | -259.9132 | .1643 | -199.0200 | .1875 | 1603.4360 |
| 27 | .1563 | .1563 | 3.7645 | .1563 | 63.6612 | .1563 | -294.5792 | .1321 | -227.0555 | .1563 | 1542.7842 |
| 28 | .1250 | .1250 | 3.8190 | .1250 | 67.6203 | .1250 | -314.5814 | .1000 | -256.8217 | .1250 | 1493.5615 |
| 29 | .0938 | .0938 | 3.8704 | .0938 | 67.8533 | .0938 | -323.8562 | .0679 | -313.1910 | .0938 | 1439.4028 |
| 30 | .0625 | .0625 | 4.0452 | .0625 | 64.1781 | .0625 | -318.0546 | .0357 | -301.6170 | .0625 | 1395.2751 |
| 31 | .0313 | .0313 | 3.7273 | .0313 | 59.1752 | .0313 | -306.1475 | .0036 | -390.5942 | .0313 | 1315.1689 |
| 32 | .0313 | .0313 | -2.0986 | .0313 | 20.0463 | .0313 | 38.5597 | .0607 | 53.0857 | .0313 | -774.5666 |
| 33 | .0625 | .0625 | -1.7847 | .0625 | 59.1447 | .0625 | -147.0558 | .0929 | 55.9563 | .0625 | -245.9485 |
| 34 | .0937 | .0937 | -1.3110 | .0937 | 75.5428 | .0937 | -243.1517 | .1250 | 57.6540 | .0937 | 128.3677 |
| 35 | .1250 | .1250 | -.7343 | .1250 | 86.0979 | .1250 | -298.0271 | .1552 | 44.6364 | .1250 | 439.0277 |
| 36 | .1563 | .1563 | -.0684 | .1563 | 76.0690 | .1563 | -316.0947 | .1853 | 6.7466 | .1563 | 734.5830 |
| 37 | .1875 | .1875 | .5535 | .1875 | 25.7422 | .1875 | -294.0541 | .2155 | -32.6152 | .1875 | 1034.5656 |
| 38 | .2188 | .2188 | 1.0858 | .2188 | -37.4853 | .2188 | -251.8086 | .2457 | -67.3864 | .2188 | 1319.4035 |
| 39 | .2500 | .2500 | 1.4408 | .2500 | -54.6629 | .2500 | -211.5466 | .2759 | -90.1078 | .2500 | 1533.4164 |
| 40 | .2813 | .2813 | 1.6988 | .2813 | -40.9663 | .2813 | -164.2406 | .3060 | -107.1067 | .2813 | 1716.9271 |
| 41 | .3125 | .3125 | 1.8322 | .3125 | -7.2238 | .3125 | -120.1525 | .3362 | -113.3012 | .3125 | 1866.5859 |
| 42 | .3438 | .3438 | 1.8675 | .3438 | 12.3028 | .3438 | -91.4976 | .3664 | -110.1136 | .3438 | 1949.5734 |
| 43 | .3750 | .3750 | 1.8318 | .3750 | 18.5201 | .3750 | -70.0210 | .3966 | -104.1926 | .3750 | 1996.9997 |
| 44 | .4063 | .4063 | 1.7831 | .4063 | 17.1651 | .4063 | -55.8055 | .4267 | -94.5723 | .4063 | 2021.0725 |
| 45 | .4375 | .4375 | 1.6282 | .4375 | 13.5137 | .4375 | -42.1093 | .4569 | -91.3018 | .4375 | 2006.4598 |
| 46 | .4688 | .4688 | 1.4959 | .4688 | 12.4504 | .4688 | -26.6607 | .4871 | -81.2246 | .4688 | 2010.8281 |
| 47 | .5000 | .5000 | 1.4538 | .5000 | 12.2531 | .5000 | -10.9074 | .5172 | -76.0135 | .5000 | 2014.4030 |
| 48 | .5313 | .5313 | 1.2463 | .5313 | 11.9896 | .5313 | 4.2757 | .5474 | -72.4756 | .5313 | 1961.1819 |
| 49 | .5625 | .5625 | 1.1544 | .5625 | 11.4311 | .5625 | 16.9513 | .5776 | -60.5096 | .5625 | 1922.7421 |
| 50 | .5938 | .5938 | 1.0832 | .5938 | 10.5534 | .5938 | 27.4695 | .6078 | -54.5505 | .5938 | 1865.9004 |
| 51 | .6250 | .6250 | 1.0269 | .6250 | 9.3045 | .6250 | 35.8149 | .6379 | -48.5193 | .6250 | 1793.9780 |
| 52 | .6563 | .6563 | 1.4608 | .6563 | 9.0808 | .6563 | 43.1271 | .6681 | -40.0172 | .6563 | 1744.0449 |
| 53 | .6875 | .6875 | .9389 | .6875 | 7.4211 | .6875 | 45.2747 | .6983 | -39.3476 | .6875 | 1578.7011 |
| 54 | .7188 | .7188 | .9441 | .7188 | 6.8230 | .7188 | 48.1426 | .7284 | -35.3002 | .7188 | 1464.1293 |

Figure A.2.- Continued.

```
55      .7500      .7500    1.0328      .7500     6.3076      .7500    49.1325      .7586  -31.5621      .7500 1334.1984
56      .7813      .7813    1.2671      .7813     5.8215      .7813    48.2877      .7888  -27.9952      .7813 1190.4777
57      .8125      .8125    1.6887      .8125     5.4206      .8125    45.5817      .8190  -24.4539      .8125 1030.4991
58      .8437      .8437    2.3181      .8437     5.0341      .8437    40.6758      .8491  -21.2165      .8437  846.5093
59      .8750      .8750    3.1611      .8750     4.5903      .8750    33.2001      .8793  -18.9875      .8750  630.1062
60      .9062      .9062    4.3495      .9062     3.9949      .9062    22.7723      .9095  -18.1252      .9062  376.1257
61      .9375      .9375    -.8723      .9375     4.0444      .9375     9.3163      .9397  -13.9357      .9375   73.0336
62      .9687      .9687   24.4162      .9687     8.5940      .9687   -15.1745     .9698  -38.7317      .9687 -419.8816
```

Figure A.2.- Continued.

```
UNIT PERTURBATION OF WM AND UNIT STRAINING OF XBASE
FOR CALIBRATION SOLUTIONS 6 THROUGH 6


                       • 6TH CALB SOLN •
POINT    XBASE      XSTRUNIT    WMUNIT

   1      .9687       .9687   85.4341
   2      .9375       .9375 -195.5425
   3      .9062       .9062  -73.2089
   4      .8750       .8750 -103.2774
   5      .8437       .8437 -137.1931
   6      .8125       .8125 -130.1613
   7      .7813       .7813 -110.6727
   8      .7500       .7500  -99.2898
   9      .7188       .7188  -98.7822
  10      .6875       .6875 -106.3977
  11      .6563       .6563  -93.3852
  12      .6250       .6250  -88.7640
  13      .5938       .5938  -82.9426
  14      .5625       .5625  -80.9244
  15      .5313       .5313  -70.7242
  16      .5000       .5000  -68.5586
  17      .4688       .4688  -68.1042
  18      .4375       .4375  -40.0619
  19      .4063       .4063  -24.6671
  20      .3750       .3750   -8.0421
  21      .3438       .3438  -55.7364
  22      .3125       .3125 -139.4742
  23      .2813       .2813 -218.3122
  24      .2500       .2500 -304.8216
  25      .2188       .2188 -363.2004
  26      .1875       .1875 -220.2327
  27      .1563       .1563  179.5793
  28      .1250       .1250  972.0918
  29      .0938       .0938 2388.4336
  30      .0625       .0625 6013.0030
  31      .0313       .031310829.3858
  32      .0313       .0313 4319.9999
  33      .0625       .0625  974.4519
  34      .0937       .0937 -336.1720
  35      .1250       .1250 -849.5837
  36      .1563       .1563 -863.6749
  37      .1875       .1875 -370.0835
  38      .2188       .2188  321.6473
  39      .2500       .2500  678.9298
  40      .2813       .2813  973.2190
  41      .3125       .3125 1123.6623
  42      .3438       .3438 1043.2128
  43      .3750       .3750  941.1998
  44      .4063       .4063  759.0115
  45      .4375       .4375  621.9917
  46      .4688       .4688  507.6942
  47      .5000       .5000  403.4571
  48      .5313       .5313  357.8155
  49      .5625       .5625  304.2645
  50      .5938       .5938  258.3880
  51      .6250       .6250  218.0293
  52      .6563       .6563  132.6033
  53      .6875       .6875  150.2109
  54      .7188       .7188  125.2795
```

Figure A.2.- Continued.

```
 55      .7500      .7500  109.5129
 56      .7813      .7813  108.1062
 57      .8125      .8125  118.9669
 58      .8437      .8437  116.0773
 59      .8750      .8750   66.5779
 60      .9062      .9062    1.4576
 61      .9375      .9375  -18.1001
 62      .9687      .9687   46.1274
```

Figure A.2.- Continued.

```
       * * * * * * * * * * * * * * * * * * * * * * * * * * *
       *                                                   *
       *                    C O N M I N                    *
       *                                                   *
       *                FORTRAN PROGRAM FOR                *
       *                                                   *
       *         CONSTRAINED FUNCTION MINIMIZATION         *
       *                                                   *
       * * * * * * * * * * * * * * * * * * * * * * * * * * *


CONSTRAINED FUNCTION MINIMIZATION

CONTROL PARAMETERS

IPRINT  NDV    ITMAX    NCON    NSIDE  ICNDIR   NSCAL   NFDG
  5       6       6       6       1       7      -2       0

LINOBJ  ITRM     N1      N2      N3      N4      N5
  0       3       8      18      20      20      40

    CT              CTMIN           CTL             CTLMIN
 -.10000E+00      .40000E-02     -.10000E-01      .10000E-02

    THETA           PHI             DELFUN          DABFUN
  .10000E+01      .50000E+01      .10000E-03      .17077E-02

    FDCH            FDCHM           ALPHAX          ABOBJ1
  .10000E-01      .10000E-02      .10000E+00      .50000E-01

LOWER BOUNDS ON DECISION VARIABLES (VLB)
  1)    -.15000E+01   .80000E+00   .44444E+00   .33333E+00   .60000E+00   .60000E+00

UPPER BOUNDS ON DECISION VARIABLES (VUB)
  1)    0.            .24000E+01   .12222E+01   .26667E+01   .20000E+01   .24000E+01

SCALING VECTOR (SCAL)
  .1000E+02    .2500E+00    .4500E+00    .1500E+01    .5000E-01    .5000E-02

ALL CONSTRAINTS ARE NON-LINEAR


INITIAL FUNCTION INFORMATION

OBJ =    .170765E+01

DECISION VARIABLES (X-VECTOR)
  1)    -.93094E+01   .29650E+00   .55000E+00   .95806E+00   .32891E-01   .51525E-02

CONSTRAINT VALUES (G-VECTOR)
  1)    -.28002E+01  -.97200E+00  -.14455E+02  -.96575E-01  -.15965E+01  -.40346E+00
```

Figure A.2.- Continued.

```
      BEGIN ITERATION NUMBER     1

      CT =    -.10000E+00      CTL =    -.10000E-01      PHI =     .50000E+01


                                                   *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                             INLET     OUTLET     TRANS.    MAX.TH.    IN/OUT      MAX.       L.E.       T.E.
         NO.        INLET      CONE      SOLIDITY           BLADE      BLADE      LOC.       LOC.      TURNING    THICK.      RAD.       RAD.
        BLADES      RADIUS     ANGLE                        ANGLE      ANGLE     /CHORD     /CHORD      RATE      /CHORD     /CHORD     /CHORD
                     (L)       (DEG)                        (DEG)      (DEG)

         34        .45400    6.66400    2.25200    52.000    -9.2163    .29650     .55000     .95806     .03289     .00515     .00500



 X ARRAY
             .968750     .937500     .906250     .875000     .843750
             .812500     .781250     .750000     .718750     .687500
             .656250     .625000     .593750     .562500     .531250
             .500000     .468750     .437500     .406250     .375000
             .343750     .312500     .281250     .250000     .218750
             .187500     .156250     .125000     .093750     .062500
             .031250     .031250     .062500     .093750     .125000
             .156250     .187500     .218750     .250000     .281250
             .312500     .343750     .375000     .406250     .437500
             .468750     .500000     .531250     .562500     .593750
             .625000     .656250     .687500     .718750     .750000
             .781250     .812500     .843750     .875000     .906250
             .937500     .968750

  Y ARRAY
             584.076     500.337     475.238     463.430     455.400
             448.954     444.076     440.771     438.803     437.961
             439.329     440.014     441.234     442.820     445.789
             447.710     450.009     454.064     457.497     462.420
             467.467     473.780     479.851     488.249     496.446
             508.451     523.050     541.205     564.395     599.393
             633.203     836.552     847.968     851.223     846.083
             834.497     820.359     805.330     788.882     770.861
             754.360     739.430     723.656     710.984     697.714
             688.937     680.986     671.750     665.374     658.826
             652.092     645.132     635.822     629.366     622.726
             615.621     607.512     597.461     584.391     567.523
             548.168     535.779



 OUTPUT FROM OBJCON

    OBJECTIVE FUNCTION   DIFFS     =  .85122E+03
                         WO        =  .49855E+03
                         DIFFS/WO  =  .17074E+01

    CONSTRAINT 1         BLTKS     =  .27996E+00

    CONSTRAINT 2         YMAX      =  .63320E+03
                         YMIN      =  .43796E+03
                         DIFFP     =  .14458E+01

    CONSTRAINT 3      WMB(MBO-2,1) =  .54817E+03
                      WMB(MBO-2,2) =  .50034E+03
```

Figure A.2.- Continued.

```
                        TECLSR   =  .59789E+00



                                             *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                INLET    OUTLET    TRANS.    MAX.TH.   IN/OUT     MAX.      L.E.      T.E.
         NO.      INLET     CONE    SOLIDITY    BLADE     BLADE     LOC.      LOC.     TURNING    THICK.    RAD.      RAD.
       BLADES    RADIUS     ANGLE               ANGLE     ANGLE    /CHORD    /CHORD     RATE     /CHORD    /CHORD    /CHORD
                   (L)      (DEG)               (DEG)     (DEG)

         34       .45400   6.66400   2.25200   52.000   -9.3094    .29946    .55000    .95806    .03289    .00515    .00500



X ARRAY
         .968750     .937500     .906250     .875000     .843750
         .812500     .781250     .750000     .718750     .687500
         .656250     .625000     .593750     .562500     .531250
         .500000     .468750     .437500     .406250     .375000
         .343750     .312500     .281250     .250000     .218750
         .187500     .156250     .125000     .093750     .062500
         .031250     .031250     .062500     .093750     .125000
         .156250     .187500     .218750     .250000     .281250
         .312500     .343750     .375000     .406250     .437500
         .468750     .500000     .531250     .562500     .593750
         .625000     .656250     .687500     .718750     .750000
         .781250     .812500     .843750     .875000     .906250
         .937500     .968750

 Y ARRAY
         585.909     500.527     475.378     463.529     455.444
         448.945     444.024     440.683     438.683     437.808
         439.162     439.825     441.025     442.593     445.553
         447.460     449.744     453.792     457.233     462.536
         467.151     473.459     479.527     487.949     496.191
         508.253     522.888     541.050     564.235     599.207
         633.031     836.807     848.310     851.569     846.407
         834.729     820.384     805.118     788.585     770.581
         754.168     739.293     723.541     710.869     697.603
         688.835     680.887     671.669     665.301     658.757
         652.024     645.023     635.756     629.298     622.649
         615.521     607.371     597.260     584.111     567.130
         548.261     533.531



OUTPUT FROM OBJCON

   OBJECTIVE FUNCTION   DIFFS       =  .85157E+03
                        WO          =  .49855E+03
                        DIFFS/WO    =  .17081E+01

   CONSTRAINT 1         BLTKS       =  .28326E+00

   CONSTRAINT 2         YMAX        =  .63303E+03
                        YMIN        =  .43781E+03
                        DIFFP       =  .14459E+01

   CONSTRAINT 3     WMB(MBO-2,1)    =  .54826E+03
                    WMB(MBO-2,2)    =  .50053E+03
```

Figure A.2.- Continued.

```
                         TECLSR    =  .59667E+00



                                         *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                      INLET    OUTLET    TRANS.   MAX.TH.   IN/OUT    MAX.     L.E.     T.E.
         NO.     INLET     CONE    SOLIDITY   BLADE    BLADE     LOC.     LOC.    TURNING  THICK.    RAD.     RAD.
       BLADES    RADIUS    ANGLE               ANGLE    ANGLE    /CHORD   /CHORD    RATE    /CHORD   /CHORD   /CHORD
                  (L)      (DEG)               (DEG)    (DEG)

         34     .45400   6.66400   2.25200   52.000   -9.3094   .29650   .54450   .95806   .03289   .00515   .00500



X ARRAY
        .968750     .937500     .906250     .875000     .843750
        .812500     .781250     .750000     .718750     .687500
        .656250     .625000     .593750     .562500     .531250
        .500000     .468750     .437500     .406250     .375000
        .343750     .312500     .281250     .250000     .218750
        .187500     .156250     .125000     .093750     .062500
        .031250     .031250     .062500     .093750     .125000
        .156250     .187500     .218750     .250000     .281250
        .312500     .343750     .375000     .406250     .437500
        .468750     .500000     .531250     .562500     .593750
        .625000     .656250     .687500     .718750     .750000
        .781250     .812500     .843750     .875000     .906250
        .937500     .968750

 Y ARRAY
        585.942     500.405     475.206     463.321     455.209
        448.692     443.759     440.410     438.407     437.534
        438.893     439.565     440.779     442.369     445.366
        447.313     449.644     453.744     457.241     462.635
        467.384     473.912     480.189     488.851     497.278
        509.535     524.319     542.580     565.816     600.766
        634.540     836.535     848.943     852.683     847.791
        836.242     821.925     806.614     789.911     771.606
        754.851     739.759     723.871     711.125     697.795
        688.945     680.910     671.610     665.174     658.574
        651.799     644.759     635.485     629.013     622.360
        615.238     607.104     597.022     583.914     566.993
        548.198     533.589



OUTPUT FROM OBJCON

   OBJECTIVE FUNCTION   DIFFS     =  .85268E+03
                        WO        =  .49855E+03
                        DIFFS/WO  =  .17103E+01

   CONSTRAINT 1         BLTKS     =  .30418E+00

   CONSTRAINT 2         YMAX      =  .63454E+03
                        YMIN      =  .43753E+03
                        DIFFP     =  .14503E+01

   CONSTRAINT 3     WMB(MBO-2,1)  =  .54820E+03
                    WMB(MBO-2,2)  =  .50040E+03
```

Figure A.2.- Continued.

```
                         TECLSR   =  .59741E+00



                                              *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                 INLET    OUTLET    TRANS.    MAX.TH.   IN/OUT     MAX.      L.E.      T.E.
          NO.      INLET     CONE    SOLIDITY    BLADE     BLADE     LOC.      LOC.     TURNING   THICK.     RAD.      RAD.
        BLADES    RADIUS     ANGLE               ANGLE     ANGLE    /CHORD    /CHORD     RATE     /CHORD    /CHORD    /CHORD
                    (L)      (DEG)               (DEG)     (DEG)

          34       .45400   6.66400   2.25200   52.000   -9.3094    .29650    .55000    .96764    .03289    .00515    .00500



 X ARRAY
          .968750     .937500     .906250     .875000     .843750
          .812500     .781250     .750000     .718750     .687500
          .656250     .625000     .593750     .562500     .531250
          .500000     .468750     .437500     .406250     .375000
          .343750     .312500     .281250     .250000     .218750
          .187500     .156250     .125000     .093750     .062500
          .031250     .031250     .062500     .093750     .125000
          .156250     .187500     .218750     .250000     .281250
          .312500     .343750     .375000     .406250     .437500
          .468750     .500000     .531250     .562500     .593750
          .625000     .656250     .687500     .718750     .750000
          .781250     .812500     .843750     .875000     .906250
          .937500     .968750

  Y ARRAY
          586.337     500.777     475.659     463.823     455.737
          449.235     444.309     440.961     438.951     438.061
          439.395     440.040     441.220     442.758     445.677
          447.543     449.777     453.767     457.140     462.344
          466.803     472.880     478.743     486.863     494.787
          506.576     521.012     539.030     562.063     597.128
          632.376     837.637     848.781     851.710     846.170
          834.089     819.507     804.075     787.352     769.212
          752.705     737.799     722.181     709.606     696.498
          687.856     679.943     670.825     664.577     658.097
          651.430     644.488     635.279     628.867     622.258
          615.166     607.047     596.962     583.832     566.876
          548.079     533.116



 OUTPUT FROM OBJCON

    OBJECTIVE FUNCTION   DIFFS    =  .85171E+03
                         WO       =  .49855E+03
                         DIFFS/WO =  .17084E+01

    CONSTRAINT 1         BLTKS    =  .27981E+00

    CONSTRAINT 2         YMAX     =  .63238E+03
                         YMIN     =  .43806E+03
                         DIFFP    =  .14436E+01

    CONSTRAINT 3     WMB(MBO-2,1) =  .54808E+03
                     WMB(MBO-2,2) =  .50078E+03
```

Figure A.2.- Continued.

```
                    TECLSR    =   .59128E+00



                                        *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                       INLET     OUTLET     TRANS.    MAX.TH.    IN/OUT     MAX.       L.E.       T.E.
       NO.       INLET      CONE     SOLIDITY         BLADE      BLADE      LOC.       LOC.     TURNING    THICK.      RAD.       RAD.
     BLADES     RADIUS     ANGLE                      ANGLE      ANGLE     /CHORD     /CHORD     RATE     /CHORD     /CHORD     /CHORD
                  (L)      (DEG)                      (DEG)      (DEG)

       34       .45400    6.66400    2.25200         52.000    -9.3094     .29650     .55000     .95806     .03389     .00515     .00500



X ARRAY
         .968750      .937500      .906250      .875000      .843750
         .812500      .781250      .750000      .718750      .687500
         .656250      .625000      .593750      .562500      .531250
         .500000      .468750      .437500      .406250      .375000
         .343750      .312500      .281250      .250000      .218750
         .187500      .156250      .125000      .093750      .062500
         .031250      .031250      .062500      .093750      .125000
         .156250      .187500      .218750      .250000      .281250
         .312500      .343750      .375000      .406250      .437500
         .468750      .500000      .531250      .562500      .593750
         .625000      .656250      .687500      .718750      .750000
         .781250      .812500      .843750      .875000      .906250
         .937500      .968750

 Y ARRAY
         585.812      500.848      475.937      464.269      456.323
         449.937      445.117      441.870      439.959      439.164
         440.607      441.346      442.616      444.242      447.268
         449.223      451.543      455.641      459.135      464.943
         469.062      475.837      481.321      489.665      497.779
         509.709      524.242      542.343      565.474      600.412
         634.171      835.973      847.888      851.474      846.590
         835.238      821.342      806.548      790.281      772.420
         756.056      741.206      725.483      712.839      699.569
         690.809      682.865      673.595      667.190      660.591
         653.790      646.740      637.313      630.742      623.964
         616.694      608.385      598.092      584.727      567.494
         548.322      533.086



OUTPUT FROM OBJCON

   OBJECTIVE FUNCTION   DIFFS     =   .85147E+03
                        WO        =   .49855E+03
                        DIFFS/WO  =   .17079E+01

   CONSTRAINT 1         BLTKS     =   .29081E+00

   CONSTRAINT 2         YMAX      =   .63417E+03
                        YMIN      =   .43916E+03
                        DIFFP     =   .14440E+01

   CONSTRAINT 3     WMB(MBO-2,1)  =   .54832E+03
                    WMB(MBO-2,2)  =   .50085E+03
```

Figure A.2.- Continued.

```
                    TECLSR    =  .59343E+00



                                          *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                     INLET     OUTLET    TRANS.    MAX.TH.   IN/OUT    MAX.      L.E.      T.E.
           NO.      INLET     CONE     SOLIDITY     BLADE     BLADE     LOC.      LOC.      TURNING   THICK.    RAD.      RAD.
          BLADES    RADIUS    ANGLE                 ANGLE     ANGLE     /CHORD    /CHORD    RATE      /CHORD    /CHORD    /CHORD
                     (L)      (DEG)                 (DEG)     (DEG)

           34      .45400    6.66400   2.25200     52.000    -9.3094    .29650    .55000    .95806    .03289    .00615    .00500


X ARRAY
          .968750      .937500      .906250      .875000      .843750
          .812500      .781250      .750000      .718750      .687500
          .656250      .625000      .593750      .562500      .531250
          .500000      .468750      .437500      .406250      .375000
          .343750      .312500      .281250      .250000      .218750
          .187500      .156250      .125000      .093750      .062500
          .031250      .031250      .062500      .093750      .125000
          .156250      .187500      .218750      .250000      .281250
          .312500      .343750      .375000      .406250      .437500
          .468750      .500000      .531250      .562500      .593750
          .625000      .656250      .687500      .718750      .750000
          .781250      .812500      .843750      .875000      .906250
          .937500      .968750

 Y ARRAY
          586.031      500.331      475.311      463.435      455.316
          448.824      443.923      440.593      438.594      437.711
          439.077      439.744      440.949      442.517      445.486
          447.394      449.677      453.751      457.205      462.523
          467.092      473.320      479.303      487.610      495.742
          507.885      522.879      541.822      566.423      605.030
          643.685      841.067      849.109      851.009      845.302
          833.639      819.938      805.551      789.426      771.676
          755.314      740.299      724.427      711.577      698.185
          689.306      681.254      671.991      665.571      658.984
          652.214      645.128      635.885      629.403      622.739
          615.612      607.474      597.362      584.164      567.120
          548.231      533.552


OUTPUT FROM OBJCON

   OBJECTIVE FUNCTION   DIFFS     =  .85101E+03
                        WO        =  .49855E+03
                        DIFFS/WO  =  .17070E+01

   CONSTRAINT 1         BLTKS     =  .42386E+00

   CONSTRAINT 2         YMAX      =  .64369E+03
                        YMIN      =  .43771E+03
                        DIFFP     =  .14706E+01

   CONSTRAINT 3      WMB(MBO-2,1) =  .54823E+03
                     WMB(MBO-2,2) =  .50033E+03
```

Figure A.2.- Continued.

```
                    TECLSR    =  .59876E+00

    THERE ARE     1 ACTIVE CONSTRAINTS
    CONSTRAINT NUMBERS ARE
        4

    THERE ARE     0 VIOLATED CONSTRAINTS

    THERE ARE     1 ACTIVE SIDE CONSTRAINTS
    DECISION VARIABLES AT LOWER OR UPPER BOUNDS (MINUS INDICATES LOWER BOUND)
        3

    GRADIENT OF OBJ
      1)    -.26392E-01   .37807E-01  -.21940E+00   .11434E+00   .12830E-01  -.33759E-02

    GRADIENTS OF ACTIVE AND VIOLATED CONSTRAINTS
    CONSTRAINT NUMBER    4
      1)     .21332E-01   .22680E-01  -.24471E+00  -.18588E+00  -.44941E-01   .78414E-01

    SIDE CONSTRAINT ON VARIABLE    3
      1)    0.            0.            .10000E+01  0.            0.            0.


    PUSH-OFF FACTORS, (THETA(I), I=1,NAC)
      1)     .11730E-02  0.

    CONSTRAINT PARAMETER, BETA =    .36299E+00

    SEARCH DIRECTION (S-VECTOR)
      1)     .32046E+00  -.10000E+01   .39056E-13  -.43887E+00   .19546E+00  -.72800E+00

    ONE-DIMENSIONAL SEARCH
    INITIAL SLOPE =  -.9148E-01  PROPOSED ALPHA =   .1186E+00



 * * CONSTRAINED ONE-DIMENSIONAL SEARCH INFORMATION * * *


    PROPOSED DESIGN
    ALPHA =  .11860E+00
    X-VECTOR
  -.8929E+01   .2668E+00   .5500E+00   .8800E+00   .3405E-01   .4721E-02
```

Figure A.2.- Continued.

```
                                         *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                          INLET     OUTLET     TRANS.    MAX.TH.    IN/OUT     MAX.       L.E.       T.E.
     NO.       INLET      CONF       SOLIDITY    BLADE      BLADE      LOC.       LOC.      TURNING    THICK.     RAD.       RAD.
   BLADES     RADIUS     ANGLE                   ANGLE      ANGLE     /CHORD     /CHORD      RATE     /CHORD     /CHORD     /CHORD
                (L)      (DEG)                   (DEG)      (DEG)

     34       .45400    6.66400    2.25200      52.000    -8.9293     .26685     .55000     .87999     .03405     .00472     .00500



X ARRAY
         .968750     .937500     .906250     .875000     .843750
         .812500     .781250     .750000     .718750     .687500
         .656250     .625000     .593750     .562500     .531250
         .500000     .468750     .437500     .406250     .375000
         .343750     .312500     .281250     .250000     .218750
         .187500     .156250     .125000     .093750     .062500
         .031250     .031250     .062500     .093750     .125000
         .156250     .187500     .218750     .250000     .281250
         .312500     .343750     .375000     .406250     .437500
         .468750     .500000     .531250     .562500     .593750
         .625000     .656250     .687500     .718750     .750000
         .781250     .812500     .843750     .875000     .906250
         .937500     .968750

 Y ARRAY
         575.226     498.998     473.581     461.860     454.132
         448.015     443.428     440.389     438.698     438.254
         439.690     440.765     442.260     444.293     447.409
         449.890     452.824     457.082     461.385     466.261
         473.241     481.773     489.466     499.183     509.712
         522.635     538.120     557.091     582.208     613.227
         650.082     805.736     837.247     843.322     841.747
         835.030     826.076     815.978     802.800     786.405
         769.349     753.299     736.954     722.919     709.390
         699.074     690.470     680.975     673.220     666.054
         658.757     651.200     641.678     634.454     627.364
         619.856     611.397     601.083     587.877     571.010
         549.410     545.087


OUTPUT FROM OBJCON

   OBJECTIVE FUNCTION   DIFFS     =  .84332E+03
                        WO        =  .49855E+03
                        DIFFS/WO  =  .16916E+01

   CONSTRAINT 1         BLTKS     =  .19679E+00

   CONSTRAINT 2         YMAX      =  .65008E+03
                        YMIN      =  .43825E+03
                        DIFFP     =  .14833E+01

   CONSTRAINT 3     WMB(MBO-2,1)  =  .54941E+03
                    WMB(MBO-2,2)  =  .49900E+03
```

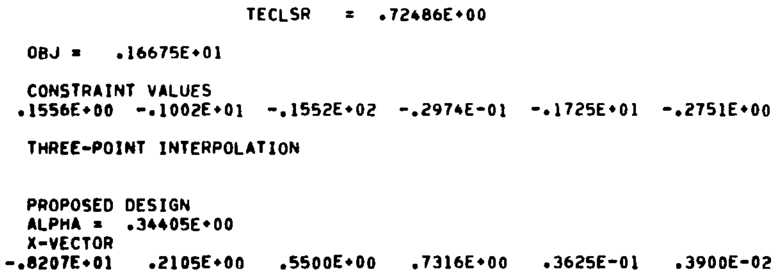
Figure A.2.- Continued.

```
                     TECLSR   =  .63015E+00

  OBJ =   .16916E+01

  CONSTRAINT VALUFS
-.1968E+01  -.9803E+00  -.1483E+02  -.7291E-01  -.1630E+01  -.3698E+00

  TWO-POINT INTERPOLATION


  PROPOSED DESIGN
  ALPHA =  .38598E+00
  X-VECTOR
-.8072E+01   .2000E+00   .5500E+00   .7040E+00   .3666E-01   .3748E-02
```

Figure A.2.- Continued.

```
                                   *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                  INLET     OUTLET     TRANS.     MAX.TH.    IN/OUT     MAX.       L.E.       T.E.
   NO.       INLET      CONE       SOLIDITY       BLADE     BLADE      LOC.       LOC.       TURNING    THICK.     RAD.       RAD.
  BLADES     RADIUS     ANGLE                     ANGLE     ANGLE      /CHORD     /CHORD     RATE       /CHORD     /CHORD     /CHORD
              (L)       (DEG)                     (DEG)     (DEG)

   34        .45400     6.66400    2.25200        52.000    -8.0725    .20000     .55000     .70396     .03666     .00375     .00500



X ARRAY
         .968750     .937500     .906250     .875000     .843750
         .812500     .781250     .750000     .718750     .687500
         .656250     .625000     .593750     .562500     .531250
         .500000     .468750     .437500     .406250     .375000
         .343750     .312500     .281250     .250000     .218750
         .187500     .156250     .125000     .093750     .062500
         .031250     .031250     .062500     .093750     .125000
         .156250     .187500     .218750     .250000     .281250
         .312500     .343750     .375000     .406250     .437500
         .468750     .500000     .531250     .562500     .593750
         .625000     .656250     .687500     .718750     .750000
         .781250     .812500     .843750     .875000     .906250
         .937500     .968750

 Y ARRAY
         550.516     494.472     469.416     457.972     451.012
         445.739     441.893     439.521     438.501     438.930
         440.705     442.613     444.763     447.681     451.328
         454.923     459.030     464.065     469.819     475.041
         483.575     497.330     510.004     521.974     536.848
         553.060     570.624     590.966     617.176     649.870
         680.737     771.425     811.313     824.141     828.722
         828.531     829.594     831.320     830.192     820.187
         804.400     786.288     768.411     751.285     736.461
         723.326     712.703     702.584     692.254     683.150
         674.537     665.675     655.453     646.455     638.311
         629.888     620.680     609.854     596.460     579.793
         552.461     570.387


OUTPUT FROM OBJCON

   OBJECTIVE FUNCTION   DIFFS     =  .83132E+03
                        WO        =  .49855E+03
                        DIFFS/WO  =  .16675E+01

   CONSTRAINT 1         BLTKS     = -.15560E-01

   CONSTRAINT 2         YMAX      =  .68074E+03
                        YMIN      =  .43850E+03
                        DIFFP     =  .15524E+01

   CONSTRAINT 3     WMB(MBO-2,1)  =  .55246E+03
                    WMR(MBO-2,2)  =  .49447E+03
```

Figure A.2.- Continued.

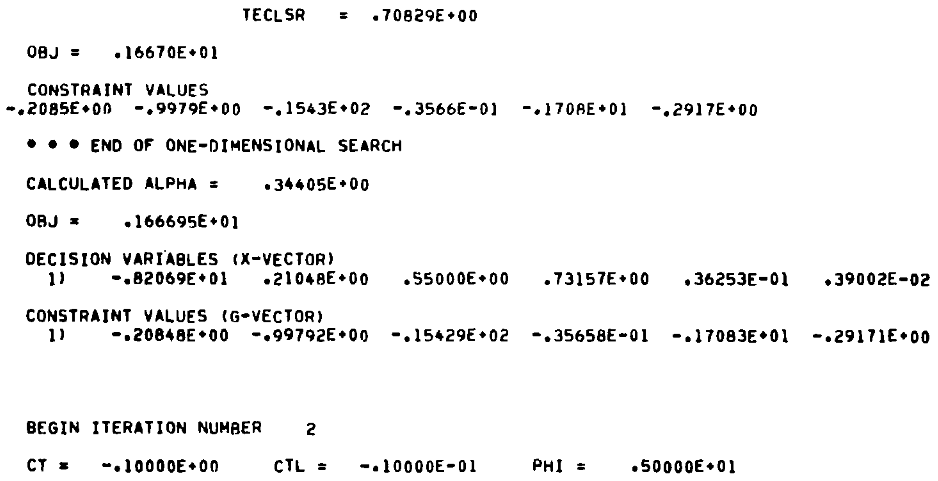


```
                         TECLSR    =  .72486E+00

  OBJ =    .16675E+01

  CONSTRAINT VALUES
 .1556E+00  -.1002E+01  -.1552E+02  -.2974E-01  -.1725E+01  -.2751E+00

  THREE-POINT INTERPOLATION


  PROPOSED DESIGN
  ALPHA =  .34405E+00
  X-VECTOR
-.8207E+01   .2105E+00   .5500E+00   .7316E+00   .3625E-01   .3900E-02
```

Figure A.2.- Continued.

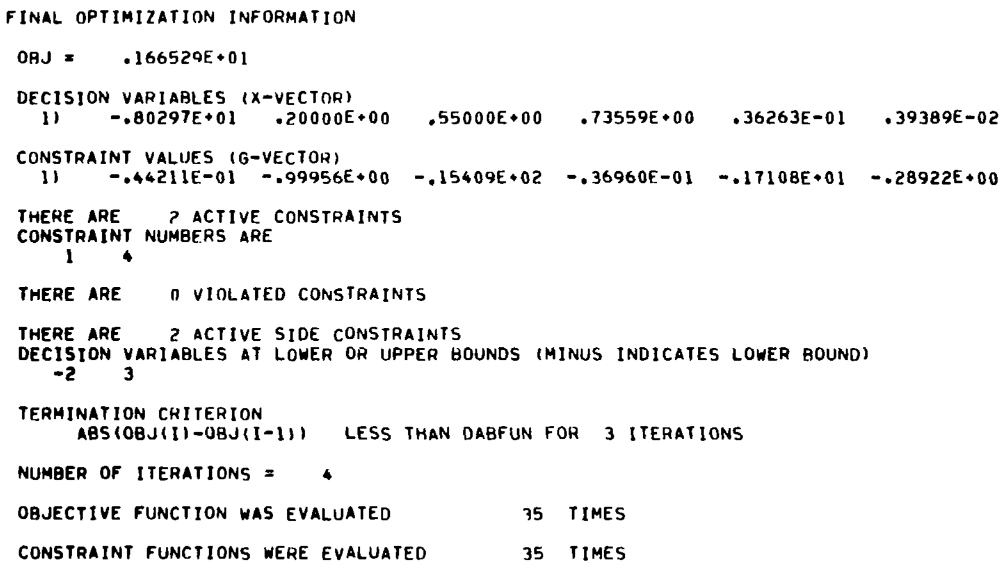
```
                                   *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                   INLET    OUTLET   TRANS.   MAX.TH.   IN/OUT     MAX.     L.E.     T.E.
   NO.      INLET     CONE    SOLIDITY   BLADE     BLADE     LOC.      LOC.   TURNING  THICK.     RAD.     RAD.
 BLADES    RADIUS     ANGLE              ANGLE     ANGLE    /CHORD    /CHORD    RATE   /CHORD   /CHORD   /CHORD
             (L)      (DEG)              (DEG)     (DEG)

   34      .45400   6.66400   2.25200   52.000   -8.2069   .21048    .55000    .73157   .03625   .00390   .00500



X ARRAY
         .968750      .937500      .906250      .875000      .843750
         .812500      .781250      .750000      .718750      .687500
         .656250      .625000      .593750      .562500      .531250
         .500000      .468750      .437500      .406250      .375000
         .343750      .312500      .281250      .250000      .218750
         .187500      .156250      .125000      .093750      .062500
         .031250      .031250      .062500      .093750      .125000
         .156250      .187500      .218750      .250000      .281250
         .312500      .343750      .375000      .406250      .437500
         .468750      .500000      .531250      .562500      .593750
         .625000      .656250      .687500      .718750      .750000
         .781250      .812500      .843750      .875000      .906250
         .937500      .968750

 Y ARRAY
         554.440      495.278      470.079      458.591      451.514
         446.110      442.149      439.674      438.551      438.852
         440.560      442.346      444.394      447.189      450.736
         454.173      458.122      463.009      468.580      473.631
         482.259      495.175      506.951      518.634      532.909
         548.497      565.728      585.899      612.229      643.711
         676.661      773.620      815.504      827.247      831.057
         830.276      829.937      829.753      826.301      815.041
         798.820      780.988      763.374      746.734      732.177
         719.420      709.164      699.143      689.165      680.415
         672.011      663.358      653.257      644.542      636.568
         628.294      619.208      608.467      595.108      578.415
         551.941      566.495


OUTPUT FROM OBJCON

   OBJECTIVE FUNCTION   DIFFS     =  .83106E+03
                        WO        =  .49855E+03
                        DIFFS/WO  =  .16670E+01

   CONSTRAINT 1         BLTKS     =  .20848E-01

   CONSTRAINT 2         YMAX      =  .67666E+03
                        YMIN      =  .43855E+03
                        DIFFP     =  .15429E+01

   CONSTRAINT 3     WMB(MBO-2,1)  =  .55194E+03
                    WMB(MBO-2,2)  =  .49528E+03
```

Figure A.2.- Continued.



```
                     TECLSR    =  .70829E+00

 OBJ =    .16670E+01

 CONSTRAINT VALUES
-.2085E+00  -.9979E+00  -.1543E+02  -.3566E-01  -.1708E+01  -.2917E+00

 • • • END OF ONE-DIMENSIONAL SEARCH

 CALCULATED ALPHA =    .34405E+00

 OBJ =    .166695E+01

 DECISION VARIABLES (X-VECTOR)
   1)    -.82069E+01   .21048E+00   .55000E+00   .73157E+00   .36253E-01   .39002E-02

 CONSTRAINT VALUES (G-VECTOR)
   1)    -.20848E+00  -.99792E+00  -.15429E+02  -.35658E-01  -.17083E+01  -.29171E+00



 BEGIN ITERATION NUMBER    2

 CT =   -.10000E+00     CTL =   -.10000E-01     PHI =    .50000E+01
```

Figure A.2.- Continued.



```
FINAL OPTIMIZATION INFORMATION

 OBJ =    .166529E+01

 DECISION VARIABLES (X-VECTOR)
   1)    -.80297E+01   .20000E+00   .55000E+00   .73559E+00   .36263E-01   .39389E-02

 CONSTRAINT VALUES (G-VECTOR)
   1)    -.44211E-01  -.99956E+00  -.15409E+02  -.36960E-01  -.17108E+01  -.28922E+00

 THERE ARE    2 ACTIVE CONSTRAINTS
 CONSTRAINT NUMBERS ARE
     1    4

 THERE ARE    0 VIOLATED CONSTRAINTS

 THERE ARE    2 ACTIVE SIDE CONSTRAINTS
 DECISION VARIABLES AT LOWER OR UPPER BOUNDS (MINUS INDICATES LOWER BOUND)
    -2    3

 TERMINATION CRITERION
      ABS(OBJ(I)-OBJ(I-1))   LESS THAN DABFUN FOR  3 ITERATIONS

 NUMBER OF ITERATIONS =    4

 OBJECTIVE FUNCTION WAS EVALUATED          35  TIMES

 CONSTRAINT FUNCTIONS WERE EVALUATED       35  TIMES
```

Figure A.2.- Continued.

```
                              *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                              INLET    OUTLET    TRANS.   MAX.TH.   IN/OUT     MAX.      L.E.      T.E.
  NO.       INLET     CONE      SOLIDITY      BLADE     BLADE     LOC.      LOC.    TURNING   THICK.     RAD.      RAD.
 BLADES     RADIUS    ANGLE                   ANGLE     ANGLE    /CHORD    /CHORD    RATE     /CHORD    /CHORD    /CHORD
             (L)      (DEG)                   (DEG)     (DEG)

  34        .45400   6.66400    2.25200      52.000   -8.0297    .20000    .55000    .73559    .03626    .00394    .00500



X ARRAY
          .968750     .937500     .906250     .875000     .843750
          .812500     .781250     .750000     .718750     .687500
          .656250     .625000     .593750     .562500     .531250
          .500000     .468750     .437500     .406250     .375000
          .343750     .312500     .281250     .250000     .218750
          .187500     .156250     .125000     .093750     .062500
          .031250     .031250     .062500     .093750     .125000
          .156250     .187500     .218750     .250000     .281250
          .312500     .343750     .375000     .406250     .437500
          .468750     .500000     .531250     .562500     .593750
          .625000     .656250     .687500     .718750     .750000
          .781250     .812500     .843750     .875000     .906250
          .937500     .968750

 Y ARRAY
          551.119     494.850     469.915     458.527     451.557
          446.251     442.372     439.964     438.901     439.254
          440.997     442.810     444.888     447.705     451.267
          454.707     458.662     463.548     469.088     473.693
          482.427     495.670     507.322     518.886     532.924
          548.211     565.190     585.230     611.560     642.955
          676.287     773.752     815.380     826.614     830.225
          829.402     829.251     829.606     826.571     815.313
          798.841     780.729     762.982     746.369     731.856
          719.154     708.939     698.905     688.952     680.241
          671.864     663.297     653.173     644.471     636.534
          628.317     619.321     608.705     595.505     579.029
          551.713     570.457


OUTPUT FROM OBJCON

   OBJECTIVE FUNCTION     DIFFS     =   .83023E+03
                          WO        =   .49855E+03
                          DIFFS/WO  =   .16653E+01

   CONSTRAINT 1           BLTKS     =   .44211E-02

   CONSTRAINT 2           YMAX      =   .67629E+03
                          YMIN      =   .43890E+03
                          DIFFP     =   .15409E+01

   CONSTRAINT 3       WMB(MBO-2,1)  =   .55171E+03
                      WMB(MBO-2,2)  ■   .49485E+03
```

Figure A.2.- Continued.

```
                    TECLSR   =  .71078E+00


OPTIMIZATION RESULTS


OBJECTIVE FUNCTION
GLOBAL LOCATION    1     FUNCTION VALUE  .16653E+01


DESIGN VARIABLES

         D. V.     GLOBAL       LOWER                       UPPER
   ID     NO.     VAR. NO.      BOUND         VALUE         BOUND
    1      1          2      -.15000E+02   -.80297E+01   0.
    2      2          3       .20000E+00    .20000E+00    .60000E+00
    3      3          4       .20000E+00    .55000E+00    .55000E+00
    4      4          5       .50000E+00    .73559E+00    .40000E+01
    5      5          6       .30000E-01    .36263E-01    .10000E+00
    6      6          7       .30000E-02    .39389E-02    .12000E-01


DESIGN CONSTRAINTS

          GLOBAL       LOWER                      UPPER
    ID    VAR. NO.      BOUND         VALUE         BOUND
    1        8      0.             .44211E-02    .10000E+02
    3        9      0.             .15409E+01    .16000E+01
    5       10      -.10000E+01    .71078E+00    .10000E+01
```

Figure A.2.- Continued.

```
                                   *** INPUT FOR BLADE ELEMENT PROGRAM ***

                                                 INLET    OUTLET   TRANS.   MAX.TH.   IN/OUT    MAX.     L.E.     T.E.
    NO.      INLET     CONE     SOLIDITY         BLADE    BLADE    LOC.     LOC.      TURNING   THICK.   RAD.     RAD.
   BLADES    RADIUS    ANGLE                     ANGLE    ANGLE    /CHORD   /CHORD    RATE      /CHORD   /CHORD   /CHORD
              (L)      (DEG)                     (DEG)    (DEG)

    34       .45400   6.66400   2.25200         52.000   -8.0297   .20000   .55000    .73559    .03626   .00394   .00500



                                   *** OUTPUT FROM BLADE ELEMENT PROGRAM ***

                                                            ELEMENT
                                                            SETTING
                                                  CHORD      ANGLE
                                                   (L)       (DEG)

                                                 .19322     23.5522

        * MERID. LOC. FROM L.E. CENT. **  ** THETA LOC. FROM L.E. CENT. **  ********* BLADE ANGLES *********  SEGMENT LENGTHS
        ********************************  ********************************  (WITH RESPECT TO LOCAL CONIC RAY)  ***************

          INLET   OUTLET   TRANS.  MAX.TH.    INLET   OUTLET   TRANS.  MAX.TH.    INLET   OUTLET   TRANS.  MAX.TH.     FIRST   SECOND
           (L)     (L)      (L)     (L)       (RAD)   (RAD)    (RAD)   (RAD)      (DEG)   (DEG)    (DEG)   (DEG)       (L)     (L)

SUCT.   -.00061  .17564  .02675  .08501     .00101  .16727  .06970  .15112     52.848 -11.222  44.807  20.661     .04159  .16190

CENT.   0.00000  .17546  .02807  .08624    0.00000  .16528  .06653  .14405     52.000  -8.030  42.376  20.661     .04136  .15935

PRES.    .00059  .17538  .02940  .08748    -.00105  .16325  .06334  .13699     51.166  -4.794  39.883  20.661     .04119  .15704


                                          **** CONIC ANGLE COORD. - E ****  ********* BLADE ANGLES *********
                                          ** (FROM LEADING EDGE CENT.) ***  (WITH RESPECT TO L.E. CENT. RAY)

                                            INLET   OUTLET   TRANS.  MAX.TH.    INLET   OUTLET   TRANS.  MAX.TH.
                                            (DEG)   (DEG)    (DEG)   (DEG)      (DEG)   (DEG)    (DEG)   (DEG)

                                  SUCT.      .007   1.112     .463   1.005     52.855 -10.110  45.271  21.666

                                  CENT.     0.000   1.099     .442    .958     52.000  -8.030  42.819  21.619

                                  PRES.     -.007   1.085     .421    .911     51.159  -3.709  40.304  22.530
```

Figure A.2.- Continued.

```
                         *** OUTPUT THAT CAN BE PUNCHED FOR TSONIC INPUT ***


                                 *****************************
                                 *                           *
                                 *     CHORD      STGR       *
                                 *      (L)       (RAD)      *
                                 *                           *
                                 *     .17718    .165276     *
                                 *                           *
**************************************************************************************************
*                                               *                                                *
*          *** SUCTION SURFACE ***              *          *** PRESSURE SURFACE ***              *
*                                               *                                                *
*      ********************************         *      ********************************          *
*                                               *                                                *
*      RI         RO        BETI       RETO     *      RI         RO        BETI       BETO      *
*      (L)        (L)       (DEG)      (DEG)    *      (L)        (L)       (DEG)      (DEG)     *
*                                               *                                                *
*    .00076     .00097    52.8551   -10.1097    *    .00076     .00097    51.1587    -3.7086     *
*                                               *                                                *
*                                               *                                                *
*             ZMSP           THSP               *             ZMSP           THSP                *
*              (L)           (RAD)              *              (L)           (RAD)               *
*                                               *                                                *
*            .00015         .001012             *            .00135        -.001051              *
*            .00644         .018624             *            .00775         .015605              *
*            .01569         .042414             *            .01729         .037720              *
*            .02688         .068304             *            .02898         .061165              *
*            .04209         .097782             *            .04470         .087489              *
*            .05884         .122866             *            .06153         .110221              *
*            .07687         .143206             *            .07931         .129167              *
*            .09593         .158534             *            .09786         .144173              *
*            .11571         .168663             *            .11700         .155129              *
*            .13592         .173491             *            .13656         .161966              *
*            .15219         .173520             *            .15237         .164450              *
*            .16637         .170770             *            .16624         .164451              *
*            .17641         .167241             *            .17614         .163216              *
*                                               *                                                *
**************************************************************************************************
```

Figure A.2.- Continued.

*** PLOT OF BLADE SURFACE IN THETA - M COORDINATES ***

Figure A.2.- Continued.

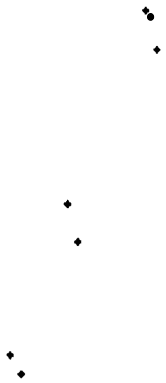


Figure A.2.- Continued.

```
                                --- INPUT FOR TSONIC BLADE-TO-BLADE FLOW SOLVER ---

   GAM              AR             TIP            RHOIP             WTFL                          OMEGA            ORF
 1.400000        1716.480        599.7600        .3345860E-02    .5700000E-02  0.              0.              1.910000
  BETAI           BETAO           CHORDF          STGRF             FSMI            FSMO
 48.20000       0.               .1771834        .1652756      0.              0.
  REDFAC          DENTOL           SSM1            SSM2
 1.000000        .1000000E-02  0.              0.

MBI    MBO                    MM   NBRI    NBL   NRSP   MOPT   LOPT   LRVB
  24     56      0      0     72     15     34     13      0      1      0

 BLADE SURFACE 1  --  UPPER SURFACE
   RI1            RO1             BETI1           BETO1           SPLNO1
 .7610700E-03    .9660876E-03    52.85512        -10.10968       13.00000
   MSP1  ARRAY
 .1544666E-03    .6437113E-02    .1568635E-01    .2687976E-01    .4208902E-01    .5883798E-01    .7687469E-01    .9592700E-01
 .1157074        .1359176        .1521902        .1663708        .1764053
   THSP1  ARRAY
 .1012280E-02    .1862413E-01    .4241444E-01    .6830414E-01    .9778183E-01    .1228661        .1432064        .1585341
 .1686632        .1734907        .1735195        .1707699        .1672414

 BLADE SURFACE 2  --  LOWER SURFACE
   RI2            RO2             BETI2           BETO2           SPLNO2
 .7610700E-03    .9660876E-03    51.15866        -3.708649       13.00000
   MSP2  ARRAY
 .1353915E-02    .7749708E-02    .1729088E-01    .2898442E-01    .4470456E-01    .6153388E-01    .7930961E-01    .9785967E-01
 .1170045        .1365588        .1523700        .1662433        .1761365
   THSP2  ARRAY
-.1050920E-02    .1560516E-01    .3771963E-01    .6116454E-01    .8748856E-01    .1102210        .1291670        .1441733
 .1551291        .1619659        .1644503        .1644505        .1632162

   MR  ARRAY
-.1300000       -.5000000E-02    .5000000E-02    .2003000E-01    .4003000E-01    .8003000E-01    .1000300        .1250300
 .1500400        .1752600        .1852600        .2250000        .2700000
   RMSP  ARRAY
 .4540000        .4540000        .4540000        .4540000        .4540000        .4540000        .4540000        .4540000
 .4540000        .4540000        .4540000        .4540000        .4540000
   BESP  ARRAY
 .5000000E-01    .5000000E-01    .4990000E-01    .4960000E-01    .4925000E-01    .4850000E-01    .4815000E-01    .4770000E-01
 .4720000E-01    .4675000E-01    .4661000E-01    .4661000E-01    .4661000E-01
   PLOSS ARRAY
0.              0.               .1500000E-02    .5900000E-02    .1100000E-01    .2150000E-01    .3000000E-01    .3350000E-01
 .4000000E-01    .4700000E-01    .4800000E-01    .4800000E-01    .4800000E-01

 BLDAT  AANDK  ERSOR  STRFN  SLCRD  INTVL  SURVL
   0      0      0      0      0      0      1
```

Figure A.2.- Continued.

```
          RELATIVE           MERIDIONAL           CRITICAL           REL. FLOW
          VELOCITY            VELOCITY            VELOCITY             ANGLE
        AT M = FSMI         AT M = FSMI         AT M = FSMI       AT UPSTREAM BDY.
          745.90              497.17              1095.9              48.269
        AT M = FSMO         AT M = FSMO         AT M = FSMO      AT DOWNSTREAM BDY.
          497.92              497.92              1095.9             0.

        FSMI =   0.
        FSMO =    .17718

 CALCULATED PROGRAM CONSTANTS

    PITCH             HT             HM1
    .1847996        .1231997E-01    .5536980E-02

    ITMIN          ITMAX
       0             28

    LAMBDA              DOWNSTREAM WHIRL (RVTHO)
    252.4466                   0.

    REDUCED WEIGHT FLOW =    .5700000E-02

    NUMBER OF INTERIOR MESH POINTS =  1047

CALCULATED VELOCITY DIAGRAM INFORMATION
                       IM         W                  W/WCR                BETA
UPSTREAM BOUNDARY       1          745.10               .67988              48.269
LEADING EDGE           24          745.90               .68061              48.200
TRAILING EDGE          56          497.92               .45433             0.
DOWNSTREAM BOUNDARY    72          499.62               .45589             0.
```

Figure A.2.- Continued.

```
ITERATION  NO.   1
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1846         AT IM =  0,   IT =  7,   SURF = 1,   M =  .3571E-01
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1074
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  92


ITERATION  NO.   2
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .6432E-01   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4135E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2615E-01
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  92


ITERATION  NO.   3
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2959E-01   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4135E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .8037E-02
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  91


ITERATION  NO.   4
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1410E-01   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4135E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2790E-02
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  55


ITERATION  NO.   5
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .6708E-02   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4135E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1041E-02
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  27


ITERATION  NO.   6
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .3285E-02   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4135E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .4003E-03
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =  17


ITERATION  NO.   7
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1422E-02   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4135E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .1766E-03
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =   1


ITERATION  NO.   8
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .7977E-03   AT IM =  0,   IT =  1,   SURF = 1,   M =  .4135E-02
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .7674E-04
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =   0


ITERATION  NO.   9
MAXIMUM RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2963E-03   AT IM =  0,   IT = 15,   SURF = 2,   M =  .1739E-02
```

Figure A.2.- Continued.

```
AVERAGE RELATIVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =  .2880E-04
NUMBER OF UNCONVERGED BLADE SURFACE MESH POINTS =    0


                *                  SURFACE VELOCITIES BASED ON MERIDIONAL COMPONENTS - REDUCED WEIGHT FLOW           *
                *                                              *                                                     *
                *                    BLADE SURFACE 1           *                        BLADE SURFACE 2              *
    M           *   VELOCITY    ANGLE(DEG) SURF. LENGTH     W/WCR        *   VELOCITY    ANGLE(DEG) SURF. LENGTH     W/WCR        *
0.              *  0.             90.00      0.               0.         *  0.            -90.00      0.               0.         *
 .5537E-02      *   797.1         51.11       .9198E-02       .7273      *   659.3         49.33       .7168E-02       .6016      *
 .1107E-01      *   813.2         49.39       .1786E-01       .7420      *   631.7         47.02       .1547E-01       .5764      *
 .1661E-01      *   825.6         47.83       .2623E-01       .7533      *   596.0         44.79       .2343E-01       .5438      *
 .2215E-01      *   838.0         46.15       .3435E-01       .7646      *   571.5         42.65       .3109E-01       .5215      *
 .2768E-01      *   845.8         44.13       .4221E-01       .7718      *   551.4         40.56       .3849E-01       .5031      *
 .3322E-01      *   845.9         41.88       .4978E-01       .7719      *   534.4         38.52       .4567E-01       .4876      *
 .3876E-01      *   839.4         39.46       .5708E-01       .7659      *   519.7         36.50       .5265E-01       .4742      *
 .4430E-01      *   827.6         36.90       .6413E-01       .7551      *   507.1         34.53       .5946E-01       .4627      *
 .4983E-01      *   809.1         34.39       .7094E-01       .7383      *   497.9         32.60       .6610E-01       .4544      *
 .5537E-01      *   787.1         32.00       .7756E-01       .7182      *   488.4         30.71       .7261E-01       .4457      *
 .6091E-01      *   767.5         29.79       .8401E-01       .7003      *   481.6         28.87       .7899E-01       .4394      *
 .6644E-01      *   751.8         27.62       .9032E-01       .6860      *   474.2         27.07       .8526E-01       .4327      *
 .7198E-01      *   735.6         25.47       .9651E-01       .6712      *   469.0         25.29       .9143E-01       .4279      *
 .7752E-01      *   723.0         23.35       .1026           .6597      *   463.2         23.54       .9751E-01       .4227      *
 .8305E-01      *   709.9         21.26       .1086           .6478      *   459.5         21.83       .1035           .4193      *
 .8859E-01      *   700.7         19.21       .1145           .6394      *   454.9         20.14       .1094           .4151      *
 .9413E-01      *   691.8         17.20       .1203           .6313      *   452.2         18.46       .1153           .4126      *
 .9967E-01      *   681.5         15.23       .1261           .6219      *   449.7         16.82       .1211           .4103      *
 .1052          *   673.9         13.28       .1318           .6149      *   446.0         15.19       .1269           .4069      *
 .1107          *   666.0         11.34       .1375           .6077      *   444.0         13.58       .1326           .4052      *
 .1163          *   658.1          9.43       .1431           .6005      *   442.6         12.00       .1383           .4038      *
 .1218          *   650.4          7.53       .1487           .5935      *   441.7         10.43       .1439           .4030      *
 .1274          *   642.7          5.65       .1543           .5865      *   441.7          8.85       .1495           .4030      *
 .1329          *   632.3          3.79       .1598           .5770      *   441.3          7.28       .1551           .4027      *
 .1384          *   624.6          1.94       .1654           .5699      *   443.7          5.71       .1607           .4049      *
 .1440          *   615.9           .08       .1709           .5620      *   447.6          4.19       .1663           .4084      *
 .1495          *   605.7         -1.78       .1764           .5527      *   452.8          2.74       .1718           .4132      *
 .1550          *   593.0         -3.65       .1820           .5411      *   459.0          1.33       .1773           .4188      *
 .1606          *   579.4         -5.46       .1875           .5287      *   468.2          -.33       .1829           .4272      *
 .1661          *   561.2         -7.22       .1931           .5121      *   489.6         -2.27       .1884           .4467      *
 .1716          *   549.8         -8.86       .1987           .5016      *   567.0         -3.66       .1940           .5173      *
 .1772          *  0.            -90.00       .2045          0.          *  0.             90.00       .1995          0.          *
```

Figure A.2.- Continued.

```
SURFACE VELOCITIES BASED ON TANGENTIAL COMPONENTS
                 REDUCED WEIGHT FLOW


                      BLADE SURFACE  1
    M             VELOCITY   ANGLE(DEG)     W/WCR
0.                493.5        90.00        .4503
 .4135E-02        859.0        51.56        .7838
 .8691E-02        801.6        50.11        .7314
 .1349E-01        817.5        48.69        .7460
 .1852E-01        829.3        47.29        .7567
 .2384E-01        840.8        45.57        .7672
 .2953E-01        847.4        43.40        .7732
 .3571E-01        846.7        40.81        .7726
 .4254E-01        838.8        37.72        .7654
 .5026E-01        808.8        34.20        .7380
 .5909E-01        783.6        30.50        .7150
 .6940E-01        751.8        26.46        .6860
 .8192E-01        726.3        21.69        .6627
 .9848E-01        699.7        15.65        .6385
 .1292            657.5         5.03        .5999
 .1592            583.5        -5.01        .5324


                      BLADE SURFACE  2
    M             VELOCITY   ANGLE(DEG)     W/WCR
 .1739E-02        769.5        50.99        .7021
 .6438E-02        661.6        48.95        .6037
 .1149E-01        617.5        46.84        .5634
 .1694E-01        587.2        44.66        .5358
 .2283E-01        562.6        42.39        .5134
 .2922E-01        541.6        39.99        .4942
 .3620E-01        523.1        37.43        .4773
 .4388E-01        507.4        34.68        .4630
 .5243E-01        490.0        31.71        .4471
 .6208E-01        475.2        28.48        .4336
 .7321E-01        462.6        24.90        .4221
 .8649E-01        453.6        20.78        .4139
 .1035            444.2        15.70        .4053
 .1300            433.7         8.09        .3958
```

Figure A.2.- Continued.

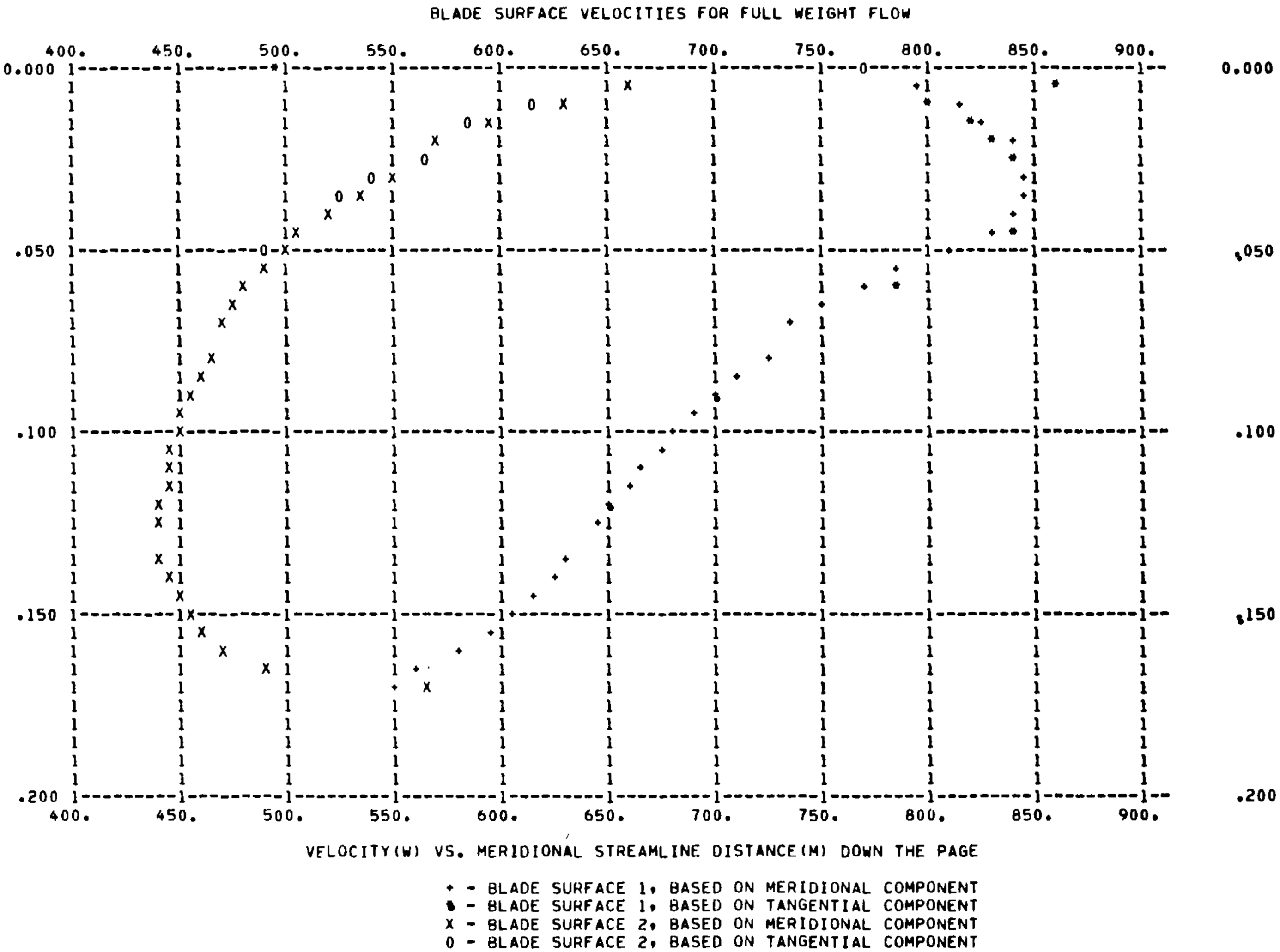


Figure A.2.- Continued.

```
                                        BLADE SURFACE PRESSURES FOR FULL WEIGHT FLOW

 IM          M              M/MC            P(1)/PT          P(2)/PT          CPT(1)           CPT(2)

 24       0.             0.                .9994            .9994           -.6204E-03       -.6204E-03
 25        .5537E-02      .3125E-01        .7228            .8030           -.2772           -.1970
 26        .1107E-01      .6250E-01        .7118            .8167           -.2882           -.1833
 27        .1661E-01      .9375E-01        .7029            .8338           -.2971           -.1662
 28        .2215E-01      .1250            .6939            .8446           -.3061           -.1554
 29        .2768E-01      .1563            .6879            .8530           -.3121           -.1470
 30        .3322E-01      .1875            .6869            .8598           -.3131           -.1402
 31        .3876E-01      .2188            .6901            .8655           -.3099           -.1345
 32        .4430E-01      .2500            .6967            .8701           -.3033           -.1299
 33        .4983E-01      .2813            .7072            .8732           -.2928           -.1268
 34        .5537E-01      .3125            .7197            .8763           -.2803           -.1237
 35        .6091E-01      .3438            .7305            .8781           -.2695           -.1219
 36        .6644E-01      .3750            .7387            .8799           -.2613           -.1201
 37        .7198E-01      .4063            .7469            .8806           -.2531           -.1194
 38        .7752E-01      .4375            .7526            .8812           -.2474           -.1188
 39        .8305E-01      .4688            .7582            .8806           -.2418           -.1194
 40        .8859E-01      .5000            .7613            .8801           -.2387           -.1199
 41        .9413E-01      .5313            .7643            .8790           -.2357           -.1210
 42        .9967E-01      .5625            .7683            .8781           -.2317           -.1219
 43        .1052          .5938            .7714            .8784           -.2286           -.1216
 44        .1107          .6250            .7750            .8784           -.2250           -.1216
 45        .1163          .6563            .7787            .8785           -.2213           -.1215
 46        .1218          .6875            .7824            .8783           -.2176           -.1217
 47        .1274          .7188            .7858            .8776           -.2142           -.1224
 48        .1329          .7500            .7903            .8768           -.2097           -.1232
 49        .1384          .7813            .7930            .8745           -.2070           -.1255
 50        .1440          .8125            .7961            .8715           -.2039           -.1285
 51        .1495          .8438            .7997            .8679           -.2003           -.1321
 52        .1550          .8750            .8044            .8638           -.1956           -.1362
 53        .1606          .9063            .8095            .8585           -.1905           -.1415
 54        .1661          .9375            .8167            .8484           -.1833           -.1516
 55        .1716          .9688            .8209            .8129           -.1791           -.1871
 56        .1772         1.000             .9527            .9527           -.4728E-01       -.4728E-01



         SURF 1                                   SURF 2
XMSP              XTHSP                  XMSP              XTHSP
.15447E-03        .10123E-02             .13539E-02       -.10509E-02
.64371E-02        .18624E-01             .77497E-02        .15605E-01
.15686E-01        .42414E-01             .17291E-01        .37720E-01
.26880E-01        .68304E-01             .28984E-01        .61165E-01
.42089E-01        .97782E-01             .44705E-01        .87489E-01
.58838E-01        .12287E+00             .61534E-01        .11022E+00
.76875E-01        .14321E+00             .79310E-01        .12917E+00
.95927E-01        .15853E+00             .97860E-01        .14417E+00
.11571E+00        .16866E+00             .11700E+00        .15513E+00
.13592E+00        .17349E+00             .13656E+00        .16197E+00
.15219E+00        .17352E+00             .15237E+00        .16445E+00
.16637E+00        .17077E+00             .16624E+00        .16445E+00
.17641E+00        .16724E+00             .17614E+00        .16322E+00


OUTPUT FROM OBJCON
```

Figure A.2.- Continued.

```
OBJECTIVE FUNCTION   DIFFS     =  .84594E+03
                     WO        =  .49792E+03
                     DIFFS/WO  =  .16990E+01

CONSTRAINT 1         BLTKS     =  .44211E-02

CONSTRAINT 2         YMAX      =  .65929E+03
                     YMIN      =  .44134E+03
                     DIFFP     =  .14938E+01

CONSTRAINT 3      WMB(MBO-2,1) =  .56124E+03
                  WMB(MBO-2,2) =  .48960E+03
                     TECLSR    =  .89556E+00
```

Fiqure A.2.- Continued.

```
FINAL OBJECTIVE COMPUTED BY TSONIC =  1.698965


FINAL CONSTRAINT VALUES
         ALTKS       DIFFP       TECLSR
      .44211E-02  .14938E+01  .89556E+00



X ARRAY
         .968750      .937500      .906250      .875000      .843750
         .812500      .781250      .750000      .718750      .687500
         .656250      .625000      .593750      .562500      .531250
         .500000      .468750      .437500      .406250      .375000
         .343750      .312500      .281250      .250000      .218750
         .187500      .156250      .125000      .093750      .062500
         .031250      .031250      .062500      .093750      .125000
         .156250      .187500      .218750      .250000      .281250
         .312500      .343750      .375000      .406250      .437500
         .468750      .500000      .531250      .562500      .593750
         .625000      .656250      .687500      .718750      .750000
         .781250      .812500      .843750      .875000      .906250
         .937500      .968750


LTRACE =  1

Y ARRAY BEFORE PERTRB CALL
         566.953      489.596      468.231      459.001      452.816
         447.620      443.724      441.341      441.690      441.695
         442.577      444.037      445.975      449.688      452.173
         454.893      459.487      463.246      468.972      474.208
         481.593      488.443      497.947      507.051      519.736
         534.387      551.407      571.509      596.015      631.744
         659.289      797.094      813.197      825.572      837.975
         845.829      845.941      839.362      827.555      809.126
         787.101      767.508      751.752      735.601      722.997
         709.946      700.748      691.827      681.542      673.904
         666.048      658.146      650.419      642.711      632.308
         624.559      615.941      605.686      592.951      579.399
         561.240      549.767
```

Figure A.2.- Continued.

```
*********************************************************
* COMPARISON OF AERODYNAMIC AND PERTURBATION SOLUTIONS *
*********************************************************


.....MACH NUMBER,
     VALUES OF PERTURBATION PARAMETERS,
     CRITICAL VALUE OF WM:

          M2 =  .1000

          Q2(1) =-8.0297     (  KOCR  )

          Q2(2) =  .2000     (    T   )

          Q2(3) =  .5500     (   ZM   )

          Q2(4) =  .7356     (    P   )

          Q2(5) =  .0363     (   TMX  )

          Q2(6) =  .0039     (  THLE  )

          WMCRIT =-66.8587


.....LOCATIONS OF MIN., MAX., AND CRITICAL PTS.
  (* DENOTES POINT ON LOWER SURFACE)


     PERTURBATION SOLN:

          MINIMUM AT X =  .7122*   (POINT NO.   9)
          MAXIMUM AT X =  .1194    (POINT NO.  34)

     AERODYNAMIC SOLN:

          MINIMUM AT X =  .7500*   (POINT NO.   8)
          MAXIMUM AT X =  .1875    (POINT NO.  37)


.....FINAL PRINTOUT AND GRAPHICAL DISPLAY OF WM

                                                                      H = MAXIMUM  VALUE OF WM =845.9406
                                                                      L = MINIMUM  VALUE OF WM =438.9010
                                                                      * = CRITICAL VALUE OF WM =-66.8587
                                                                      P = VALUE OF WM PREDICTED BY PERTURBATION SOLUTION
                                                                      A = VALUE OF WM IN AERODYNAMIC SOLUTION
                                                                      $ = AGREEMENT BETWEEN P AND A

 PT  XBASE   WMBASE  XPERT  WMPERT  XAERO   WMAERO  WMPINT H---------------------------------------------------------------------L

  1   .9687585.9460   .9680549.7994   .9688566.9527551.1194                                                A  P
  2   .9375500.5262   .9360492.2104   .9375489.5955494.8503                                                            PA
  3   .9062475.3838   .9041468.2692   .9063468.2308469.9154                                                                $
  4   .8750463.5379   .8721457.5440   .8750459.0015458.5273                                                                  $
  5   .8437455.4531   .8401450.7826   .8438452.8158451.5575                                                                   $
  6   .8125448.9545   .8081445.5287   .8125447.6203446.2512                                                                    $
  7   .7813444.0337   .7761441.7684   .7813443.7239442.3717                                                                     $
```

Figure A.2.- Continued.

```
 8   .7500440.6925   .7441439.5594   .7500441.3408439.9645
 9   .7188438.6925   .7122438.7299   .7188441.6899438.9010
10   .6875437.8173   .6802439.4101   .6875441.6948439.2542
11   .6563439.1700   .6482441.5321   .6563442.5766440.9971
12   .6250439.8327   .6162443.2946   .6250444.0366442.8098
13   .5938441.0316   .5842445.5640   .5938445.9745444.8878
14   .5625442.5981   .5522448.7173   .5625449.6875447.7054
15   .5313445.5570   .5203452.6026   .5313452.1730451.2668
16   .5000447.4626   .4883455.9259   .5000454.8932454.7072
17   .4688449.7452   .4563460.4083   .4688459.4870458.6617
18   .4375453.7909   .4243465.7523   .4375463.2464463.5475
19   .4063457.2295   .3923471.6608   .4063468.9715469.0877
20   .3750462.5307   .3603475.4134   .3750474.2081473.6932
21   .3438467.1474   .3284488.9358   .3438481.5930482.4272
22   .3125473.4596   .2964502.5190   .3125488.4431495.6698
23   .2813479.5215   .2644512.6771   .2813497.9474507.3221
24   .2500487.9145   .2324526.4762   .2500507.0512518.8856
25   .2188496.1051   .2004541.5761   .2188519.7356532.9238
26   .1875508.1057   .1684557.9958   .1875534.3871548.2109
27   .1563522.6991   .1365576.8714   .1563551.4073565.1903
28   .1250540.8496   .1045600.2040   .1250571.5092585.2300
29   .0938564.0343   .0725634.0712   .0938596.0147611.5602
30   .0625599.0169   .0405662.5095   .0625631.7438642.9552
31   .0313632.8560   .0085710.1042   .0313659.2892676.2870
32   .0313836.7472   .0554812.4625   .0313797.0941773.7523
33   .0625848.1344   .0874825.6826   .0625813.1973815.3804
34   .0937851.3453   .1194830.3923   .0938825.5723826.6141
35   .1250846.1514   .1498829.4847   .1250837.9745830.2251
36   .1563834.5030   .1801829.0993   .1563845.8290829.4024
37   .1875820.3078   .2105829.7257   .1875845.9406829.2512
38   .2188805.2289   .2409829.2858   .2188839.3616829.6062
39   .2500788.7474   .2712820.2590   .2500827.5552826.5711
40   .2813770.7026   .3016805.2661   .2813809.1264815.3133
41   .3125754.1898   .3320787.3683   .3125787.1011798.8407
42   .3438739.2561   .3623770.2638   .3438767.5078780.7293
43   .3750723.4856   .3927752.8141   .3750751.7521762.9824
44   .4063710.8176   .4231738.3766   .4063735.6008746.3690
45   .4375697.5629   .4534724.6654   .4375722.9967731.8562
46   .4688688.7980   .4838713.7454   .4688709.9455719.1542
47   .5000680.8503   .5142704.7421   .5000700.7477708.9392
48   .5313671.6336   .5445694.3740   .5313691.8266698.9053
49   .5625665.2669   .5749685.2170   .5625681.5421688.9522
50   .5938658.7253   .6053677.2071   .5938673.9036680.2410
51   .6250651.9964   .6356668.9914   .6250666.0482671.8639
52   .6563644.9958   .6660660.6116   .6563658.1457663.2973
53   .6875635.7344   .6963650.1146   .6875650.4193653.1730
54   .7188629.2778   .7267642.4657   .7188642.7110644.4714
55   .7500622.6299   .7571634.7305   .7500632.3081636.5335
56   .7813615.5034   .7874626.6743   .7813624.5586628.3174
57   .8125607.3548   .8178617.7636   .8125615.9409619.3213
58   .8437597.2455   .8482607.1599   .8437605.6857608.7046
59   .8750584.0971   .8785593.9676   .8750592.9514595.5051
60   .9062567.1183   .9089577.5979   .9062579.3986579.0288
61   .9375548.2492   .9393550.1110   .9375561.2400551.7128
62   .9687533.5057   .9696571.0680   .9687549.7669570.4574
```

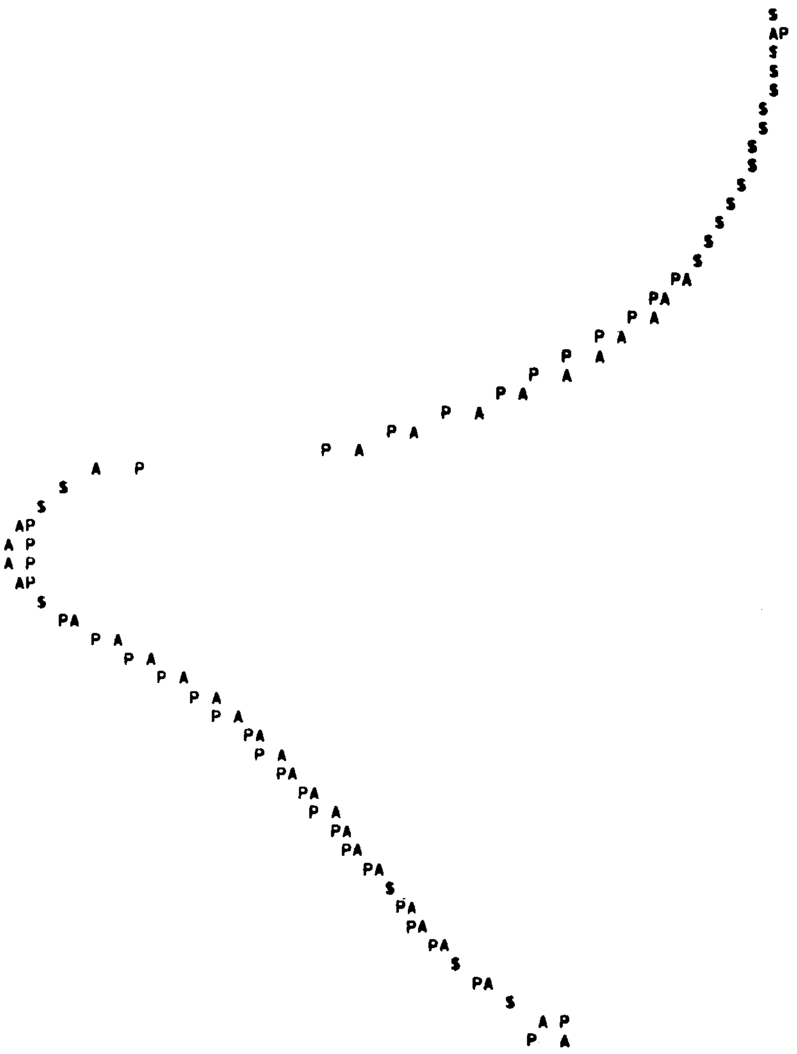


Figure A.2.- Concluded.

# APPENDIX B

# LISTING OF COMPUTER PROGRAM BLDOPT

```
      PROGRAM BLDOPT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
     *       TAPE1,TAPE7,TAPE9,TAPE10,TAPE11,TAPE12,TAPE13,TAPE14,
     *       TAPE20,TAPE40)
C
C  DRIVER PROGRAM FOR COPES OPTIMIZATION STUDY WITH OPTIONS
C  FOR PERTURBATION METHOD USE.
C  THE RELATIONSHIP AMONG PROGRAM COMPONENTS IS
C     DRIVER
C          -  COPES
C               - ANALIZ
C                     - BLADE ROUTINES
C                     - TSONIC ROUTINES
C                     - PERTRB ROUTINE
C                     - OBJCON
C
C  PROGRAM OPTIONS
C     IOPT = 1   -  OPTIMIZATION USING TSONIC SOLUTIONS ONLY -
C                   PERTURBATION METHOD BYPASSED
C            2   -  OPTIMIZATION WITH PERTURBATION METHOD EMPLOYING
C                   USER-SPECIFIED CALIBRATION SOLUTION MATRIX
C            3   -  OPTIMIZATION WITH 1 CYCLE EMPLOYING TSONIC SOLUTIONS
C                   ONLY, FOLLOWED BY ITMAX CYCLES EMPLOYING
C                   PERTURBATION METHOD
C
      COMMON/CALB/ ICALB,DVCALB(6),PSTEP,IOPT,ITMAX3,VZERO(6)
      COMMON/CNMN1/DUM(12),NDV,DUM1(6),ITMAX,DUM2(7)
      COMMON/COPES2/ RA(5000),IA(1000)
      COMMON/COPES3/DUM3(16),LOCR(25),LOCI(25),DUM4(19)
      COMMON/GLOBCM/ OBJ,V(6),C(5),EXTRA(1488)
C
      IFLAG=1
      CALL COPES(IFLAG)
      IF(IOPT.LT.3) STOP
C
C  IOPT=3     CALCULATE CALIBRATION STEPSIZES, THEN PERFORM
C             OPTIMIZATION WITH PERTURBATION SOLUTIONS
C
      NVLB=LOCR(2)
      NVUB=LOCR(3)
      CALL STEP(NDV,V,VZERO,DVCALB,RA(NVLB),RA(NVUB))
      ICALB=1
      ITMAX=ITMAX3
      DO 10 I=1,NDV
   10 RA(I)=0.0
      IFLAG=2
      CALL COPES(IFLAG)
      STOP
      END
      SUBROUTINE STEP(NDV,V,VZERO,DVCALB,VLB,VUB)
C
C  ROUTINE TO CALCULATE CALIBRATION STEPSIZES FOR IOPT=3
C  BASED ON DESIGN RESULTS AFTER 1 OPTIMIZATION CYCLE
C  EMPLOYING TSONIC SOLUTIONS ONLY.
C
      DIMENSION V(1),VZERO(1),DVCALB(1),VLB(1),VUB(1)
      DO 20 I=1,NDV
      P=V(I)-VZERO(I)
      DVCALB(I)=V(I)+0.5*P
      IF(DVCALB(I).LT.VLB(I)) DVCALB(I)=VLB(I)
      IF(DVCALB(I).GT.VUB(I)) DVCALB(I)=VUB(I)
      IF(ABS(V(I)-VLB(I)).LT.1.E-6)
     *            DVCALB(I)=0.9*(VLB(I)-VZERO(I))+VZERO(I)
      IF(ABS(V(I)-VUB(I)).LT.1.E-6)
     *           DVCALB(I)=0.9*(VUB(I)-VZERO(I))+VZERO(I)
   20 CONTINUE
C
      RETURN
      END
      SUBROUTINE ANALIZ(ICALC)
C
C  INITIALIZES, CALCULATES, AND OUTPUTS ALL DESIGN
C  VARIABLES, OBJECTIVE FUNCTION, AND CONSTRAINTS FOR
C  OPTIMIZATION WITH COPES DRIVER.
C
      COMMON/GLOBCM/ OBJ,V(6),C(5),EXTRA(1488)
      COMMON /PERT/ Q0(10),Q1,Q2(10),XM0,XM1,XM2,NPTS,KPARAM,NPARAM,
     *                LTRACE
      COMMON /INPUTB/ ALP,KICR,KOCR,NB,P,R,SOLID,T,THLE,THTE,TMX,ZM
      COMMON /MBIMBO/ MBI,MBO
      COMMON/INPUTA/ XMSP(50,2),XTHSP(50,2)
      COMMON /CALB/ ICALB,DVCALB(6),PSTEP,IOPT,ITMAX3,VZERO(6)
      DIMENSION X(200),Y(200),VV(8),IDV(6),VNAME(6)
      REAL KICR,KOCR
      LOGICAL NONLIN
      DATA XM0/0.1/, XM1/0.1/, XM2/0.1/
      IF (ICALC .GT. 1) GO TO 100
C
C  ICALC = 1       READ INPUT AND INITIALIZE PARAMETERS
C
      READ(5,1025) COMENT
      READ(5,1005) IOPT,NDV,NCN,ITMAX3
      NPARAM=NDV
      READ(5,1010) NB,R,ALP,SOLID
      READ(5,1020) (VV(I),I=1,8)
      KICR=VV(1)
      KOCR=VV(2)
      T   =VV(3)
      ZM  =VV(4)
      P   =VV(5)
      TMX =VV(6)
      THLE=VV(7)
      THTE=VV(8)
      READ(5,1025) (VNAME(I),I=1,NDV)
      READ(5,1005) (IDV(I),I=1,NDV)
      DO 5 I=1,NDV
      J=IDV(I)
      V(I)=VV(J)
    5 VZERO(I)=VV(J)
      READ(5,1010) ICALB,PSTEP
      IF(ICALB.EQ.0) GO TO 10
      READ(5,1020) (DVCALB(I),I=1,NDV)
   10 CONTINUE
C
      WRITE(6,1000)
      WRITE(6,1055) IOPT,NDV,NCN,ITMAX3
      WRITE(6,1060) NB,R,ALP,SOLID
      WRITE(6,1065) (VV(I),I=1,8)
      WRITE(6,1070) (VNAME(I),I=1,NDV)
      WRITE(6,1072) (V(I),I=1,NDV)
      WRITE(6,1075) ICALB,PSTEP
      IF(ICALB.EQ.0) GO TO 14                                           ANALIZ54
      WRITE(6,1080) (I,I=1,NDV)                                         ANALIZ55
      WRITE(6,1085) (DVCALB(I),I=1,NDV)                                 ANALIZ56
   14 CONTINUE                                                          ANALIZ57
C                                                                       ANALIZ58
      ICALL=1                                                           ANALIZ59
      JCALL=0                                                           ANALIZ60
      KPARAM=0                                                          ANALIZ61
      LTRACE=0                                                          ANALIZ62
      NONLIN=.T.                                                        ANALIZ63
      IF(IOPT.EQ.2) NONLIN=.F.                                          ANALIZ64
      READ(5,1025) COMENT                                               ANALIZ65
      CALL TSONIC                                                       ANALIZ66
      NPTS=2*(MBO-MBI-1)                                                ANALIZ67
      IF(IOPT.EQ.1) GO TO 15                                            ANALIZ68
      READ(5,1025) COMENT                                               ANALIZ69
      CALL PERTRB(ICALL,X,Y)                                            ANALIZ70
   15 CONTINUE                                                          ANALIZ71
      ICALL=2                                                           ANALIZ72
      RETURN                                                            ANALIZ73
C                                                                       ANALIZ74
C  ICALC = 2       PERFORM OPTIMIZATION CALCULATION                     ANALIZ75
C                                                                       ANALIZ76
  100 IF(ICALC.GT.2) GO TO 200                                          ANALIZ77
   20 CALL DESVAR(VV,V,IDV,NDV,ICALL,KPARAM)                            ANALIZ78
      WRITE(6,2000) NB,R,ALP,SOLID,KICR,KOCR,T,ZM,P,TMX,THLE,THTE       ANALIZ79
      CALL BLADE(0)                                                     ANALIZ80
      IF(.NOT.NONLIN) GO TO 22                                          ANALIZ81
C                                                                       ANALIZ82
C        EMPLOY TSONIC SOLUTIONS,  IOPT=1 OR 3                          ANALIZ83
C                                                                       ANALIZ84
      CALL TSONIC                                                       ANALIZ85
      CALL XY(X,Y)                                                      ANALIZ86
      WRITE(6,2005) (X(I),I=1,NPTS)                                     ANALIZ87
      WRITE(6,2010) (Y(I),I=1,NPTS)                                     ANALIZ88
      CALL OBJCON(X,Y,OBJ,C)                                            ANALIZ89
      RETURN                                                            ANALIZ90
C                                                                       ANALIZ91
C       EMPLOY BASE/CALIBRATION/PERTURBATION SOLUTIONS, IOPT=2 OR 3     ANALIZ92
C                                                                       ANALIZ93
   22 CONTINUE                                                          ANALIZ94
      IF(ICALL.EQ.4) GO TO 24                                           ANALIZ95
      CALL TSONIC                                                       ANALIZ96
      CALL XY(X,Y)                                                      ANALIZ97
   24 CALL PERVAR(Q0,Q1,Q2,V,ICALL,KPARAM)                              ANALIZ98
      CALL PERTRB(ICALL,X,Y)                                            ANALIZ99
      IF(ICALL.EQ.3) GO TO 26                                           ANALI100
      WRITE(6,2005) (X(I),I=1,NPTS)                                     ANALI101
      WRITE(6,2010) (Y(I),I=1,NPTS)                                     ANALI102
      CALL OBJCON(X,Y,OBJ,C)                                            ANALI103
      IF(ICALL.EQ.4) RETURN                                             ANALI104
      ICALL=3                                                           ANALI105
   26 CONTINUE                                                          ANALI106
      KPARAM=KPARAM+1                                                   ANALI107
      IF(KPARAM.LE.NPARAM) GO TO 20                                     ANALI108
      ICALL=4                                                           ANALI109
      RETURN                                                            ANALI110
C                                                                       ANALI111
C  ICALC  =  3      CONMIN TERMINATION AND FINAL SOLUTION DETERMINATION ANALI112
C                                                                       ANALI113
  200 CONTINUE                                                          ANALI114
      JCALL=JCALL+1                                                     ANALI115
      IF(IOPT.NE.3 .OR. JCALL.EQ.2) GO TO 30                            ANALI116
      NONLIN=.FALSE.                                                    ANALI117
      RETURN                                                            ANALI118
   30 CONTINUE                                                          ANALI119
      LTRACE=1                                                          ANALI120
      CALL DESVAR(VV,V,IDV,NDV,ICALL,KPARAM)                            ANALI121
      CALL BLADE(1)                                                     ANALI122
      CALL TSONIC                                                       ANALI123
      CALL XY(X,Y)                                                      ANALI124
      WRITE(6,1050) (XMSP(K,1),XTHSP(K,1),XMSP(K,2),XTHSP(K,2),K=1,13)  ANALI125
      CALL OBJCON(X,Y,OBJ,C)                                            ANALI126
      WRITE(6,1030) OBJ                                                 ANALI127
      WRITE(6,1035) (C(I),I=1,NCN)                                      ANALI128
      IF(IOPT.EQ.1) RETURN                                              ANALI129
      WRITE(6,2005) (X(I),I=1,NPTS)                                     ANALI130
      WRITE(6,1040) LTRACE,(Y(I),I=1,NPTS)                              ANALI131
      CALL PERVAR(Q0,Q1,Q2,V,ICALL,KPARAM)                              ANALI132
      CALL PERTRB(ICALL,X,Y)                                            ANALI133
      RETURN                                                            ANALI134
C                                                                       ANALI135
C                                                                       ANALI136
 1000 FORMAT(1H1,35X,43H--- INPUT FOR CONTROL SUBROUTINE ANALIZ ---)    ANALI137
 1005 FORMAT(10I5)                                                      ANALI138
 1010 FORMAT (I10,3F10.6)                                               ANALI139
 1020 FORMAT(8F10.0)                                                    ANALI140
 1025 FORMAT(6A10)                                                      ANALI141
 1030 FORMAT (37H1FINAL OBJECTIVE COMPUTED BY TSONIC =,F10.6//)         ANALI142
 1035 FORMAT(1H0,23HFINAL CONSTRAINT VALUES/10X,5HBLTKS,7X,5HDIFFP,     ANALI143
     *       6X,6HTECLSR/5X,4E12.5)                                     ANALI144
 1040 FORMAT(////* LTRACE =*,I3//* Y ARRAY BEFORE PERTRB CALL*/         ANALI145
     *       (5X,5F12.3))                                               ANALI146
 1045 FORMAT(////* LTRACE =*,I3//* Y ARRAY AFTER PERTRB CALL*/          ANALI147
     *       (5X,5F12.3))                                               ANALI148
 1050 FORMAT(////12X,*SURF 1*,29X,*SURF 2*/                             ANALI149
     *       5X,*XMSP*,11X,*XTHSP*,15X,*XMSP*,11X,*XTHSP*/              ANALI150
     *       (2E15.5,5X,2E15.5))                                        ANALI151
 1055 FORMAT(//1H0,4X,18HCONTROL PARAMETERS/                            ANALI152
     *       1H0,9X,6HIOPT =,I3,10X,5HNDV =,I3,10X,5HNCN =,I3,          ANALI153
     *       10X,8HITMAX3 =,I3)                                         ANALI154
 1060 FORMAT(//1H0,4X,25HCONSTANT BLADE PARAMETERS/                     ANALI155
     *       1H0,9X,2HNB,7X,1HR,7X,3HALP,7X,5HSOLID/I12,3F10.4)         ANALI156
 1065 FORMAT(//1H0,4X,25HVARIABLE BLADE PARAMETERS/                     ANALI157
     *       1H0,9X,4HKICR,6X,4HKOCR,8X,1HT,8X,2HZM,8X,1HP,9X,3HTMX,    ANALI158
     *       6X,4HTHLE,6X,4HTHTE/5X,8F10.4)                             ANALI159
 1070 FORMAT(//1H0,4X,23HACTIVE DESIGN VARIABLES/1H0,9X,6A10)           ANALI160
 1072 FORMAT(5X,6F10.4)                                                 ANALI161
 1075 FORMAT(//1H0,4X,7HICALB =,I2,6X,7HPSTEP =,F6.3)                   ANALI162
 1080 FORMAT(1H0,4X,6HDVCALB/6I12)                                      ANALI163
 1085 FORMAT(3X,6F12.4)                                                 ANALI164
 2000 FORMAT(1H1,// 46X,39H*** INPUT FOR BLADE ELEMENT PROGRAM ***   // ANALI165
     */ 49X,5HINLET,4X,6HOUTLET,4X,6HTRANS.,4X,7HMAX.TH.,3X,6HIN/OUT,5X,ANALI166
     * 4HMAX.,6X,4HL.E.,6X,4HT.E. / 10X,3HNO.,6X,5HINLET,5X,4HCONE,4X,  ANALI167
     * 8HSOLIDITY,4X,5HBLADE,5X,5HBLADE,5X,4HLOC.,6X,4HLOC.,5X,7HTURNINGANALI168
     *,3X,6HTHICK.,5X,4HRAD.,6X,4HRAD. / 8X,6HBLADES,4X,6HRADIUS,5X,    ANALI169
     * 5HANGLE,15X,5HANGLE,5X,5HANGLE,4X,6H/CHORD,4X,6H/CHORD,5X,4HRATE,ANALI170
     * 5X,6H/CHORD,4X,6H/CHORD,4X,6H/CHORD / 20X,3H(L),6X,5H(DEG),15X,  ANALI171
     * 5H(DEG),5X,5H(DEG) // 9X,I3,3X,3F10.5,F9.3,F10.4,6F10.5)         ANALI172
 2005 FORMAT(////* X ARRAY*/(5X,5F12.6))                                ANALI173
 2010 FORMAT(1H0,* Y ARRAY*/(5X,5F12.3))                                ANALI174
C                                                                       ANALI175
      END                                                               ANALI176
      SUBROUTINE DESVAR(VV,V,IDV,NDV,ICALL,KPARAM)                      DESVAR 2
C                                                                       DESVAR 3
C   IDENTIFIES DESIGN VARIABLES                                         DESVAR 4
C                                                                       DESVAR 5
      REAL KICR,KOCR                                                    DESVAR 6
      COMMON /CALB/ ICALB,DVCALB(6),PSTEP,IOPT,ITMAX3,VZERO(6)          DESVAR 7
      COMMON /INPUTB/ ALP,KICR,KOCR,NB,P,R,SOLID,T,THLE,THTE,TMX,ZM     DESVAR 8
      DIMENSION VV(12),V(1),IDV(1)                                      DESVAR 9
      DO 10 I=1,NDV                                                     DESVAR10
      J=IDV(I)                                                          DESVAR11
      VV(J)=V(I)                                                        DESVAR12
   10 CONTINUE                                                          DESVAR13
      IF(ICALL.NE.3) GO TO 20                                           DESVAR14
      K=IDV(KPARAM)                                                     DESVAR15
      IF(ICALB.EQ.0) VV(K)=(1.0+PSTEP)*VV(K)                            DESVAR16

      IF(ICALB.EQ.0) VV(K)=(1.0+PSTEP)*VV(K)                            DESVAR16
      IF(ICALB.GT.0) VV(K)=DVCALB(KPARAM)                               DESVAR17
   20 CONTINUE                                                          DESVAR18
      KICR=VV(1)                                                        DESVAR19
      KOCR=VV(2)                                                        DESVAR20
      T   =VV(3)                                                        DESVAR21
      ZM  =VV(4)                                                        DESVAR22
      P   =VV(5)                                                        DESVAR23
      TMX =VV(6)                                                        DESVAR24
      THLE=VV(7)                                                        DESVAR25
      THTE=VV(8)                                                        DESVAR26
      RETURN                                                            DESVAR27
      END                                                               DESVAR28
      SUBROUTINE PERVAR(Q0,Q1,Q2,V,ICALL,KPARAM)                        PERVAR 2
C                                                                       PERVAR 3
C   SETS VALUES OF DESIGN VARIABLES FOR USE IN                          PERVAR 4
C   PERTURBATION SOLUTION CALCULATION.                                  PERVAR 5
C                                                                       PERVAR 6
      DIMENSION Q0(1),Q2(1),V(1)                                        PERVAR 7
      COMMON /CALB/ ICALB,DVCALB(6),PSTEP,IOPT,ITMAX3,VZERO(6)          PERVAR 8
      IF (ICALL .GT. 2) GO TO 20                                        PERVAR 9
      DO 10 I=1,6                                                       PERVAR10
   10 Q0(I)=V(I)                                                        PERVAR11
      RETURN                                                            PERVAR12
   20 IF (ICALL .GT. 3) GO TO 30                                        PERVAR13
      IF(ICALB.EQ.0) Q1=(1. + PSTEP)*V(KPARAM)                          PERVAR14
      IF(ICALB.GT.0) Q1=DVCALB(KPARAM)                                  PERVAR15
      RETURN                                                            PERVAR16
   30 DO 40 I=1,6                                                       PERVAR17
   4  Q2(I)=5(I)                                                        PER5AR18
      RETURN                                                            PERVAR19
   40 Q2(I)=V(I)                                                        PERVAR18
      RETURN                                                            PERVAR19
      END                                                               PERVAR20
      SUBROUTINE XY(X,Y)                                                XY     2
C                                                                       XY     3
C   DETERMINES SURFACE VELOCITY AND SURFACE COORDINATE ARRAYS           XY     4
C                                                                       XY     5
      COMMON /VARCOM/ RDUM(400),WMB(100,2),SDUM(400),IDUM(100)          XY     6
      COMMON /MVNORM/ XMVN(100)                                         XY     7
      COMMON /MBIMBO/ MBI,MBO                                           XY     8
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      DIMENSION X(200),Y(200)                                           XY     9
      ND2=MBO-MBI-1                                                     XY    10
      DO 10 I=1,ND2                                                     XY    11
      X(I)=XMVN(MBO-I)                                                  XY    12
      X(ND2+I)=XMVN(MBI+I)                                              XY    13
      Y(I)=WMB(MBO-I,2)                                                 XY    14
   10 Y(ND2+I)=WMB(MBI+I,1)                                             XY    15
      RETUPN                                                            XY    16
      END                                                               XY    17
      SUBROUTINE OBJCON(X,Y,DIFFS,C)                                    OBJCON 2
      REAL KICR,KOCR                                                    OBJCON 3
      COMMON/INPUTA/ XMSP(50,2),XTHSP(50,2)                             OBJCON 4
      COMMON /INPUTB/ALP,KICR,KOCR,NB,P,R,SOLID,T,THLE,THTE,TMX,ZM      OBJCON 5
      COMMON /MBIMBO/ MBI,MBO                                           OBJCON 6
      COMMON/WIWO/WI,WO                                                 OBJCON 7
      COMMON/VARCOM/ADUM(400),WMB(100,2),BDUM(400),IDUM(100)            OBJCON 8
      DIMENSION X(200),Y(200),C(5)                                      OBJCON 9
C                                                                       OBJCON10
C   CALCULATION OF OBJECTIVE FUNCTION                                   OBJCON11
C                                                                       OBJCON12
      ND2=MBO-MBI-1                                                     OBJCON13
      DIFFS=Y(ND2+1)                                                    OBJCON14
      ND21=ND2-1                                                        OBJCON15
      DO 10 I=1,ND21                                                    OBJCON16
   10 IF(Y(ND2+I).GT.DIFFS) DIFFS=Y(ND2+I)                              OBJCON17
      WRITE(6,1000) DIFFS,WO                                            OBJCON18
      DIFFS=DIFFS/WO                                                    OBJCON19
      WRITE(6,1010) DIFFS                                               OBJCON20
C                                                                       OBJCON21
C   CONSTRAINT NO. 1  -  BLADE THICKNESS                                OBJCON22
C                                                                       OBJCON23
      BCHORD=2.*3.1415927*R*SOLID/FLOAT(NB)                             OBJCON24
      TEDIAM=2.*THTE*BCHORD                                             OBJCON25
      DTMIN=1.E10                                                       OBJCON26
      DO 20 I=2,12                                                      OBJCON27
      DRTH=(XTHSP(I,1)-XTHSP(I,2))*R                                    OBJCON28
      DZ=XMSP(I,1)-XMSP(I,2)                                            OBJCON29
      DT=SQRT(DRTH*DRTH+DZ*DZ)                                          OBJCON30
      TKODTE=(DT-TEDIAM)/TEDIAM                                         OBJCON31
   20 IF(TKODTE.LT.DTMIN) DTMIN=TKODTE                                  OBJCON32
      BLTKS=DTMIN                                                       OBJCON33
      WRITE(6,1020) BLTKS                                               OBJCON34
      C(1)=BLTKS                                                        OBJCON35
C                                                                       OBJCON36
C   CONSTRAINT NO. 2  -  PRESSURE SURFACE DIFFUSION                     OBJCON37
C                                                                       OBJCON38
      A=ND2/2                                                           OBJCON39
      B=2.*ND2/3                                                        OBJCON40
      N12=INT(A)                                                        OBJCON41
      N23=INT(B)                                                        OBJCON42
      YMAX=Y(ND2)                                                       OBJCON43
      YMIN=YMAX                                                         OBJCON44
      DO 30 I=N12,ND2                                                   OBJCON45
   30 IF(Y(I).GT.YMAX) YMAX=Y(I)                                        OBJCON46
      DO 40 I=2,N23                                                     OBJCON47
   40 IF(Y(I).LT.YMIN) YMIN=Y(I)                                        OBJCON48
      DIFFP=YMAX/YMIN                                                   OBJCON49
      WRITE(6,1030) YMAX,YMIN,DIFFP                                     OBJCON50
      C(2)=DIFFP                                                        OBJCON51
C                                                                       OBJCON52
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C   CONSTRAINT NO. 3  -  TRAILING EDGE CLOSURE                          OBJCON53
C                                                                       OBJCON54
      N1=2*(MBO-MBI)-3                                                  OBJCON55
      TECLSR=(Y(N1)-Y(2))/80.                                           OBJCON56
      WRITE (6,1040) Y(N1),Y(2),TECLSR                                  OBJCON57
      C(3)=TECLSR                                                       OBJCON58
C                                                                       OBJCON59
      RETURN                                                            OBJCON60
 1000 FORMAT(////* OUTPUT FROM OBJCON*/1H0,3X,                          OBJCON61
     *     *OBJECTIVE FUNCTION*,3X,*DIFFS     =*,E12.5/                 OBJCON62
     *     25X,*WO        =*,E12.5)                                     OBJCON63
 1010 FORMAT (25X,*DIFFS/WO =*,E12.5)                                   OBJCON64
 1020 FORMAT(1H0,3X,*CONSTRAINT 1*, 9X,*BLTKS     =*,E12.5)             OBJCON65
 1030 FORMAT(1H0,3X,*CONSTRAINT 2*, 9X,*YMAX      =*,E12.5/             OBJCON66
     *      25X,*YMIN      =*,E12.5/                                    OBJCON67
     *      25X,*DIFFP     =*,E12.5)                                    OBJCON68
 1040 FORMAT(1H0,3X,*CONSTRAINT 3*, 5X,*WMB(MBO-2,1) =*,E12.5/          OBJCON69
     *      21X,*WMB(MBO-2,2) =*,E12.5/                                 OBJCON70
     *      25X,*TECLSR    =*,E12.5)                                    OBJCON71
      END                                                               OBJCON72
      SUBROUTINE PERTRB (ICALL,X,Y)                                     PERTRB 2
C                                                                       PERTRB 3
C************************ SUBROUTINE PERTURB ***************************PERTRB 4
C                                                                       PERTRB 5
C     ICALL=1 ... READ INPUT AND PRINT CONTROL PARAMETERS.              PERTRB 6
C                                                                       PERTRB 7
C     ICALL=2 ... PERFORM CALCULATIONS ON BASE SOLUTION.                PERTRB 8
C                                                                       PERTRB 9
C     ICALL=3 ...'PERFORM CALCULATIONS ON CALIBRATION SOLUTION.         PERTRB10
C                                                                       PERTRB11
C     ICALL=4 ... RETURN PERTURBATION SOLUTION TO CALLING               PERTRB12
C                 SUBROUTINE.                                           PERTRB13
C                                                                       PERTRB14
C***********************************************************************PERTRB15
C                                                                       PERTRB16
      DIMENSION XLOC0(6),XLOC1(6),XLOC2(6),XLOC3(6),XFIX0(8),XFIX1(8)   PERTRB17
      DIMENSION LCR0(4),LCR1(4),LCR2(4),LCR3(4),ISEQ0(8),ISEQ1(8)       PERTRB18
      DIMENSION HEAD0(5),HEAD1(5),HEAD2(5),HEAD3(5)                     PERTRB19
      DIMENSION XOUT(8),DEL1(10),ORD(10),X(200),Y(200)                  PERTRB20
      DIMENSION FLAG(8),STRING(100),STRUNI(100)                         PERTRB21
      REAL M0,M1,M2                                                     PERTRB22
      COMMON /COEFF/ C(10,7),D(10,7),DELX(200)                          PERTRB23
      COMMON /HEAD/ TITLE(8),JOBKEY                                     PERTRB24
      COMMON /PARAM/ PARNAM(10),LSELCT(6),LUNIT,LPLOT,NSELCT,A,B,VNAM(2)PERTRB25
      COMMON /PERT/ Q0(10),Q1,Q2(10),M0,M1,M2,N,KPARAM,NPARAM,LTRACE    PERTRB26
      COMMON /MINMAX/ YMIN,YMAX,YCR2                                    PERTRB27
      COMMON /SAVE/ XCSAVE(10,200),YCSAVE(10,200)                       PERTRB28
      COMMON /XY/ XBASE(200),XCALB(200),XPERT(200),XAERO(200),          PERTRB29
     % XUNIT(200),YBASE(200),YCALB(200),YPERT(200),YAERO(200),          PERTRB30
     % YINTP(200),YPRTI(200),DUMMY(200)                                 PERTRB31
      COMMON /XUYU/ XUSAVE(10,200),YUNIT(10,200)                        PERTRB32
      LEVEL 2, XCSAVE,YCSAVE,XUSAVE,YUNIT,C,D,DELX                      PERTRB33
      LEVEL 2, XBASE,XCALB,XPERT,XAERO,XUNIT,YBASE,YCALB,YPERT,YAERO,   PERTRB34
     % YINTP,YPRTI,DUMMY                                                PERTRB35
      DATA LTERM/0/, LCORR/0/                                           PERTRB36
      DATA HEAD0 /4HBASE,4H SOL,4HUTIO,4HN:  ,4H    /,                  PERTRB37
     %     HEAD1 /4HCALI,4HBRAT,4HION ,4HSOLN,4H:   /,                  PERTRB38
     %     HEAD2 /4HPERT,4HURBA,4HTION,4H SOL,4HN:  /,                  PERTRB39
     %     HEAD3 /4HAERO,4HDYNA,4HMIC ,4HSOLN,4H:   /                   PERTRB40
      DATA ORD /5H 1ST ,5H 2ND ,5H 3RD ,5H 4TH ,                        PERTRB41
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     %          5H 5TH ,5H 6TH ,5H 7TH ,5H 8TH ,5H 9TH ,5H10TH /        PERTRB42
C                                                                       PERTRB43
C***********************************************************************PERTRD44
C                                                                       PERTRB45
C     USER-SUPPLIED STATEMENT FUNCTION YCRIT(Z) DETERMINES CRITICAL     PERTRB46
C     VALUES OF FLOW VARIABLE YCRIT AS FUNCTION OF FLOW PARAMETER Z.    PERTRB47
C     IGRAD (+1 OR -1) IS THE USER-SUPPLIED ALGEBRAIC SIGN OF DYCRIT/DX PERTRB48
C     USED IN LOCATING THE CRITICAL POINT.                              PERTRD49
C                                                                       PERTRB50
C     IN THE PRESENT VERSION OF THE CODE, YCRIT REPRESENTS THE FULL-    PERTRB51
C     POTENTIAL CRITICAL PRESSURE COEFFICIENT FOR AIR (GAMMA = 1.4), Z  PERTRB52
C     IS THE FREE STREAM MACH NUMBER, AND IGRAD CORRESPONDS TO POSITIVE PERTRB53
C     PRESSURE GRADIENT (+1).                                           PERTRB54
C                                                                       PERTRB55
      YCRIT(Z)=2.0*(((2.0+0.4*Z**2)/2.4)**(1.4/0.4)-1.0)/(1.4*Z**2)     PERTRB56
      IGRAD=1                                                           PERTRB57
C                                                                       PERTRB58
C***********************************************************************PERTRB59
      GO TO (501,502,503,504),ICALL                                     PERTRB60
C                                                                       PERTRB61
C.....INPUT CONTROL, GEOMETRY, AND STRAINING PARAMETERS.                PERTRB62
C                                                                       PERTRB63
  501 CALL INPUT (NPARAM)                                               PERTRB64
C                                                                       PERTRB65
C.....WRITE TITLE AND INPUT PARAMETERS.                                 PERTRB66
C                                                                       PERTRB67
      WRITE(6,1005)                                                     PERTRB68
      WRITE (6,1000) TITLE                                              PERTRB69
      WRITE (6,1010) N,A,B,NPARAM                                       PERTRB70
C                                                                       PERTRB71
      NFIX=NSELCT+2                                                     PERTRB72
      NSEG=NFIX-1                                                       PERTRB73
C                                                                       PERTRB74
C.....PRINT INFORMATION REGARDING STRAINING TO BE USED.                 PERTRB75
C                                                                       PERTRB76
      WRITE (6,1020) NFIX                                               PERTRB77
      WRITE (6,1040)                                                    PERTRB78
      DO 20 I=1,NSELCT                                                  PERTRB79
      IF (LSELCT(I) .EQ. 1) WRITE (6,1050) VNAM                         PERTRB80
      IF (LSELCT(I) .EQ. 2) WRITE (6,1060) VNAM                         PERTRB81
      IF (LSELCT(I) .LE. 2) GO TO 20                                    PERTRB82
      LCORR=1                                                           PERTRB83
      LPR=LSELCT(I)-2                                                   PERTRB84
      WRITE (6,1070) VNAM,ORD(LPR)                                      PERTRB85
   20 CONTINUE                                                          PERTRB86
      RETURN                                                            PERTRB87
C                                                                       PERTRB88
C.....BEGIN CALCULATIONS ON BASE SOLUTION.                              PERTRB89
C                                                                       PERTRB90
  502 YCR0=YCRIT(M0)                                                    PERTRB91
      WRITE (6,1080) HEAD0                                              PERTRB92
      WRITE (6,1090) VNAM                                               PERTRB93
      WRITE (6,1100) M0                                                 PERTRB94
      IF (NPARAM .EQ. 1) WRITE (6,1110) Q0(1),PARNAM(1)                 PERTRB95
      IF (NPARAM .GT. 1) WRITE (6,1120) (K,Q0(K),PARNAM(K),K=1,NPARAM)  PERTRB96
      WRITE (6,1130) VNAM,YCR0                                          PERTRB97
C                                                                       PERTRB98
C.....NORMALIZE X COORDINATES AND LOCATE MINIMUM, MAXIMUM, AND CRITICAL PERTRB99
C     POINTS FOR BASE SOLUTION.                                         PERTR100
C                                                                       PERTR101
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      CALL COPY12 (N,X,XBASE)
      CALL COPY12 (N,Y,YBASE)
      CALL SCALE (N,XBASE,1,A,B)
      CALL LOCATE (N,XBASE,YBASE,YCR0,IGRAD,LMN0,LMX0,NCR0,LCR0,XLOC0)
      YBCMIN=YBASE(LMN0)
      YBCMAX=YBASE(LMX0)
      WRITE (6,1140)
      WRITE (6,1150)
      CALL UPLOW (A,B,XLOC0,6,NCR0+2,XOUT,FLAG)
      WRITE (6,1160) XOUT(1),FLAG(1),LMN0,XOUT(2),FLAG(2),LMX0
      IF (NCR0 .GT. 0) WRITE (6,1170) NCR0,
     %     (ORD(I),XOUT(I+2),FLAG(I+2),LCR0(I),I=1,NCR0)
C
C.....LOAD SELECTED STRAINING POINTS INTO FIXED-POINT ARRAY FOR BASE
C     SOLUTION.
C
      XFIX0(1)=0.0
      XFIX0(NFIX)=1.0
      DO 50 I=1,NSELCT
      XFIX0(I+1)=XLOC0(LSELCT(I))
   50 CONTINUE
C
C.....ARRANGE SELECTED FIXED POINTS IN A MONOTONE SEQUENCE.
C
      CALL SORT (NFIX,XFIX0,ISEQ0)
      WRITE (6,1200)
      WRITE (6,1150)
      CALL UPLOW (A,B,XFIX0,8,NFIX,XOUT,FLAG)
      WRITE (6,1210) (I,XOUT(I),FLAG(I),I=1,NFIX)
      RETURN
C
C.....BEGIN CALCULATIONS ON CALIBRATION SOLUTIONS.
C
  503 K=KPARAM
      YCR1=YCRIT(M1)
      DEL1(K)=Q1-Q0(K)
      CALL COPY12 (N,X,XCALB)
      CALL COPY12 (N,Y,YCALB)
      CALL COPYVA (1,N,K,XCALB,XCSAVE)
      CALL COPYVA (1,N,K,YCALB,YCSAVE)
      IF (NPARAM .EQ. 1) WRITE (6,1080) HEAD1
      IF (NPARAM .GT. 1) WRITE (6,1220) ORD(K),HEAD1
      WRITE (6,1090) VNAM
      WRITE (6,1230) M1
      IF (NPARAM .GT. 1) WRITE (6,1240)
      DO 60 KK=1,NPARAM
      IF (NPARAM .EQ. 1) WRITE (6,1250) Q1,PARNAM(1)
      IF (NPARAM .GT. 1 .AND. KK .EQ. K) WRITE (6,1260) KK,Q1,PARNAM(KK)
      IF (KK .NE. K) WRITE (6,1270) KK,Q0(KK),PARNAM(KK)
   60 CONTINUE
      WRITE (6,1130) VNAM,YCR1
C
C.....NORMALIZE X COORDINATES AND LOCATE MINIMUM, MAXIMUM, AND CRITICAL
C     POINTS FOR KTH CALIBRATION SOLUTION.
C
      CALL SCALE (N,XCALB,1,A,B)
      CALL LOCATE (N,XCALB,YCALB,YCR1,IGRAD,LMN1,LMX1,NCR1,LCR1,XLOC1)
      YTMIN=YCALB(LMN1)
      YTMAX=YCALB(LMX1)
      IF (YTMIN .LT. YBCMIN) YBCMIN=YTMIN
      IF (YTMAX .GT. YBCMAX) YBCMAX=YTMAX
      WRITE (6,1140)
      WRITE (6,1150)
      CALL UPLOW (A,B,XLOC1,6,NCR1+2,XOUT,FLAG)
      WRITE (6,1160) XOUT(1),FLAG(1),LMN1,XOUT(2),FLAG(2),LMX1
      IF (NCR1 .GT. 0) WRITE (6,1170) NCR1,
     %     (ORD(I),XOUT(I+2),FLAG(I+2),LCR1(I),I=1,NCR1)
C
C.....CHECK FOR INVALID STRAINING SPECIFICATION.
C
      ICOUNT=0
      DO 70 I=1,NSELCT
      IF (LSELCT(I) .LE. 2) GO TO 70
      ICOUNT=ICOUNT+1
      IF (NCR0 .NE. NCR1) LTERM=1
   70 CONTINUE
C
C.....STOP EXECUTION IF CRITICAL POINTS ARE TO BE USED IN STRAINING AND
C     NUMBER OF CRITICAL POINTS IN BASE AND CALIBRATION SOLUTIONS ARE
C     UNEQUAL.
C
      IF (LTERM .EQ. 1) GO TO 900
C
C.....STOP EXECUTION IF NUMBER OF CRITICAL POINTS SELECTED EXCEEDS
C     NUMBER ACTUALLY LOCATED.
C
      IF (ICOUNT .GT. NCR0) GO TO 905
C
C.....LOAD SELECTED STRAINING POINTS INTO FIXED-POINT ARRAY FOR KTH
C     CALIBRATION SOLUTION.
C
      XFIX1(1)=0.0
      XFIX1(NFIX)=1.0
      DO 100 I=1,NSELCT
      XFIX1(I+1)=XLOC1(LSELCT(I))
  100 CONTINUE
C
C.....ARRANGE SELECTED FIXED POINTS IN A MONOTONE SEQUENCE.
C
      CALL SORT (NFIX,XFIX1,ISEQ1)
      WRITE (6,1200)
      WRITE (6,1150)
      CALL UPLOW (A,B,XFIX1,8,NFIX,XOUT,FLAG)
      WRITE (6,1210) (I,XOUT(I),FLAG(I),I=1,NFIX)
C
C.....STOP EXECUTION IF ORDER OF OCCUPRENCE OF CRITICAL POINTS IN BASE
C     AND CALIBRATION SOLUTIONS DOES NOT CORRESPOND.
C
      DO 110 I=1,NFIX
      IF (ISEQ0(I) .NE. ISEQ1(I)) GO TO 910
  110 CONTINUE
C
C.....COMPUTE COEFFICIENTS IN KTH UNIT STRAINING OF XBASE
C
C           XSTR = C(K,I) + D(K,I)*XBASE,  I=1,2, ... ,NSEG,
C
C     WHERE NSEG IS THE NUMBER OF LINEAR SEGMENTS.
C
      DO 130 I=1,NSEG
      CNUM=XFIX1(I)*XFIX0(I+1)-XFIX1(I+1)*XFIX0(I)
      DNUM=XFIX1(I+1)-XFIX1(I)                                          PERTR222
      DENOM=XFIX0(I+1)-XFIX0(I)                                         PERTR223
      C(K,I)=CNUM/DENOM                                                 PERTR224
      D(K,I)=DNUM/DENOM                                                 PERTR225
  130 CONTINUE                                                          PERTR226
C                                                                       PERTR227
C.....DETERMINE KTH UNIT STRAINING OF XBASE.                            PERTR228
C                                                                       PERTR229
      CALL STRAIN (N,K,NSEG,XFIX0,XBASE,1.0)                            PERTR230
      DO 140 I=1,N                                                      PERTR231
  140 XUNIT(I)=XBASE(I)+DELX(I)                                         PERTR232
C                                                                       PERTR233
C.....INTERPOLATE CALIBRATION SOLUTION TO BASE FLOW POINTS CORRESPONDINGPERTR234
C     TO UNIT STRAINING.                                                PERTR235
C                                                                       PERTR236
      CALL INTERP (N,XCALB,YCALB,XUNIT,YINTP)                           PERTR237
C                                                                       PERTR238
C.....CORRECT VALUES ON EITHER SIDE OF CRITICAL POINTS, IF THESE ARE    PERTR239
C     USED IN STRAINING.                                                PERTR240
C                                                                       PERTR241
      IF (LCORR .EQ. 0) GO TO 160                                       PERTR242
      DO 150 I=1,NCR1                                                   PERTR243
      YINTP(LCR0(I))=YCALB(LCR1(I))                                     PERTR244
      YINTP(LCR0(I)+1)=YCALB(LCR1(I)+1)                                 PERTR245
  150 CONTINUE                                                          PERTR246
  160 CONTINUE                                                          PERTR247
C                                                                       PERTR248
C.....DETERMINE THE KTH UNIT PERTURBATION.                              PERTR249
C                                                                       PERTR250
      DO 170 I=1,N                                                      PERTR251
  170 YUNIT(K,I)=(YINTP(I)-YBASE(I))/DEL1(K)                            PERTR252
C                                                                       PERTR253
C.....SAVE UNIT STRAINING IF REQUIRED FOR LATER PRINTOUT.               PERTR254
C                                                                       PERTR255
      IF (LUNIT .EQ. 0) GO TO 180                                       PERTR256
      CALL SCALE (N,XUNIT,2,A,B)                                        PERTR257
      CALL COPYVA (1,N,K,XUNIT,XUSAVE)                                  PERTR258
  180 IF (KPARAM .LT. NPARAM) RETURN                                    PERTR259
C                                                                       PERTR260
C.....PRINT UNIT PERTURBATION(S) AND UNIT STRAINING(S) IF LUNIT .NE. 0. PERTR261
C                                                                       PERTR262
      IF (LUNIT .EQ. 0) RETURN                                          PERTR263
      CALL SCALE (N,XBASE,2,A,B)                                        PERTR264
      IRPT=0                                                            PERTR265
      IF (NPARAM .GT. 5) IRPT=1                                         PERTR266
      KSTART=1                                                          PERTR267
      KSTOP=5                                                           PERTR268
      IF (KSTOP .GT. NPARAM) KSTOP=NPARAM                               PERTR269
      GO TO 200                                                         PERTR270
  190 KSTART=6                                                          PERTR271
      KSTOP=NPARAM                                                      PERTR272
  200 CONTINUE                                                          PERTR273
      WRITE (6,1280) VNAM                                               PERTR274
      IF (NPARAM .GT. 1) WRITE (6,1290) KSTART,KSTOP                    PERTR275
      IF (NPARAM .EQ. 1) WRITE (6,1300)                                 PERTR276
      IF (NPARAM .EQ. 1) GO TO 210                                      PERTR277
      NUM=KSTOP-KSTART+1                                                PERTR278
      IF (NUM .EQ. 1) WRITE (6,1310) (ORD(K),K=KSTART,KSTOP)            PERTR279
      IF (NUM .EQ. 2) WRITE (6,1320) (ORD(K),K=KSTART,KSTOP)            PERTR280
      IF (NUM .EQ. 3) WRITE (6,1330) (ORD(K),K=KSTART,KSTOP)            PERTR281
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      IF (NUM .EQ. 4) WRITE (6,1340) (ORD(K),K=KSTART,KSTOP)            PERTR282
      IF (NUM .EQ. 5) WRITE (6,1345) (ORD(K),K=KSTART,KSTOP)            PERTR283
  210 CONTINUE                                                          PERTR284
      CALL FILL (1,0,STPUNI)                                            PERTR285
      KLAST=20*(KSTOP-KSTART+1)                                         PERTR286
      WRITE (6,1350) (STRUNI(K),K=1,KLAST)                              PERTR287
      WRITE (6,1360)                                                    PERTR288
      DO 220 I=1,N                                                      PERTR289
  220 WRITE (6,1370) I,XBASE(I),(XUSAVE(K,I),YUNIT(K,I),K=KSTART,KSTOP) PERTR290
      IF (IPPT .EQ. 0) GO TO 230                                        PERTR291
      IRPT=0                                                            PERTR292
      GO TO 190                                                         PERTR293
  230 CALL SCALE (N,XBASE,1,A,B)                                        PERTR294
      RETURN                                                            PERTR295
C                                                                       PERTR296
C.....CONSTRUCT PERTURBATION SOLUTIONS FOR REQUIRED CASES.              PERTR297
C                                                                       PERTR298
  504 YCR2=YCRIT(M2)                                                    PERTR299
      YCR3=YCR2                                                         PERTR300
      CALL COPY12 (N,X,XAERO)                                           PERTR301
      IF (LTRACE .EQ. 1) CALL COPY12 (N,Y,YAERO)                        PERTR302
C                                                                       PERTR303
C.....INITIALIZE STRAINED COOPDINATE AND PERTURBATION SOLUTION.         PERTR304
C                                                                       PERTR305
      DO 250 I=1,N                                                      PERTR306
      XPERT(I)=XBASE(I)                                                 PERTR307
  250 YPERT(I)=YBASE(I)                                                 PERTR308
C                                                                       PERTR309
C.....ADD IN CONTRIBUTIONS FROM ALL PERTURBATIONS.                      PERTR310
C                                                                       PERTR311
      DO 270 K=1,NPARAM                                                 PERTR312
      DEL2=Q2(K)-Q0(K)                                                  PERTR313
      DEL21=DEL2/DEL1(K)                                                PERTR314
      CALL STRAIN (N,K,NSEG,XFIX0,XBASE,DEL21)                          PERTR315
      DO 260 I=1,N                                                      PERTR316
      XPERT(I)=XPERT(I)+DELX(I)                                         PERTR317
  260 YPERT(I)=YPERT(I)+DEL2*YUNIT(K,I)                                 PERTR318
  270 CONTINUE                                                          PERTR319
C                                                                       PERTR320
C.....ADJUST VALUES NEAR CRITICAL POINT FOR MONOTONE BEHAVIOR.          PERTR321
C                                                                       PERTR322
      IF (LCORR .EQ. 1) CALL MONO (NCR0,LCR0,XPERT,YPERT)               PERTR323
C                                                                       PERTR324
C.....INTERPOLATE SOLUTION IN STRAINED COORDINATES TO BASE X VALUES.    PERTR325
C                                                                       PERTR326
      CALL INTERP (N,XPERT,YPERT,XBASE,DUMMY)                           PERTR327
      CALL COPY21 (N,DUMMY,Y)                                           PERTR328
C                                                                       PERTR329
      IF (LTRACE.EQ.0) RETURN                                           PERTR330
C                                                                       PERTR331
C.....COMPARISON OF PERTURBATION AND AERODYNAMIC SOLUTIONS.             PERTR332
C                                                                       PERTR333
C                                                                       PERTR334
C.....LOCATE MINIMUM, MAXIMUM, AND CRITICAL POINTS IN PERTURBATION      PERTR335
C     SOLUTION.                                                         PERTR336
C                                                                       PERTR337
      CALL SCALE (N,XPERT,2,A,B)                                        PERTR338
      CALL SCALE (N,XPERT,1,A,B)                                        PERTR339
      CALL LOCATE (N,XPERT,YPERT,YCR2,IGRAD,LMN2,LMX2,NCR2,LCR2,XLOC2)  PERTR340
      YMIN=YPERT(LMN2)                                                  PERTR341
      YMAX=YPERT(LMX2)                                                  PERTR342
      YPCMIN=YMIN                                                       PERTR343
      YPCMAX=YMAX                                                       PERTR344
      WRITE (6,1380)                                                    PERTR345
      WRITE (6,1090) VNAM                                               PERTR346
      WRITE (6,1390) M2                                                 PERTR347
      IF (NPARAM .EQ. 1) WRITE (6,1400) Q2(1),PARNAM(1)                 PERTR348
      IF (NPARAM .GT. 1) WRITE (6,1410) (K,Q2(K),PARNAM(K),K=1,NPARAM)  PERTR349
      WRITE (6,1130) VNAM,YCR2                                          PERTR350
      WRITE (6,1140)                                                    PERTR351
      WRITE (6,1150)                                                    PERTR352
      CALL UPLOW (A,B,XLOC2,6,NCR2+2,XOUT,FLAG)                         PERTR353
      WRITE (6,1420) HEAD2,XOUT(1),FLAG(1),LMN2,XOUT(2),FLAG(2),LMX2    PERTR354
      IF (NCR2 .GT. 0) WRITE (6,1430) NCR2,                             PERTR355
     %     (ORD(I),XOUT(I+2),FLAG(I+2),LCR2(I),I=1,NCR2)                PERTR356
      CALL SCALE (N,XBASE,2,A,B)                                        PERTR357
C                                                                       PERTR358
C.....LOCATE MINIMUM, MAXIMUM, AND CRITICAL POINTS IN AERODYNAMIC       PERTR359
C     SOLUTION.                                                         PERTR360
C                                                                       PERTR361
      CALL SCALE (N,XAERO,1,A,B)                                        PERTR362
      CALL LOCATE (N,XAERO,YAERO,YCR3,IGRAD,LMN3,LMX3,NCR3,LCR3,XLOC3)  PERTR363
      YMIN=YAERO(LMN3)                                                  PERTR364
      YMAX=YAERO(LMX3)                                                  PERTR365
      IF (YMIN .LT. YPCMIN) YPCMIN=YMIN                                 PERTR366
      IF (YMAX .GT. YPCMAX) YPCMAX=YMAX                                 PERTR367
      CALL UPLOW (A,B,XLOC3,6,NCR3+2,XOUT,FLAG)                         PERTR368
      WRITE (6,1420) HEAD3,XOUT(1),FLAG(1),LMN3,XOUT(2),FLAG(2),LMX3    PERTR369
      IF (NCR3 .GT. 0) WRITE (6,1430) NCR3,                             PERTR370
     %     (ORD(I),XOUT(I+2),FLAG(I+2),LCR3(I),I=1,NCR3)                PERTR371
      CALL INTERP (N,XPERT,YPERT,XAERO,YPRTI)                           PERTR372
      CALL LOCATE (N,XAERO,YPRTI,YCR3,IGRAD,LMN3,LMX3,NCR3,LCR3,XLOC3)  PERTR373
      YTMIN=YPRTI(LMN3)                                                 PERTR374
      YTMAX=YPRTI(LMX3)                                                 PERTR375
      IF (YTMIN .LT. YMIN) YMIN=YTMIN                                   PERTR376
      IF (YTMAX .GT. YMAX) YMAX=YTMAX                                   PERTR377
      CALL SCALE (N,XPERT,2,A,B)                                        PERTR378
      CALL SCALE (N,XAERO,2,A,B)                                        PERTR379
      CALL FILL (2,0,STRING)                                            PERTR380
      WRITE (6,1440) VNAM                                               PERTR381
      WRITE (6,1450) VNAM,YMAX,VNAM,YMIN,VNAM,YCR2,VNAM,VNAM            PERTR382
      WRITE (6,1460) VNAM,VNAM,VNAM,VNAM,(STRING(I),I=1,72)             PERTR383
      DO 280 I=1,N                                                      PERTR384
      CALL FILL (3,I,STRING)                                            PERTR385
  280 WRITE (6,1470) I,XBASE(I),YBASE(I),XPERT(I),YPERT(I),             PERTR386
     % XAERO(I),YAERO(I),YPRTI(I),(STRING(II),II=1,72)                  PERTR387
C                                                                       PERTR388
C.....IF LPLOT .NE. 0 GENERATE PERIPHERAL PLOT OF PERTURBATION AND      PERTR389
C     AERODYNAMIC SOLUTIONS.                                            PERTR390
C                                                                       PERTR391
      IF (LPLOT .EQ. 0) GO TO 320                                       PERTR392
      YMIN=YBCMIN                                                       PERTR393
      YMAX=YBCMAX                                                       PERTR394
      IF (YPCMIN .LT. YMIN) YMIN=YPCMIN                                 PERTR395
      IF (YPCMAX .GT. YMAX) YMAX=YPCMAX                                 PERTR396
      CALL DRVPLT (N,NPARAM,YMIN,YMAX,YCR2)                             PERTR397
  320 CALL SCALE (N,XBASE,1,A,B)                                        PERTR398
      RETURN                                                            PERTR399
C                                                                       PERTR400
C.....ABNORMAL TERMINATION OF COMPUTATION.                              PERTR401
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C                                                                       PERTR402
  900 WRITE (6,9000)                                                    PERTR403
      GO TO 999                                                         PERTR404
  905 WRITE (6,9050)                                                    PERTR405
      GO TO 999                                                         PERTR406
  910 WRITE (6,9100)                                                    PERTR407
C                                                                       PERTR408
  999 WRITE (6,9500)                                                    PERTR409
      STOP                                                              PERTR410
C                                                                       PERTR411
C.....I/O FORMAT STATEMENTS FOLLOW.                                     PERTR412
C                                                                       PERTR413
 1000 FORMAT(1H0,132(1H*)/                                              PERTR414
     %          1X,1H*,25X,8A10,25X,1H*/                                PERTR415
     %          1X,132(1H*)////)                                        PERTR416
 1005 FORMAT(1H1,35X,37H--- INPUT FOR PERTURBATION METHOD ---//)        PERTR417
 1010 FORMAT (1X,29H.....LIST OF INPUT PARAMETERS//                     PERTR418
     %          6X,3HN =,I4//                                           PERTR419
     %          6X,3HA =,F5.1,4X,3HB =,F5.1//                           PERTR420
     %          6X,8HNPARAM =,I2///)                                    PERTR421
 1020 FORMAT (1X,22H.....STRAINING OPTIONS//                            PERTR422
     %          6X,23HNUMBER OF FIXED POINTS:,I2/)                      PERTR423
 1040 FORMAT (6X,45HFIXED POINTS WILL BE AUTOMATICALLY DETERMINED/      PERTR424
     %          6X,44HBY THE PROGRAM FOR ALL SOLUTIONS AS FOLLOWS://    PERTR425
     %         11X,14HTWO END POINTS)                                   PERTR426
 1050 FORMAT (11X,16HPOINT OF MINIMUM,1X,2A1)                           PERTR427
 1060 FORMAT (11X,16HPOINT OF MAXIMUM,1X,2A1)                           PERTR428
 1070 FORMAT (11X,2A1,6HCRIT (,A5,6HPOINT))                             PERTR429
 1080 FORMAT (1H1,26HRESULTS OF COMPUTATIONS ON,1X,5A4///)              PERTR430
 1090 FORMAT (1X,17H.....MACH NUMBER,/                                  PERTR431
     %          6X,34HVALUES OF PERTURBATION PARAMETERS,/               PERTR432
     %          6X,17HCRITICAL VALUE OF,1X,2A1,1H:/)                    PERTR433
 1100 FORMAT (11X,4HM0 =,F7.4/)                                         PERTR434
 1110 FORMAT (11X,4HQ0 =,F10.4,5X,1H(,A8,1H)/)                          PERTR435
 1120 FORMAT (11X,3HQ0(,I1,3H) =,F10.4,5X,1H(,A8,1H)/)                  PERTR436
 1130 FORMAT (11X,2A1,6HCRIT =,F8.4///)                                 PERTR437
 1140 FORMAT (1X,47H.....LOCATIONS OF MIN., MAX., AND CRITICAL PTS.)    PERTR438
 1150 FORMAT (3X,34H(* DENOTES POINT ON LOWER SURFACE)/)                PERTR439
 1160 FORMAT (6X,14HMINIMUM AT X =,F7.4,A1,3X,10H(POINT NO.,I4,1H)/     PERTR440
     %          6X,14HMAXIMUM AT X =,F7.4,A1,3X,10H(POINT NO.,I4,1H))   PERTR441
 1170 FORMAT (6X,I1,1X,18HCRITICAL POINT(S):/                           PERTR442
     %          (9X,A5,6HAT X =,1X,F6.4,A1,3X,                          PERTR443
     %                  16H(AFTER POINT NO.,I4,1H)))                    PERTR444
 1200 FORMAT (///1X,29H.....LOCATION OF FIXED POINTS)                   PERTR445
 1210 FORMAT (11X,5HXFIX(,I1,3H) =,F7.4,A1)                             PERTR446
 1220 FORMAT (1H1,26HRESULTS OF COMPUTATIONS ON,1X,A5,5A4///)           PERTR447
 1230 FORMAT (11X,4HM1 =,F7.4/)                                         PERTR448
 1240 FORMAT (2X,41H(** DENOTES PERTURBATION FROM BASE VALUE)/)         PERTR449
 1250 FORMAT (11X,4HQ1 =,F10.4,5X,1H(,A8,1H)/)                          PERTR450
 1260 FORMAT (9X,5H**Q1(,I1,3H) =,F10.4,5X,1H(,A8,1H)/)                 PERTR451
 1270 FORMAT (11X,3HQ1(,I1,3H) =,F10.4,5X,1H(,A8,1H)/)                  PERTR452
 1280 FORMAT (1H1,20HUNIT PERTURBATION OF,1X,2A1,1X,                    PERTR453
     %                27HAND UNIT STRAINING OF XBASE)                   PERTR454
 1290 FORMAT (26H FOR CALIBRATION SOLUTIONS,I2,1X,7HTHROUGH,I2)         PERTR455
 1300 FORMAT (//1H )                                                    PERTR456
 1310 FORMAT (///19X,1(1H*,A5,11HCALB SOLN *,3X))                       PERTR457
 1320 FORMAT (///19X,2(1H*,A5,11HCALB SOLN *,3X))                       PERTR458
 1330 FORMAT (///19X,3(1H*,A5,11HCALB SOLN *,3X))                       PERTR459
 1340 FORMAT (///19X,4(1H*,A5,11HCALB SOLN *,3X))                       PERTR460
 1345 FOPMAT (///19X,5(1H*,A5,11HCALB SOLN *,3X))                       PERTR461
 1350 FORMAT(1X,5HPOINT,4X,5HXBASE,4X,100A1)                           PERTR462
 1360 FORMAT (1X)                                                      PERTR463
 1370 FORMAT (1X,I4,1X,11F10.4)                                        PERTR464
 1380 FORMAT (1H1,56(1H*)/1X,2H* ,                                     PERTR465
    % 52HCOMPARISON OF AERODYNAMIC AND PERTURBATION SOLUTIONS,         PERTR466
    % 2H */1X,56(1H*)///)                                              PERTR467
 1390 FORMAT (11X,4HM2 =,F7.4/)                                        PERTR468
 1400 FORMAT (11X,4HQ2 =,F7.4,5X,1H(,A8,1H)/)                          PERTR469
 1410 FORMAT (11X,3HQ2(,I1,3H) =,F7.4,5X,1H(,A8,1H)/)                  PERTR470
 1420 FORMAT (/6X,5A4//                                                PERTR471
    %        11X,14HMINIMUM AT X =,F7.4,A1,3X,10H(POINT NO.,I4,1H)/    PERTR472
    %        11X,14HMAXIMUM AT X =,F7.4,A1,3X,10H(POINT NO.,I4,1H))    PERTR473
 1430 FORMAT (1H ,10X,I1,1X,18HCRITICAL POINT(S):/                     PERTR474
    %        (14X,A5,6HAT X =,F7.4,A1,3X,                              PERTR475
    %             16H(AFTER POINT NO.,I4,1H)))                         PERTR476
 1440 FORMAT (///1X,44H.....FINAL PRINTOUT AND GRAPHICAL DISPLAY OF,1X, PERTR477
    %           2A1)                                                   PERTR478
 1450 FORMAT (/72X,21HH = MAXIMUM  VALUE OF,1X,2A1,1X,1H=,F8.4/        PERTR479
    %         72X,21HL = MINIMUM  VALUE OF,1X,2A1,1X,1H=,F8.4/         PERTR480
    %         72X,21H* = CRITICAL VALUE OF,1X,2A1,1X,1H=,F8.4/         PERTR481
    %         72X,12HP = VALUE OF,1X,2A1,1X,                           PERTR482
    %             34HPREDICTED BY PERTURBATION SOLUTION/               PERTR483
    %         72X,12HA = VALUE OF,1X,2A1,1X,                           PERTR484
    %             23HIN AERODYNAMIC SOLUTION/                          PERTR485
    %         72X,29H$ = AGREEMENT BETWEEN P AND A)                    PERTR486
 1460 FORMAT (/2X,2HPT,2X,5HXBASE,3X,2A1,4HBASE,2X,5HXPERT,3X,2A1,     PERTR487
    %           4HPERT,2X,5HXAERO,3X,2A1,4HAERO,2X,2A1,4HPINT,1X,72A1/)PERTR488
 1470 FORMAT (1X,I3,7F8.4,1X,72A1)                                     PERTR489
C                                                                      PERTR490
C.....ABNORMAL TERMINATION FORMATS FOLLOW.                             PERTR491
C                                                                      PERTR492
 9000 FORMAT (///1X,28HNUMBER OF CRITICAL POINTS IN/                   PERTR493
    %           1X,30HBASE AND CALIBRATION SOLUTIONS/                  PERTR494
    %           1X,31HARE UNEQUAL - CALCULATION ENDED)                 PERTR495
 9050 FORMAT (///1X,25HNUMBER OF CRITICAL POINTS/                      PERTR496
    %           1X,23HSELECTED EXCEEDS NUMBER/                         PERTR497
    %           1X,30HACTUALLY LOCATED - CALCULATION/                  PERTR498
    %           1X,5HENDED)                                            PERTR499
 9100 FORMAT (///1X,28HORDER OF SPECIFIED POINTS IN/                   PERTR500
    %           1X,30HBASE AND CALIBRATION SOLUTIONS/                  PERTR501
    %           1X,39HDOES NOT CORRESPOND - CALCULATION ENDED)         PERTR502
 9500 FORMAT (1H1)                                                     PERTR503
      END                                                              PERTR504
      SUBROUTINE COPY12 (N,XIN,XOUT)                                   COPY12 2
C                                                                      COPY12 3
C.....COPIES ELEMENTS OF VECTOR XIN (LEVEL 1) TO VECTOR XOUT (LEVEL 2). COPY12 4
C                                                                      COPY12 5
      DIMENSION XIN(200),XOUT(200)                                     COPY12 6
      LEVEL 2, XOUT                                                    COPY12 7
      DO 10 I=1,N                                                      COPY12 8
   10 XOUT(I)=XIN(I)                                                   COPY12 9
      RETURN                                                           COPY1210
      END                                                              COPY1211
      SUBROUTINE COPY21 (N,XIN,XOUT)                                   COPY21 2
C                                                                      COPY21 3
C.....COPIES ELEMENTS OF VECTOR XIN (LEVEL 2) TO VECTOR XOUT (LEVEL 1). COPY21 4
C                                                                      COPY21 5
      DIMENSION XIN(200),XOUT(200)                                     COPY21 6
      LEVEL 2, XIN                                                     COPY21 7
      DO 10 I=1,N                                                      COPY21 8
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   10 XOUT(I)=XIN(I)                                                   COPY21 9
      RETURN                                                           COPY2110
      END                                                              COPY2111
      SUBROUTINE COPYVA (ICALL,N,K,VECTOR,ARRAY)                       COPYVA 2
C                                                                      COPYVA 3
C.....COPIES ELEMENTS OF VECTOR INTO KTH ROW OF ARRAY.                  COPYVA 4
C                                                                      COPYVA 5
      DIMENSION VECTOR(200),ARRAY(10,200)                              COPYVA 6
      LEVEL 2, VECTOR,ARRAY                                            COPYVA 7
      IF (ICALL .EQ. 2) GO TO 20                                       COPYVA 8
      DO 10 I=1,N                                                      COPYVA 9
   10 ARRAY(K,I)=VECTOR(I)                                             COPYVA10
      RETURN                                                           COPYVA11
   20 CONTINUE                                                         COPYVA12
      DO 30 I=1,N                                                      COPYVA13
   30 VECTOR(I)=ARRAY(K,I)                                             COPYVA14
      RETURN                                                           COPYVA15
      END                                                              COPYVA16
      SUBROUTINE DRVPLT (N,NPARAM,YMIN,YMAX,YCR2)                      DRVPLT 2
      DIMENSION HLINE3(3),XPLOT(200),YPLOT(200)                        DRVPLT 3
      COMMON /HEAD/ ZTITLE(8),JOBKEY                                   DRVPLT 4
      COMMON /SAVE/ XCSAVE(10,200),YCSAVE(10,200)                      DRVPLT 5
      COMMON /XY/ XBASE(200),XCALB(200),XPERT(200),XAERO(200),         DRVPLT 6
     % XUNIT(200),YBASE(200),YCALB(200),YPERT(200),YAERO(200),         DRVPLT 7
     % YINTP(200),YPRTI(200),DUMMY(200)                                DRVPLT 8
      LEVEL 2, XCSAVE,YCSAVE                                           DRVPLT 9
      LEVEL 2, XBASE,XCALB,XPERT,XAERO,XUNIT,YBASE,YCALB,YPERT,YAERO,  DRVPLT10
     % YINTP,YPRTI,DUMMY                                               DRVPLT11
      DATA NPLOT /0/                                                   DRVPLT12
      IF (NPLOT .EQ. 0) CALL BETA                                      DRVPLT13
      MIN=10.0*(YMIN-0.1)                                              DRVPLT14
      MAX=10.0*(YMAX+0.1)                                              DRVPLT15
      YMIN=0.1*MIN                                                     DRVPLT16
      YMAX=0.1*MAX                                                     DRVPLT17
      DO 20 K=1,NPARAM                                                 DRVPLT18
      NPLOT=NPLOT-1                                                    DRVPLT19
      ENCODE (22,1010,HLINE3) K,NPARAM                                 DRVPLT20
      CALL BGNPL (-1)                                                  DRVPLT21
      CALL MIXALF ("L/CST")                                            DRVPLT22
      CALL MX3ALF ("INSTR","%")                                        DRVPLT23
      CALL SIMPLX                                                      DRVPLT24
      CALL TITLE (1H ,1,1HX,1,"%E0.5)C%EX(P)$",100,6.0,8.0)            DRVPLT25
      CALL HEADIN ("PLOT (OF) C%L0.25H0.7(P)$",100,3,3)                DRVPLT26
      CALL HEADIN (JOBKEY,9,2,3)                                       DRVPLT27
      CALL HEADIN (HLINE3,22,2,3)                                      DRVPLT28
      CALL GRAF (0.0,"SCALE",1.0,YMAX,"SCALE",YMIN)                    DRVPLT29
      CALL FRAME                                                       DRVPLT30
      IF (YCR2 .GT. YMAX) GO TO 10                                     DRVPLT31
      CALL RLVEC (0.0,YCR2,0.2,YCR2,0000)                              DRVPLT32
      CALL RLMESS ("C%L(P%BE(*)$",100,0.21,YCR2)                       DRVPLT33
   10 CONTINUE                                                         DRVPLT34
      CALL DASH                                                        DRVPLT35
      CALL COPY21 (N,XBASE,XPLOT)                                      DRVPLT36
      CALL COPY21 (N,YBASE,YPLOT)                                      DRVPLT37
      CALL CURVE (XPLOT,YPLOT,N,0)                                     DRVPLT38
      CALL RESET ("DASH")                                              DRVPLT39
      CALL DOT                                                         DRVPLT40
      CALL COPYVA (2,N,K,XCALB,XCSAVE)                                 DRVPLT41
      CALL COPYVA (2,N,K,YCALB,YCSAVE)                                 DRVPLT42
      CALL COPY21 (N,XCALB,XPLOT)                                      DRVPLT43
      CALL COPY21 (N,YCALB,YPLOT)
      CALL CURVE (XPLOT,YPLOT,N,0)
      CALL RESET ("DOT")
      CALL MARKER (1)
      CALL COPY21 (N,XPERT,XPLOT)
      CALL COPY21 (N,YPERT,YPLOT)
      CALL CURVE (XPLOT,YPLOT,N,-1)
      CALL RESET ("MARKER")
      CALL COPY21 (N,XAERO,XPLOT)
      CALL COPY21 (N,YAERO,YPLOT)
      CALL CURVE (XPLOT,YPLOT,N,0)
      CALL ENDPL (NPLOT)
   20 CONTINUE
 1010 FORMAT (16HCALIBRATION NO. ,I1,4H OF ,I1)
      RETURN
      END
      SUBROUTINE FILL (ICALL,I,STRING)
C
C.....FILLS ARRAY STRING WITH CHARACTERS FOR TABLE HEADINGS AND PRINTER
C     PLOTS.
C
      DIMENSION STRING(100),UNIT(20)
      COMMON /PARAM/ PARNAM(10),LSELCT(6),LUNIT,LPLOT,NSELCT,A,B,VNAM(2)
      COMMON /MINMAX/ YMIN,YMAX,YCR2
      COMMON /XY/ XBASE(200),XCALB(200),XPERT(200),XAERO(200),
     % XUNIT(200),YBASE(200),YCALB(200),YPERT(200),YAERO(200),
     % YINTP(200),YPRTI(200),DUMMY(200)
      LEVEL 2, XBASE,XCALB,XPERT,XAERO,XUNIT,YBASE,YCALB,YPERT,YAERO,
     % YINTP,YPRTI,DUMMY
      DATA IENT /0/
      DATA STAR/1H*/, P/1HP/, AA/1HA/, DASH/1H-/, H/1HH/, EL/1HL/,
     %     BLANK/1H /, DOLLAR/1H$/
      DATA UNIT /1HX,1HS,1HT,1HR,1HU,1HN,1HI,1HT,1H ,1H ,
     %           1H ,1H ,1H ,1HU,1HN,1HI,1HT,1H ,1H ,1H /
      GO TO (10,30,50), ICALL
   10 IENT=IENT+1
      IF (IENT .GT. 1) RETURN
      UNIT(12)=VNAM(1)
      UNIT(13)=VNAM(2)
      DO 20 J=1,20
      DO 20  K=1,5
      II=J+20*(K-1)
   20 STRING(II)=UNIT(J)
      RETURN
   30 RANGE=YMAX-YMIN
      IFLAG=0
      IF (YCR2.GT.YMAX .OR. YCR2.LT.YMIN) IFLAG=1
      DO 40 II=1,72
   40 STRING(II)=DASH
      STRING(1)=H
      STRING(72)=EL
      IF (IFLAG.EQ.1) RETURN
      NSTAR=1+(YMAX-YCR2)/RANGE*71
      STRING(NSTAR)=STAR
      RETURN
   50 CONTINUE
      DO 60 II=1,72
   60 STRING(II)=BLANK
      IF (IFLAG.EQ.0) STRING(NSTAR)=STAR
      YP=YPRTI(I)
      NPERT=1+(YMAX-YP)/RANGE*71
      STRING(NPERT)=P
      YC=YAERO(I)
      NCHEK=1+(YMAX-YC)/RANGE*71
      STRING(NCHEK)=AA
      IF (NPERT .EQ. NCHEK) STRING(NPERT)=DOLLAR
      RETURN
      END
      SUBROUTINE INPUT (NPARAM)
C
C     INPUT FOR SUBROUTINE PERTURB IS REQUIRED IN THE FOLLOWING FORM.
C     FOR DETAILS SEE ACCOMPANYING MANUAL.
C
C**** ITEM NO. 1 - ONE CARD (8A10) *************************************
C
C          TITLE      IDENTIFIES JOB - PRINTED AS HEADLINE ON FIRST PAGE
C                     OF OUTPUT. FIRST NINE CHARACTERS ARE USED TO
C                     IDENTIFY PERIPHERAL PLOT.
C
C**** ITEM NO. 2 - ONE CARD (16I5) *************************************
C
C          NSELCT     NUMBER OF POINTS (IN ADDITION TO END POINTS) TO BE
C                     HELD INVARIANT IN STRAINING.
C                           NOTE: 1 .LE. NSELCT .LE. 6.
C
C          LUNIT      CONTROLS WHETHER OR NOT UNIT COORDINATE STRAINING(S)
C                     AND UNIT PERTURBATION(S) ARE PRINTED.
C
C                     LUNIT = 0 ... NO OUTPUT
C                     LUNIT = 1 ... OUTPUT
C
C          LPLOT      SPECIFIES WHETHER OR NOT AN ADDITIONAL PLOT BY A
C                     PERIPHERAL DEVICE IS TO BE MADE (SOFTWARE MUST BE
C                     SUPPLIED BY USER IN SUBROUTINE DRVPLT).
C
C                     LPLOT = 0 ... NO PERIPHERAL PLOT
C                     LPLOT = 1 ... PERIPHERAL PLOT
C
C**** ITEM NO. 3 - ONE CARD (16I5) *************************************
C
C          LSELCT(I) ...
C                     ARRAY OF LENGTH 6 OF WHICH NSELCT ELEMENTS ARE READ
C                     IN. SPECIFIES NATURE OF POINTS TO BE HELD INVARIANT
C                     ACCORDING TO THE CODE
C
C                             1 ... MINIMUM PT. HELD INVARIANT
C                             2 ... MAXIMUM PT. HELD INVARIANT
C                             3 ... 1ST CRITICAL PT. HELD INVARIANT
C                             4 ... 2ND CRITICAL PT. HELD INVARIANT
C                             5 ... 3RD CRITICAL PT. HELD INVARIANT
C                             6 ... 4TH CRITICAL PT. HELD INVARIANT
C
C                     NOTE THAT THE CODE NUMBERS CAN BE ASSIGNED IN ANY
C                     ORDER, E.G.
C
C                                       LSELCT(1) = 1
C                                       LSELCT(2) = 3
C                                       LSELCT(3) = 4
C
C                     IS EQUIVALENT TO
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C                                                                       INPUT 54
C                                     LSELCT(1) = 4                     INPUT 55
C                                     LSELCT(2) = 1                     INPUT 56
C                                     LSELCT(3) = 3                     INPUT 57
C                                                                       INPUT 58
C                   BOTH CORRESPONDING TO NSELCT = 3 WITH THE MINIMUM,  INPUT 59
C                   AND FIRST AND SECOND CRITICAL POINTS HELD INVARIANT.INPUT 60
C                                                                       INPUT 61
C**** ITEM NO. 4 - ONE CARD (2A1) **************************************INPUT 62
C                                                                       INPUT 63
C         VNAM      CHARACTER STRING OF LENGTH 2 WHICH SYMBOLIZES       INPUT 64
C                   DEPENDENT VARIABLE, E.G. "CP" FOR PRESSURE          INPUT 65
C                   COEFFICIENT.                                        INPUT 66
C                                                                       INPUT 67
C**** ITEM NO. 5 - ONE CARD (10A8) *************************************INPUT 68
C                                                                       INPUT 69
C         PARNAM(K) ...                                                 INPUT 70
C                   ARRAY OF 8-CHARACTER STRINGS WHICH IDENTIFY THE     INPUT 71
C                   PARAMETERS VARIED. NPARAM ELEMENTS OF THE ARRAY     INPUT 72
C                   ARE READ IN.                                        INPUT 73
C                                                                       INPUT 74
C**** ITEM NO. 6 - ONE CARD (8F10.6) ***********************************INPUT 75
C                                                                       INPUT 76
C         A         SCALING PARAMETER (A = -X(1), WHERE X(1) IS FIRST   INPUT 77
C                   DATA POINT ON LOWER SURFACE ... SEE MANUAL).        INPUT 78
C                                                                       INPUT 79
C         B         SCALING PARAMETER (B = X(N), WHERE X(N) IS LAST DATAINPUT 80
C                   POINT ON UPPER SURFACE ... SEE MANUAL).             INPUT 81
C                                                                       INPUT 82
C***********************************************************************INPUT 83
C                                                                       INPUT 84
      COMMON /HEAD/ TITLE(8),JOBKEY                                     INPUT 85
      COMMON /PARAM/ PARNAM(10),LSELCT(6),LUNIT,LPLOT,NSELCT,A,B,VNAM(2)INPUT 86
      READ (5,900) TITLE                                                INPUT 87
      DECODE (9,950,TITLE(1)) JOBKEY                                    INPUT 88
      READ (5,1000) NSELCT,LUNIT,LPLOT                                  INPUT 89
      READ (5,1000) (LSELCT(I),I=1,NSELCT)                              INPUT 90
      READ (5,1010) VNAM                                                INPUT 91
      READ (5,1020) (PARNAM(I),I=1,NPARAM)                              INPUT 92
      READ (5,1030) A,B                                                 INPUT 93
      RETURN                                                            INPUT 94
  900 FORMAT (8A10)                                                     INPUT 95
  950 FORMAT (A9)                                                       INPUT 96
 1000 FORMAT (16I5)                                                     INPUT 97
 1010 FORMAT (2A1)                                                      INPUT 98
 1020 FORMAT (10A8)                                                     INPUT 99
 1030 FORMAT (8F10.6)                                                   INPUT100
      END                                                               INPUT101
      SUBROUTINE INTERP (N,X,Y,XI,YI)                                   INTERP 2
C                                                                       INTERP 3
C.....GIVEN THE SET OF POINTS X(I), Y(I), I=1,N, AND THE SET XI(J),     INTERP 4
C     J=1,N, USES LINEAR INTERPOLATION TO COMPUTE THE SET YI(J), J=1,N. INTERP 5
C                                                                       INTERP 6
      DIMENSION X(200),Y(200),XI(200),YI(200)                           INTERP 7
      LEVEL 2, X,Y,XI,YI                                                INTERP 8
      NM1=N-1                                                           INTERP 9
      JSTART=1                                                          INTERP10
      DO 70 I=1,N                                                       INTERP11
      IF (XI(I) .LE. X(1)) GO TO 10                                     INTERP12
      IF (XI(I) .GE. X(N)) GO TO 20                                     INTERP13
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      GO TO 30                                                          INTERP14
   10 J=1                                                               INTERP15
      GO TO 60                                                          INTERP16
   20 J=N-1                                                             INTERP17
      GO TO 60                                                          INTERP18
   30 CONTINUE                                                          INTERP19
      DO 50 J=JSTART,NM1                                                INTERP20
      IF (XI(I) .NE. X(J)) GO TO 40                                     INTERP21
      YI(I)=Y(J)                                                        INTERP22
      GO TO 70                                                          INTERP23
   40 IF (XI(I) .GT. X(J) .AND. XI(I) .LT. X(J+1)) GO TO 60             INTERP24
   50 CONTINUE                                                          INTERP25
   60 SLOPE=(Y(J+1)-Y(J))/(X(J+1)-X(J))                                 INTERP26
      YI(I)=Y(J)+SLOPE*(XI(I)-X(J))                                     INTERP27
      JSTART=J                                                          INTERP28
   70 CONTINUE                                                          INTERP29
      RETURN                                                            INTERP30
      END                                                               INTERP31
      SUBROUTINE LOCATE (N,X,Y,YCRIT,IGRAD,LMIN,LMAX,NCRIT,LCRIT,XLOC)  LOCATE 2
C                                                                       LOCATE 3
C.....OPERATES ON THE INPUT ARRAY Y, LOCATING MINIMUM AND MAXIMUM       LOCATE 4
C     VALUES, AND ALL CRITICAL POINTS (Y=YCRIT) FOR WHICH DY/DX (IN     LOCATE 5
C     PHYSICAL COORDINATES) HAS ALGEBRAIC SIGN GIVEN BY IGRAD. NCRIT    LOCATE 6
C     IS NUMBER OF CRITICAL POINTS. POINTS FOUND ARE STORED IN THE ARRAYLOCATE 7
C     XLOC AS FOLLOWS                                                   LOCATE 8
C                                                                       LOCATE 9
C                          XLOC(1) = MINIMUM PT.                        LOCATE10
C                          XLOC(2) = MAXIMUM PT.                        LOCATE11
C                          XLOC(3) = CRITICAL PT. NO. 1                 LOCATE12
C                          ...     = ...                                LOCATE13
C                          XLOC(6) = CRITICAL PT. NO. 4                 LOCATE14
C                                                                       LOCATE15
      DIMENSION X(200),Y(200),LCRIT(4),XCRIT(4),XLOC(6)                 LOCATE16
      LEVEL 2, X,Y                                                      LOCATE17
      COMMON /FLOREV/ IREV                                              LOCATE18
      IFLOW=-1                                                          LOCATE19
      LMIN=1                                                            LOCATE20
      LMAX=1                                                            LOCATE21
      ISTART=2                                                          LOCATE22
      IF (IREV .EQ. 0) GO TO 10                                         LOCATE23
      LMIN=2                                                            LOCATE24
      LMAX=2                                                            LOCATE25
      ISTART=3                                                          LOCATE26
   10 CONTINUE                                                          LOCATE27
      NCRIT=0                                                           LOCATE28
      DO 30 I=ISTART,N                                                  LOCATE29
      IF (IREV .NE. 0 .AND. I .EQ. N) GO TO 20                          LOCATE30
      IF (Y(I) .GT. Y(LMAX)) LMAX=I                                     LOCATE31
      IF (Y(I) .LT. Y(LMIN)) LMIN=I                                     LOCATE32
   20 CONTINUE                                                          LOCATE33
      IF ((Y(I) .GT. YCRIT .AND. Y(I-1) .GT. YCRIT) .OR.                LOCATE34
     %    (Y(I) .LT. YCRIT .AND. Y(I-1) .LT. YCRIT)) GO TO 30           LOCATE35
      IF (I .GT. IREV) IFLOW=1                                          LOCATE36
      IF ((Y(I)-Y(I-1))*FLOAT(IFLOW*IGRAD) .LT. 0.0) GO TO 30           LOCATE37
      NCRIT=NCRIT+1                                                     LOCATE38
      LCRIT(NCRIT)=I-1                                                  LOCATE39
      SLOPE=(X(I)-X(I-1))/(Y(I)-Y(I-1))                                 LOCATE40
      XCRIT(NCRIT)=X(I-1)+SLOPE*(YCRIT-Y(I-1))                          LOCATE41
   30 CONTINUE                                                          LOCATE42
      XLOC(1)=X(LMIN)                                                   LOCATE43
      XLOC(2)=X(LMAX)                                                   LOCATE44
      IF (NCRIT .EQ. 0) RETURN                                          LOCATE45
      DO 40 I=1,NCRIT                                                   LOCATE46
   40 XLOC(I+2)=XCRIT(I)                                                LOCATE47
      RETURN                                                            LOCATE48
      END                                                               LOCATE49
      SUBROUTINE MONO (N,L,X,Y)                                         MONO   2
C                                                                       MONO   3
C.....CHECKS POINTS IN VICINITY OF A CRITICAL POINT FOR MONOTONE        MONO   4
C     BEHAVIOR, AND ADJUSTS VALUES IF NECESSARY TO GIVE A LINEAR        MONO   5
C     PROFILE.                                                          MONO   6
C                                                                       MONO   7
      DIMENSION L(4),X(200),Y(200)                                      MONO   8
      LEVEL 2, X,Y                                                      MONO   9
      DO 10 I=1,N                                                       MONO  10
      LS=L(I)                                                           MONO  11
      Y1=Y(LS-1)                                                        MONO  12
      Y2=Y(LS)                                                          MONO  13
      Y3=Y(LS+1)                                                        MONO  14
      Y4=Y(LS+2)                                                        MONO  15
      IF ((Y1 .LT. Y2) .AND. (Y2 .LT. Y3) .AND. (Y3 .LT. Y4)) GO TO 10  MONO  16
      IF ((Y1 .GT. Y2) .AND. (Y2 .GT. Y3) .AND. (Y3 .GT. Y4)) GO TO 10  MONO  17
      X1=X(LS-1)                                                        MONO  18
      X2=X(LS)                                                          MONO  19
      X3=X(LS+1)                                                        MONO  20
      X4=X(LS+2)                                                        MONO  21
      SLOPE=(Y4-Y1)/(X4-X1)                                             MONO  22
      Y(LS)=Y1+SLOPE*(X2-X1)                                            MONO  23
      Y(LS+1)=Y1+SLOPE*(X3-X1)                                          MONO  24
   10 CONTINUE                                                          MONO  25
      RETURN                                                            MONO  26
      END                                                               MONO  27
      SUBROUTINE SCALE (N,X,M,A,B)                                      SCALE  2
C                                                                       SCALE  3
C.....ENTRY WITH M = 1 CONVERTS FROM PHYSICAL X (0 TO -A ON LOWER       SCALE  4
C     SURFACE, 0 TO B ON UPPER SURFACE) TO NORMALIZED X (0 .LT. X .LT.  SCALE  5
C     1) ENTRY WITH M=2 REVERSES THE PROCESS. NZ (DETERMINED WHEN M=1)  SCALE  6
C     CORRESPONDS TO POINT AT NOSE OF BLADE OR AIRFOIL.                 SCALE  7
C                                                                       SCALE  8
      COMMON /FLOREV/ NZ                                                SCALE  9
      DIMENSION X(200)                                                  SCALE 10
      LEVEL 2, X                                                        SCALE 11
      IF (M .EQ. 2) GO TO 30                                            SCALE 12
      CONTINUE                                                          SCALE 13
      NZ=0                                                              SCALE 14
      DO 10 I=2,N                                                       SCALE 15
      IF (X(I) .LT. X(I-1)) NZ=I                                        SCALE 16
   10 CONTINUE                                                          SCALE 17
      DO 20 I=1,N                                                       SCALE 18
      IF (I .LE. NZ) T=-X(I)                                            SCALE 19
      IF (I .GT. NZ) T=X(I)                                             SCALE 20
      X(I)=(T-A)/(B-A)                                                  SCALE 21
   20 CONTINUE                                                          SCALE 22
      RETURN                                                            SCALE 23
   30 DO 40 I=1,N                                                       SCALE 24
      X(I)=ABS((B-A)*X(I)+A)                                            SCALE 25
   40 CONTINUE                                                          SCALE 26
      RETURN                                                            SCALE 27
      END                                                               SCALE 28
      SUBROUTINE SORT (N,X,ISEQ)                                        SORT   2
C                                                                       SORT   3
C.....ARRANGES THE SET X(1), X(2), ... , X(N) IN A MONOTONE INCREASING  SORT   4
C     SEQUENCE. ISEQ GIVES ORDER OF SUBSCRIPTS IN REARRANGED SEQUENCE.  SORT   5
C                                                                       SORT   6
      DIMENSION X(8),ISEQ(8)                                            SORT   7
      NM1=N-1                                                           SORT   8
      DO 10 I=1,N                                                       SORT   9
   10 ISEQ(I)=I                                                         SORT  10
   20 ITEST=0                                                           SORT  11
      DO 30 I=1,NM1                                                     SORT  12
      IF (X(I) .LE. X(I+1)) GO TO 30                                    SORT  13
      XSAVE=X(I)                                                        SORT  14
      X(I)=X(I+1)                                                       SORT  15
      X(I+1)=XSAVE                                                      SORT  16
      ISAVE=ISEQ(I)                                                     SORT  17
      ISEQ(I)=ISEQ(I+1)                                                 SORT  18
      ISEQ(I+1)=ISAVE                                                   SORT  19
      ITEST=1                                                           SORT  20
   30 CONTINUE                                                          SORT  21
      IF (ITEST .EQ. 1) GO TO 20                                        SORT  22
      RETURN                                                            SORT  23
      END                                                               SORT  24
      SUBROUTINE STRAIN (N,K,NSEG,XFIX,XIN,PARM)                        STRAIN 2
C                                                                       STRAIN 3
C.....COMPUTES STRAINING INCREMENT DELX FROM INPUT ARRAY XIN, USING     STRAIN 4
C     PIECEWISE LINEAR STRAINING WITH NSEG LINEAR SEGMENTS. FOR UNIT    STRAIN 5
C     STRAINING, INPUT VALUE OF PARM IS 1.0; FOR GENERAL CASE,          STRAIN 6
C                                                                       STRAIN 7
C                        PARM ■ (Q2(K)-Q0(K))/(Q1-Q0(K)).               STRAIN 8
C                                                                       STRAIN 9
      DIMENSION XFIX(8),XIN(200)                                        STRAIN10
      COMMON /COEFF/ C(10,7),D(10,7),DELX(200)                          STRAIN11
      LEVEL 2, C,D,DELX,XIN                                             STRAIN12
      JSTART=1                                                          STRAIN13
      DO 30 I=1,N                                                       STRAIN14
      DO 10 J=JSTART,NSEG                                               STRAIN15
      IF (XIN(I) .GE. XFIX(J) .AND. XIN(I) .LE. XFIX(J+1)) GO TO 20     STRAIN16
   10 CONTINUE                                                          STRAIN17
   20 DELX(I)=PARM*(C(K,J)+(D(K,J)-1.0)*XIN(I))                         STRAIN18
      JSTART=J                                                          STRAIN19
   30 CONTINUE                                                          STRAIN20
      RETURN                                                            STRAIN21
      END                                                               STRAIN22
      SUBROUTINE UPLOW (A,B,XIN,K,N,XOUT,FLAG)                          UPLOW  2
C                                                                       UPLOW  3
C.....CONVERTS NORMALIZED ARRAY XIN TO PHYSICAL ARRAY XOUT AND FLAGS    UPLOW  4
C     POINTS ON LOWER SURFACE WITH A "*".                               UPLOW  5
C                                                                       UPLOW  6
      DIMENSION XIN(K),XOUT(8)                                          UPLOW  7
      DIMENSION FLAG(8)                                                 UPLOW  8
      DATA BLANK/1H /, STAR/1H*/                                        UPLOW  9
      XNOSE=-A/(B-A)                                                    UPLOW 10
      DO 10 I=1,N                                                       UPLOW 11
      FLAG(I)=BLANK                                                     UPLOW 12
      IF (XIN(I) .LT. XNOSE) FLAG(I)=STAR                               UPLOW 13
      XOUT(I)=ABS((B-A)*XIN(I)+A)                                       UPLOW 14
   10 CONTINUE                                                          UPLOW 15
      RETURN                                                            UPLOW 16
      END                                                               UPLOW 17
      SUBROUTINE TSONIC                                                 TSONIC 2
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)                        TSONIC 3
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,      TSONIC 4
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MPO,MM,     TSONIC 5
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,    TSONIC 6
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),      TSONIC 7
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),        TSONIC 8
     5   PLOSS(50),MSP(50,2),THSP(50,2)                                 TSONIC 9
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1, TSONIC10
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,   TSONIC11
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),     TSONIC12
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),        TSONIC13
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),   TSONIC14
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),            TSONIC15
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),   TSONIC16
     7   BEH(100,2),PLOSMH(100,2)                                       TSONIC17
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)               TSONIC18
      LEVEL 2,  A,U,K,RHO                                               TSONIC19
      COMMON /HRBAAK/ H(4),R(4),B(4),KAK(4),KA(4),RZ,BZ,IH(4)           TSONIC20
      COMMON /VARCOM/ RHOHB(100,2),RHOVB(100,2),WMB(100,2),WTB(100,2),  TSONIC21
     1   WWCRM(100,2),LABEL(1,100)                                      TSONIC22
      COMMON /SLCOM/ USL(100,11),TSL(100,11)                            TSONIC23
      LEVEL 2,  USL,TSL                                                 TSONIC24
      COMMON /BCDCOM/ INIT(2),EM(50,2),D2TDM2(100,2)                    TSONIC25
      COMMON /PLTCOM/ TSLPT(1100),XDOWN(400),YACROS(400)                TSONIC26
      LEVEL 2,  TSLPT,XDOWN,YACROS                                      TSONIC27
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,    TSONIC28
     1   UPPER,S1,ST                                                    TSONIC29
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1                 TSONIC30
      DATA ICALL/0/                                                     TSONIC31
      ICALL=ICALL+1                                                     TSONIC32
      IEND=-1                                                           TSONIC33
      ITER = 0                                                          TSONIC34
      INIT(1) = 0                                                       TSONIC35
      INIT(2) = 0                                                       TSONIC36
      CALL TINPUT                                                       TSONIC37
      IF(ICALL.EQ.1) RETURN                                             TSONIC38
      IF (BLDAT.GE.2) CALL BLDPLT                                       TSONIC39
      CALL PRECAL                                                       TSONIC40
   30 ITER = ITER+1                                                     TSONIC41
      CALL COEF                                                         TSONIC42
      CALL SOR                                                          TSONIC43
      CALL VELMER                                                       TSONIC44
      CALL VELTAN                                                       TSONIC45
      CALL STRLIN                                                       TSONIC46
      CALL OUTPUT                                                       TSONIC47
      IF(NER(2).GT.0) RETURN                                            TSONIC48
      IF(IEND.LE.0) GO TO 30                                            TSONIC49
      IF(REDFAC.LT.1.) CALL TVELCY                                      TSONIC50
      RETURN                                                            TSONIC51
      END                                                               TSONIC52
      SUBROUTINE TINPUT                                                 INPUU  2
C                                                                       INPUU  3
C  INPUT READS AND PRINTS ALL INPUT DATA CARDS AND CALCULATES HORIZONTALINPUU  4
C  SPACING (MV ARRAY)                                                   INPUU  5
C                                                                       INPUU  6
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)                        INPUU  7
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,      INPUU  8
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,     INPUU  9
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,    INPUU 10
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),      INPUU 11
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     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),        INPUU 12
     5   PLOSS(50),MSP(50,2),THSP(50,2)                                 INPUU 13
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1, INPUU 14
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,   INPUU 15
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),     INPUU 16
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),        INPUU 17
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),   INPUU 18
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),            INPUU 19
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),   INPUU 20
     7   BEH(100,2),PLOSMH(100,2)                                       INPUU 21
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)               INPUU 22
      LEVEL 2,  A,U,K,RHO                                               INPUU 23
      COMMON /MBIMBO/ MBIZ,MBOZ                                         INPUU 24
      COMMON /MVNORM/ XMVN(100)                                         INPUU 25
      DIMENSION SPLNO(2),CARD(8)                                        INPUU 26
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,    INPUU 27
     1   UPPER,S1,ST                                                    INPUU 28
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1                 INPUU 29
      DATA ICALL/0/, END/10H$END      /                                 INPUU 30
C                                                                       INPUU 31
C  READ AND PRINT ALL INPUT DATA                                        INPUU 32
C                                                                       INPUU 33
      NREAD = 1                                                         INPUU 34
      NWRIT = 6                                                         INPUU 35
      ICALL=ICALL+1                                                     INPUU 36
      IF (ICALL.GT.1) GO TO 2                                           INPUU 37
    1 READ (5,990) CARD                                                 INPUU 38
      IF (CARD(1).EQ.END) GO TO 2                                       INPUU 39
      WRITE(1,990) CARD                                                 INPUU 40
      GO TO 1                                                           INPUU 41
    2 REWIND 1                                                          INPUU 42
      WRITE(NWRIT,1000)                                                 INPUU 43
      WRITE(NWRIT,1110)                                                 INPUU 44
      READ (NREAD,1030) GAM,AR,TIP,RHOIP,WTFL,BLANK,OMEGA,ORF           INPUU 45
      WRITE(NWRIT,1040) GAM,AR,TIP,RHOIP,WTFL,BLANK,OMEGA,ORF           INPUU 46
      READ (NREAD,1030) BETAI,BETAO,BLANK,BLANK,FSMI,FSMO               INPUU 47
      READ (NREAD,1030) REDFAC,DENTOL,SSM1,SSM2                         INPUU 48
      IF (DENTOL.LE.0.) DENTOL = .01                                    INPUU 49
C -- MOPT = 0, NO CORRECTION TO THE BESP ARRAY (REDFAC MUST EQUAL 1.0)  INPUU 50
C     MOPT = 1, READ IN WOWCR ARRAY FOR CALCULATING REDUCED FLOW BESP   INPUU 51
C     MOPT = 2, REDUCED BESP ARRAY CALCULATED BY PROGRAM.               INPUU 52
      READ (NREAD,1010) MBI,MBO,BLANK,BLANK,MM,NBBI,NBL,NRSP,MOPT,LOPT, INPUU 53
     1   LRVB                                                           INPUU 54
      MBIZ=MBI                                                          INPUU 55
      MBOZ=MBO                                                          INPUU 56
      IF (LRVB.EQ.1) GO TO 6                                            INPUU 57
      WRITE(NWRIT,1120)                                                 INPUU 58
      WRITE(NWRIT,1040)BETAI,BETAO,CHORD(1),STGR(1),FSMI,FSMO           INPUU 59
      GO TO 8                                                           INPUU 60
    6 WRITE(NWRIT,1122)                                                 INPUU 61
      LAMBDA = BETAI                                                    INPUU 62
      RVTHO  = BETAO                                                    INPUU 63
      WRITE(NWRIT,1040) LAMBDA,RVTHO,CHORD(1),STGR(1)                   INPUU 64
    8 WRITE(NWRIT,1125)                                                 INPUU 65
      WRITE(NWRIT,1040) REDFAC,DENTOL,SSM1,SSM2                         INPUU 66
      WRITE(NWRIT,1130)                                                 INPUU 67
      WRITE(NWRIT,1020) MBI,MBO,BLANK,BLANK,MM,NBBI,NBL,NRSP,MOPT,LOPT, INPUU 68
     1   LRVB                                                           INPUU 69
      DO 10 J=1,2                                                       INPUU 70
      IF (J.EQ.1) WRITE(NWRIT,1140)                                     INPUU 71
      IF (J.EQ.2) WRITE(NWRIT,1150)
      WRITE(NWRIT,1180) J,J,J,J,J
      READ (NREAD,1030) BLANK,BLANK,BLANK,BLANK,SPLNO(J)
      WRITE(NWRIT,1040) RI(J),RO(J),BETI(J),BETO(J),SPLNO(J)
      NSPI(J) = SPLNO(J)
      NSP = NSPI(J)
      WRITE(NWRIT,1190) J
      WRITE(NWRIT,1040) (MSP(I,J),I=1,NSP)
      WRITE(NWRIT,1200) J
   10 WRITE(NWRIT,1040) (THSP(I,J),I=1,NSP)
      WRITE(NWRIT,1210)
      READ (NREAD,1030) (MR(I),I=1,NRSP)
      WRITE(NWRIT,1040) (MR(I),I=1,NRSP)
      WRITE(NWRIT,1220)
      READ (NREAD,1030) (RMSP(I),I=1,NRSP)
      WRITE(NWRIT,1040) (RMSP(I),I=1,NRSP)
      WRITE(NWRIT,1230)
      READ (NREAD,1030) (BESPF(I),I=1,NRSP)
      WRITE(NWRIT,1040) (BESPF(I),I=1,NRSP)
      DO  20  I=1, NRSP
      BESP(I) = BESPF(I)
   20 PLOSS(I) = 0.
      IF (MOPT.NE.1) GO TO 40
      WRITE(NWRIT,1236)
      READ (NREAD,1030) (WOWCR(I),I=1,NRSP)
      WRITE(NWRIT,1040) (WOWCR(I),I=1,NRSP)
   40 IF (LOPT.EQ.0) GO TO 60
      WRITE(NWRIT,1237)
      READ (NREAD,1030) (PLOSS(I),I=1,NRSP)
      WRITE(NWRIT,1040) (PLOSS(I),I=1,NRSP)
   60 WRITE(NWRIT,1240)
      READ (NREAD,1010) BLDAT,AANDK,ERSOR,STRFN,SLCRD,INTVL,SURVL
      WRITE(NWRIT,1020) BLDAT,AANDK,ERSOR,STRFN,SLCRD,INTVL,SURVL
      IF(ICALL.EQ.1) RETURN
      IF (MM.LE.100.AND.NBBI.LE.50.AND.NRSP.LE.50.AND.NSPI(1).LE.50
     1   .AND.NSPI(2).LE.50) GO TO 70
      WRITE(NWRIT,1250)
      STOP
   70 IF (REDFAC.EQ.1..OR.MOPT.NE.0) GO TO 75
      WRITE(NWRIT,1260)
      STOP
C
C  CALCULATE MV ARRAY
C
   75 HM1 = CHORD(1)/FLOAT(MBO-MBI)
      DO 80 IM=1,MM
      MV(IM) = FLOAT(IM-MBI)*HM1
      XMVN(IM)=MV(IM)/CHORD(1)
      IF (SSM1.EQ.SSM2) GO TO 80
      IF (MV(IM).LT.SSM1) IMS1 = IM+1
      IF (MV(IM).LE.SSM2) IMS2 = IM
   80 CONTINUE
      MV(MBO) = CHORD(1)
      XMVN(MBO)=1.0
C
C  CALCULATE MISCELLANEOUS CONSTANTS
C
      NER(1) = 0
      NER(2) = 0
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      NER(1) = 0
      NER(2) = 0
      PITCH = 2.*3.1415927/FLOAT(NBL)
      HT = PITCH/FLOAT(NBBI)
      DTLR = HT/1000.
      DMLR = HM1/1000.
      BV(1) ■ 0.
      BV(2) = 1.
      MBIM1 = MBI-1
      MBIP1 = MBI+1
      MBOM1 = MBO-1
      MBOP1 = MBO+1
      MMM1 = MM-1
      CP = AR/(GAM-1.)*GAM
      EXPON ■ 1./(GAM-1.)
      TWW = 2.*OMEGA/WTFL
      CPTIP = 2.*CP*TIP
      TGROG = 2.*GAM*AR/(GAM+1.)
      CALL SPLINT(MR,RMSP,NRSP,MV,MM,RM,SAL,AAA)
      CALL SPLINT(MR,BESPF,NRSP,MV,MM,BEF,DBFDM,AAA)
      CALL SPLINT(MR,BESP,NRSP,MV,MM,BE,DBDM,AAA)
      CALL SPLINT(MR,PLOSS,NRSP,MV,MM,PLOSIM,BBB,AAA)
C
C  CALCULATE GEOMETRICAL CONSTANTS
C
      CHORD(2) = CHORD(1)
      STGR(2) = STGR(1)
      MLE(1) ■ 0.
      MLE(2) = 0.
      THLE(1) = 0.
      THLE(2) = PITCH
      RMI(1) = RM(MBI)
      RMI(2) = RM(MBI)
      RMO(1) ■ RM(MBO)
      RMO(2) = RM(MBO)
C
C  INITIALIZE U AND K ARRAYS AND SURFACE DENSITY ARRAYS
C
      DO 90 I=1,2500
      U(I) = 1.
      K(I)   = 0.
   90 RHO(I) = RHOIP
C     INITIALIZE A ARRAY

      DO 91 KDUM = 1,4
      DO 91 I = 1,2500
   91 A(I,KDUM) = 0.
      NREAD=5
      RETURN
C
C  FORMAT STATEMENTS
C
  990 FORMAT (8A10)
 1000 FORMAT(1H1,35X,
     *       51H--- INPUT FOR TSONIC BLADE-TO-BLADE FLOW SOLVER ---//)
 1010 FORMAT (16I5)
 1020 FORMAT (1X,16I7)
 1030 FORMAT (8F10.5)
 1040 FORMAT (1X,8G16.7)
 1100 FORMAT (20A4)                                                      INPUU189
 1105 FORMAT (1X,20A4)                                                   INPUU190
 1110 FORMAT (7X,3HGAM,14X,2HAR,13X,3HTIP,12X,5HRHOIP,12X,4HWTFL,11X,6H INPUU191
     1      ,10X,5HOMEGA,12X,3HORF)                                      INPUU192
 1120 FORMAT (6X,5HBETAI,11X,5HBETAO,11X,6HCHORDF,11X,5HSTGRF,12X,4HFSMIINPUU193
     1   ,12X,4HFSMO)                                                    INPUU194
 1122 FORMAT (6X,6HLAMBDA,10X,5HRVTHO,11X,6HCHORDF,10X,5HSTGRF)          INPUU195
 1125 FORMAT (6X,6HREDFAC,10X,6HDENTOL,11X,4HSSM1,12X,4HSSM2)            INPUU196
 1130 FORMAT(1H0,3X,3HMBI,4X,3HMBO,19X,2HMM,3X,4HNBBI,4X,                INPUU197
     *      3HNBL,3X,4HNRSP,3X,4HMOPT,3X,4HLOPT,3X,4HLRVB)               INPUU198
 1140 FORMAT(39H0    BLADE SURFACE 1  --  UPPER SURFACE)                 INPUU199
 1150 FORMAT(39H0    BLADE SURFACE 2  --  LOWER SURFACE)                 INPUU200
 1180 FORMAT (7X,2HRI,I1,12X,2HRO,I1,12X,4HBETI,I1,11X,4HBETO,I1,11X,5HSINPUU201
     1PLNO,I1)                                                           INPUU202
 1190 FORMAT (7X,3HMSP,I1,2X,5HARRAY)                                    INPUU203
 1200 FORMAT (7X,4HTHSP,I1,2X,5HARRAY)                                   INPUU204
 1210 FORMAT(16H0       MR  ARRAY)                                       INPUU205
 1220 FORMAT (7X,11HRMSP  ARRAY)                                         INPUU206
 1230 FORMAT (7X,11HBESP  ARRAY)                                         INPUU207
 1235 FORMAT (7X,11HBESPF ARRAY)                                         INPUU208
 1236 FORMAT (7X,11HWOWCR ARRAY)                                         INPUU209
 1237 FORMAT (7X,11HPLOSS ARRAY)                                         INPUU210
 1240 FORMAT(52H0    BLDAT  AANDK  ERSOR  STRFN  SLCRD  INTVL  SURVL)    INPUU211
 1250 FORMAT (41H1 MM,NBBI,NRSP,OR SOME SPLNO IS TOO LARGE)              INPUU212
 1260 FORMAT (56H1  WHEN REDFAC IS LESS THAN 1.0,  MOPT MUST EQUAL 1 OR INPUU213
     12)                                                                 INPUU214
      END                                                                INPUU215
      SUBROUTINE PRECAL                                                  PRECAL 2
C                                                                        PRECAL 3
C  PRECAL CALCULATES ALL REQUIRED FIXED CONSTANTS                        PRECAL 4
C                                                                        PRECAL 5
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)                         PRECAL 6
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,       PRECAL 7
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,      PRECAL 8
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,     PRECAL 9
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),       PRECAL10
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),         PRECAL11
     5   PLOSS(50),MSP(50,2),THSP(50,2)                                  PRECAL12
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,  PRECAL13
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,    PRECAL14
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),      PRECAL15
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),         PRECAL16
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),    PRECAL17
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),             PRECAL18
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),    PRECAL19
     7   BEH(100,2),PLOSMH(100,2)                                        PRECAL20
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)                PRECAL21
      LEVEL 2,  A,U,K,RHO                                                PRECAL22
      COMMON /VARCOM/ RHOHB(100,2),RHOVB(100,2),WMB(100,2),WTB(100,2),   PRECAL23
     1   WWCRM(100,2),LABEL(1,100)                                       PRECAL24
      COMMON /BCDCOM/ INIT(2),EM(50,2),D2TDM2(100,2)                     PRECAL25
      COMMON /TBBC/ TBIBC,TBOBC                                          PRECAL26
      COMMON/WIWO/ WISV,WOSV                                             PRECAL27
      DIMENSION CURV(100,2),ZMR(100),BEZMR(100),WIMOP(4),WWCR(4),        PRECAL28
     1   BETAIM(4),IMOP(4)                                               PRECAL29
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,     PRECAL30
     1   UPPER,S1,ST                                                     PRECAL31
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1                  PRECAL32
      EXTERNAL BL1,BL2                                                   PRECAL33
      DEGRAD = 180./3.1415927                                            PRECAL34
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      NEGBE = 0                                                          PRECAL35
      IEPROR ■ 0                                                         PRECAL36
C                                                                        PRECAL37
C  CALCULATE ITV, IV, TV, AND DTDMV ARRAYS                               PRECAL38
C                                                                        PRECAL39
      ITMIN = 0                                                          PRECAL40
      ITMAX = NBBI-1                                                     PRECAL41
C  ITV UPSTREAM OF BLADE                                                 PRECAL42
      FIRST = 0                                                          PRECAL43
      LAST = NBBI-1                                                      PRECAL44
      DO 10 IM=1,MBIM1                                                   PRECAL45
      ITV(IM,1) = FIRST                                                  PRECAL46
   10 ITV(IM,2) = LAST                                                   PRECAL47
C  ITV, TV, AND DTDMV ON BLADE                                           PRECAL48
      DO 20 IM=MBI,MBO                                                   PRECAL49
      LER(2) = 1                                                         PRECAL50
C     BLCD CALL NO. 1                                                    PRECAL51
      CALL BL1(MV(IM),TV(IM,1),DTDMV(IM,1),INF)                          PRECAL52
      ITV(IM,1) = INT((TV(IM,1)+DTLR)/HT)                                PRECAL53
      IF (TV(IM,1).GT.-DTLR) ITV(IM,1)=ITV(IM,1)+1                       PRECAL54
      ITMIN = MIN0(ITMIN,ITV(IM,1))                                      PRECAL55
      LER(2) = 2                                                         PRECAL56
C     BLCD CALL NO. 2                                                    PRECAL57
      CALL BL2(MV(IM),TV(IM,2),DTDMV(IM,2),INF)                          PRECAL58
      ITV(IM,2) = INT((TV(IM,2)-DTLR)/HT)                                PRECAL59
      IF (TV(IM,2).LT.DTLR) ITV(IM,2)=ITV(IM,2)-1                        PRECAL60
   20 ITMAX = MAX0(ITMAX,ITV(IM,2))                                      PRECAL61
C  ITV DOWNSTREAM OF BLADE                                               PRECAL62
      LAST = ITV(MBO,2)                                                  PRECAL63
      FIRST = LAST+1-NBBI                                                PRECAL64
      DO 40 IM=MBOP1,MM                                                  PRECAL65
      ITV(IM,1) = FIRST                                                  PRECAL66
   40 ITV(IM,2) = LAST                                                   PRECAL67
      ITMIN = MIN0(ITMIN,ITV(MM,1))                                      PRECAL68
C  IV ARRAY                                                              PRECAL69
      IV(1) = 1                                                          PRECAL70
      DO 50 IM=1,MM                                                      PRECAL71
   50 IV(IM+1) = IV(IM)+ITV(IM,2)-ITV(IM,1)+1                            PRECAL72
C                                                                        PRECAL73
C  CALCULATE BETAV AND CURV ARRAYS                                       PRECAL74
C                                                                        PRECAL75
      DO 60 SURF=1,2                                                     PRECAL76
      DO 60 IM=MBI,MBO                                                   PRECAL77
      CURV(IM,SURF) = (RM(IM)*D2TDM2(IM,SURF)+SAL(IM)*DTDMV(IM,SURF)) / PRECAL78
     1   (1.+(RM(IM)*DTDMV(IM,SURF))**2)**1.5                            PRECAL79
   60 BETAV(IM,SURF) = ATAN(DTDMV(IM,SURF)*RM(IM))*DEGRAD                PRECAL80
      NIP = IV(MM)+NBBI-1                                                PRECAL81
      IF(NIP.GT.2500) WRITE(NWRIT,1150)                                  PRECAL82
C                                                                        PRECAL83
C  CALCULATE MH AND DTDMH ARRAYS                                         PRECAL84
C                                                                        PRECAL85
      ITO = ITV(1,1)                                                     PRECAL86
      MRTS ■ 1                                                           PRECAL87
      IMS(1) = 1                                                         PRECAL88
      MH(1,1) = 0.                                                       PRECAL89
      DTDMH(1,1) = 1.E10                                                 PRECAL90
      LER(2) = 3                                                         PRECAL91
C     BLCD AND ROOT (VIA MHORIZ) CALL NO. 3                              PRECAL92
      CALL MHORIZ(MV,ITV(1,1),BL1,MBI,MBO,ITO,HT,DTLR,0,IMS(1),MH(1,1), PRECAL93
     1   DTDMH(1,1),MRTS)                                                PRECAL94
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      IF (ITV(MBO,1)-ITV(MBO,2)+NBBI.NE.2) GO TO 70                     PRECAL95
      IMSL = IMS(1)+1                                                   PRECAL96
      MH(IMSL,1) = MV(MBO)                                              PRECAL97
      DTDMH(IMSL,1) = -1.E10                                            PRECAL98
      IMS(1) = IMSL                                                     PRECAL99
   70 IMS(2) = 0                                                        PRECA100
      MRTS = 1                                                          PRECA101
      LER(2) = 4                                                        PRECA102
C     BLCD AND ROOT (VIA MHORIZ) CALL NO. 4                             PRECA103
      CALL MHORIZ(MV,ITV(1,2),BL2,MBI,MBO,ITO,HT,DTLR,1,IMS(2),MH(1,2), PRECA104
     1   DTDMH(1,2),MRTS)                                               PRECA105
      IMSMAX = MAX0(IMS(1),IMS(2))                                      PRECA106
      IF (IMSMAX.GT.100) WRITE(NWRIT,1100) IMSMAX                       PRECA107
C                                                                       PRECA108
C  CALCULATE RMH ARRAY                                                  PRECA109
C                                                                       PRECA110
      DO 80 SURF=1,2                                                    PRECA111
      CALL SPLINT(MR,RMSP,NRSP,MH(1,SURF),IMS(SURF),RMH(1,SURF),AAA,BBB)PRECA112
   80 CALL SPLINT(MR,PLOSS,NRSP,MH(1,SURF),IMS(SURF),PLOSMH(1,SURF),    PRECA113
     1   AAA,BBB)                                                       PRECA114
C                                                                       PRECA115
C  CALCULATE LAMBDA WHEN BETAI IS GIVEN AS INPUT                        PRECA116
C                                                                       PRECA117
      IF (LRVB.EQ.1) GO TO 130                                          PRECA118
      BETAI = BETAI/DEGRAD                                              PRECA119
      BETAO = BETAO/DEGRAD                                              PRECA120
      IF (FSMI.NE.FSMO) GO TO 90                                        PRECA121
      FSMI = 0.                                                         PRECA122
      FSMO ■ CHORD(1)                                                   PRECA123
   90 CALL SPLINT(MR,RMSP,NRSP,FSMI,1,RMFSMI,BLANK,AAA)                 PRECA124
      CALL SPLINT(MR,RMSP,NRSP,FSMO,1,RMFSMO,BLANK,AAA)                 PRECA125
      CALL SPLINT(MR,BESPF,NRSP,FSMI,1,BEFSMI,BLANK,AAA)                PRECA126
      CALL SPLINT(MR,BESPF,NRSP,FSMO,1,BEFSMO,BLANK,AAA)                PRECA127
      CALL SPLINT(MR,PLOSS,NRSP,FSMI,1,PLFSMI,BLANK,AAA)                PRECA128
      CALL SPLINT(MR,PLOSS,NRSP,FSMO,1,PLFSMO,BLANK,AAA)                PRECA129
      RHOVI = WTFL/BEFSMI/PITCH/COS(BETAI)/RMFSMI                       PRECA130
      WI = 0.                                                           PRECA131
      DELWMX = SQRT(TGROG*TIP)/10.                                      PRECA132
  100 TTIP = 1.-(WI**2+2.*OMEGA*RMFSMI*WI*SIN(BETAI)+(OMEGA*RMFSMI)     PRECA133
     1   **2)/CPTIP                                                     PRECA134
      IF (TTIP.LE.0.) GO TO 110                                         PRECA135
      TEMP = TTIP**(EXPON-1.)                                           PRECA136
      RHOIPL = RHOIP*(1.-PLFSMI)                                        PRECA137
      RHOT = RHOIPL*TEMP*TTIP                                           PRECA138
      FPRIME = RHOT-RHOIPL/GAM*WI/AR*(WI+OMEGA*RMFSMI*SIN(BETAI))/TIP   PRECA139
     1   *TEMP                                                          PRECA140
      IF (FPRIME.LE.0.) GO TO 110                                       PRECA141
      WINEW = WI+(RHOVI-RHOT*WI)/FPRIME                                 PRECA142
      IF (WINEW-WI.GT.DELWMX) WINEW = WI+DELWMX                         PRECA143
      IF (ABS((WINEW-WI)/WINEW).LT..000005) GO TO 120                   PRECA144
      WI = WINEW                                                        PRECA145
      GO TO 100                                                         PRECA146
  110 WRITE(NWRIT,1020)                                                 PRECA147
      IERROR = 1                                                        PRECA148
  120 LAMBDA = RMFSMI*(WI*SIN(BETAI)+OMEGA*RMFSMI)                      PRECA149
      WMI = WI*COS(BETAI)                                               PRECA150
      AA = (2.*OMEGA*LAMBDA-(OMEGA*RMFSMI)**2)/CPTIP                    PRECA151
      WCRI ■ SQRT(TGROG*TIP*(1.-AA))                                    PRECA152
C                                                                       PRECA153
C   CALCULATE RVTHO WHEN BETAO IS GIVEN AS INPUT                        PRECA154
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C                                                                       PRECA155
      RHOVO = WTFL/BEFSMO/PITCH/COS(BETAO)/RMFSMO                       PRECA156
      TWLMR = 2.*OMEGA*LAMBDA-(OMEGA*RMFSMO)**2                         PRECA157
      TTIP = 1.-TWLMR/CPTIP                                             PRECA158
      RHOIPL = RHOIP*(1.-PLFSMO)                                        PRECA159
      RHOMB2 = RHOIPL*TTIP**EXPON                                       PPECA160
      LER(1) = 1                                                        PRECA161
C     DENSTY CALL NO. 1                                                 PRECA162
      NERT = NER(1)                                                     PRECA163
      JZ = 1                                                            PRECA164
      IF (FSMO.GE.SSM1.AND.FSMO.LE.SSM2) JZ=2                           PRECA165
      CALL DENSTY(RHOVO,RHOMB2,WO,TWLMR,CPTIP,EXPON,RHOIPL,GAM,AR,TIP,  PRECA166
     1   JZ)                                                            PRECA167
      IF (NERT.NE.NER(1)) WRITE(NWRIT,1022)                             PRECA168
      RVTHO = RMFSMO*(WO*SIN(BETAO)+OMEGA*RMFSMO)                       PRECA169
      WMO = WO*COS(BETAO)                                               PRECA170
      WCRO = SQRT(TGROG*TIP*(1.-TWLMR/CPTIP))                           PRECA171
  130 TWL = 2.*OMEGA*LAMBDA                                             PRECA172
C                                                                       PRECA173
C  INITIALIZE DENSITY WHERE HORIZONTAL MESH LINES INTERSECT BLADE       PRECA174
C  AND CALCULATE BETAH ARRAY                                            PRECA175
C                                                                       PRECA176
      DO 150 SURF=1,2                                                   PRECA177
      IMSS = IMS(SURF)                                                  PRECA178
      IF (IMSS.LT.1) GO TO 150                                          PRECA179
      DO 140 IHS=1,IMSS                                                 PRECA180
      RHOHB(IHS,SURF) = RHOIP*(1.-PLOSMH(IHS,SURF))*(1.-(2.*OMEGA*      PRECA181
     1   LAMBDA-(OMEGA*RMH(IHS,SURF))**2)/CPTIP)**EXPON                 PRECA182
  140 BETAH(IHS,SURF) = ATAN(DTDMH(IHS,SURF)*RMH(IHS,SURF))*DEGRAD      PRECA183
  150 CONTINUE                                                          PRECA184
C                                                                       PRECA185
C  INITIALIZE DENSITY WHERE VERTICAL MESH LINES INTERSECT BLADE         PRECA186
C  AND AT INTERIOR POINTS                                               PRECA187
C                                                                       PRECA188
      DO 170 IM=1,MM                                                    PRECA189
      TTIP = 1.-(TWL-(OMEGA*RM(IM))**2)/CPTIP                           PRECA190
      RHOT = RHOIP*(1.-PLOSIM(IM))*TTIP**EXPON                          PRECA191
      DO 160 SURF=1,2                                                   PRECA192
  160 RHOVB(IM,SURF) = RHOT                                             PRECA193
      IPU = IV(IM)                                                      PRECA194
      IPL = IV(IM+1)-1                                                  PRECA195
      DO 170 IP=IPU,IPL                                                 PRECA196
  170 RHO(IP) = RHOT                                                    PRECA197
C                                                                       PRECA198
C   CALCULATE VELOCITY DIAGRAM INFORMATION, AND                         PRECA199
C   TAN BETA (TBI AND TBO) AT UPSTREAM AND DOWNSTREAM BOUNDARIES        PRECA200
C                                                                       PRECA201
      IMOP(1) ■ 1                                                       PRECA202
      IMOP(2) ■ MBI                                                     PRECA203
      IMOP(3) = MBO                                                     PRECA204
      IMOP(4) = MM                                                      PRECA205
      WHIRL = LAMBDA                                                    PRECA206
      DELTWL = 0.                                                       PRECA207
      DO 220 I=1,4                                                      PRECA208
      IM = IMOP(I)                                                      PRECA209
      VTHIM = WHIRL/RM(IM)                                              PRECA210
      VTHIM2 = VTHIM**2                                                 PRECA211
      WTHIM = VTHIM-OMEGA*RM(IM)                                        PRECA212
      WTHTWL = VTHIM2+DELTWL                                            PPECA213
      RHOWIM = WTFL/RM(IM)/PITCH/BEF(IM)                                PRECA214
      RHOIM = RHOVB(IM,1)                                               PRECA215
      RHOIPL = RHOIP*(1.-PLOSIM(IM))                                    PRECA216
      LER(1) = 2                                                        PRECA217
C     DENSTY CALL NO. 2                                                 PRECA218
      NERT ⊟ NER(1)                                                     PRECA219
      JZ = 1                                                            PRECA220
      CALL DENSTY(RHOWIM,RHOIM,WMIM,WTHTWL,CPTIP,EXPON,RHOIPL,GAM,AR,   PRECA221
     1   TIP,JZ)                                                        PRECA222
      IF (NERT.NE.NER(1)) WRITE(NWRIT,1024) MV(IM),IM                   PRECA223
      TBETA = WTHIM/WMIM                                                PRECA224
      BETAIM(I) ⊟ ATAN(TBETA)*DEGRAD                                    PRECA225
      AA = (TWL-(OMEGA*RM(IM))**2)/CPTIP                                PRECA226
      WCRIM = SQRT(TGROG*TIP*(1.-AA))                                   PRECA227
      WIMOP(I) = SQRT(WMIM**2+WTHIM**2)                                 PRECA228
      WWCR(I) = WIMOP(I)/WCRIM                                          PRECA229
      IF (I.EQ.2) DELTWL ⊟ 2.*OMEGA*(LAMBDA-RVTHO)                      PRECA230
      IF (I.EQ.2) WHIRL = RVTHO                                         PRECA231
  220 IF (I.EQ.1) TBI = TBETA                                           PRECA232
      TBO = TBETA                                                       PRECA233
      BTAIN = ATAN(TBI)*DEGRAD                                          PRECA234
      BTAOUT = ATAN(TBO)*DEGRAD                                         PRECA235
      IF (LRVB.NE.1) GO TO 225                                          PRECA236
      FSMI = MV(1)                                                      PRECA237
      FSMO = MV(MM)                                                     PRECA238
      RMFSMI = RM(1)                                                    PRECA239
      RMFSMO = RM(MM)                                                   PRECA240
      WI = WIMOP(1)                                                     PRECA241
      WMI = WI/SQRT(1.+TBI**2)                                          PRECA242
      WCRI ⊟ WI/WWCR(1)                                                 PRECA243
      WO ⊟ WIMOP(4)                                                     PRECA244
      WMO = WO/SQRT(1.+TBO**2)                                          PRECA245
      WCRO = WO/WWCR(4)                                                 PRECA246
  225 CONTINUE                                                          PRECA247
C                                                                       PRECA248
C   CALAULATE TAN BETA (TBIBC AND TBOBC) AT ONE-HALF MESH SPACE INSIDE  PRECA249
C   UPSTREAM AND DOWNSTREAM BOUNDARIES                                  PRECA250
C                                                                       PRECA251
      RMIM = (RM(1)+RM(2))/2.                                           PRECA252
      VTHIM ⊟ LAMBDA/RMIM                                               PRECA253
      WTHTWL = VTHIM**2                                                 PRECA254
      WTHIM = VTHIM-OMEGA*RMIM                                          PRECA255
      RHOWIM = WTFL/RMIM/PITCH/(BEF(1)+BEF(2))*2.                       PRECA256
      RHOIM = RHOVB(1,1)                                                PRECA257
      RHOIPL = RHOIP*(1.-(PLOSIM(1)+PLOSIM(2))/2.)                      PRECA258
      LER(1) ⊟ 2                                                        PRECA259
C--DENSTY CALL NO. 2-A                                                  PRECA260
      NERT = NER(1)                                                     PRECA261
      JZ = 1                                                            PRECA262
      CALL DENSTY(RHOWIM,RHOIM,WMIM,WTHTWL,CPTIP,EXPON,RHOIPL,GAM,AR,   PRECA263
     1   TIP,JZ)                                                        PRECA264
      IF(NERT.NE.NER(1)) WRITE(NWRIT,1026)                              PRECA265
      TBIBC = WTHIM/WMIM                                                PRECA266
      RMIM = (RM(MM)+RM(MM-1))/2.                                       PRECA267
      VTHIM = RVTHO/RMIM                                                PRECA268
      WTHTWL ⊟ VTHIM**2+2.*OMEGA*(LAMBDA-RVTHO)                         PRECA269
      WTHIM ⊟ VTHIM-OMEGA*RMIM                                          PRECA270
      RHOWIM = WTFL/RMIM/PITCH/(BEF(MM)+BEF(MM-1))*2.                   PRECA271
      RHOIM = RHOVB(MM,1)                                               PRECA272
      RHOIPL = RHOIP*(1.-(PLOSIM(MM)+PLOSIM(MM-1))/2.)                  PRECA273
      LER(1) = 2                                                        PRECA274
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C--DENSTY CBLL NO. 2-B                                                  PRECA275
      NERT ⊟ NER(1)                                                     PRECA276
      JZ = 1                                                            PRECA277
      CALL DENSTY(RHOWIM,RHOIM,WMIM,WTHTWL,CPTIP,EXPON,RHOIPL,GAM,AR,   PRECA278
     1   TIP,JZ)                                                        PRECA279
      IF(NERT.NE.NER(1)) WRITE(NWRIT,1026)                              PRECA280
      TBOBC = WTHIM/WMIM                                                PRECA281
C                                                                       PRECA282
C  CALCULATE REDUCED BESP WHEN REDFAC IS LESS THAN 1.0                  PRECA283
C                                                                       PRECA284
      IF (REDFAC.EQ.1.) GO TO 300                                       PRECA285
C                                                                       PRECA286
C  CALCULATE REDUCED BESP WHEN W/WCR IS GIVEN AS INPUT                  PRECA287
C                                                                       PRECA288
      IF (MOPT.NE.1) GO TO 240                                          PRECA289
      DO 230 I=1, NRSP                                                  PRECA290
      ZMR(I) = MR(I)                                                    PRECA291
      AA = (2.*OMEGA*LAMBDA-(OMEGA*RMSP(I))**2)/ CPTIP                  PRECA292
      TPPRAT = (1.-AA)/(1.-REDFAC**2*AA)                                PRECA293
      AA = (GAM-1.)/(GAM+1.)*WOWCR(I)**2                                PRECA294
      AA ⊟ (TPPRAT*(1.-AA)/(1.-REDFAC**2*TPPRAT*AA))**EXPON             PRECA295
      IF (BESPF(I).LE.0.) NEGBE = 1                                     PRECA296
  230 BEZMR(I) = BESPF(I)*AA                                            PRECA297
      NZMR = NRSP                                                       PRECA298
      IF (NEGBE.EQ.1) WRITE(NWRIT,1160)                                 PRECA299
      GO TO 290                                                         PRECA300
C                                                                       PRECA301
C  CALCULATE REDUCED BESP WHEN W/WCR IS NOT GIVEN AS INPUT              PRECA302
C                                                                       PRECA303
C  CALCULATE SOLIDITY AND FAIRING DISTANCE FROM L.E. AND T.E.           PRECA304
  240 BLDCRD = SQRT(((RM(MBI)+RM(MBO))/2.*STGR(1))**2+CHORD(1)**2)      PRECA305
      SOLDTY = BLDCRD/PITCH/RM(MBI)                                     PRECA306
      DISTLE = AMIN1(.5,AMAX1(1./6.,(11.-4.*SOLDTY)/18.))*CHORD(1)      PRECA307
      SOLDTY = BLDCRD/PITCH/RM(MBO)                                     PRECA308
      DISTTE = AMIN1(.5,AMAX1(1./6.,(11.-4.*SOLDTY)/18.))*CHORD(1)      PRECA309
C  CALCULATE REDUCED BESP UPSTREAM                                      PRECA310
      RHOIM = RHOVB(1,1)                                                PRECA311
      DO 250 IM=1,MBIM1                                                 PRECA312
      ZMR(IM) = MV(IM)                                                  PRECA313
      VTH2IM = (LAMBDA/RM(IM))**2                                       PRECA314
      RHOWM = WTFL/RM(IM)/PITCH/BEF(IM)                                 PRECA315
      RHOIPL = RHOIP*(1.-PLOSIM(IM))                                    PRECA316
      LER(1) = 3                                                        PRECA317
C     DENSTY CALL NO. 3                                                 PRECA318
      NERT = NER(1)                                                     PRECA319
      JZ ⊟ 1                                                            PRECA320
      CALL DENSTY(RHOWM,RHOIM,WMIM,VTH2IM,CPTIP,EXPON,RHOIPL,GAM,AR,TIP,PRECA321
     1   JZ)                                                            PRECA322
      IF (NERT.NE.NER(1)) WRITE(NWRIT,1024) MV(IM),IM                   PRECA323
      ENTHF = CPTIP-WMIM**2-VTH2IM                                      PRECA324
      ENTHRE ⊟ CPTIP-(WMIM**2+VTH2IM)*REDFAC**2                         PRECA325
  250 BEZMR(IM) = BEF(IM)*(ENTHF/ENTHRE)**EXPON                         PRECA326
C  CALCULATE REDUCED BESP IN BLADE                                      PRECA327
      IMLP = MBIM1                                                      PRECA328
      IM1 = MBI+INT(DISTLE/HM1)+1                                       PRECA329
      IML = MBI+INT((CHORD(1)-DISTTE)/HM1)                              PRECA330
      IF (IM1.GT.IML) GO TO 270                                         PRECA331
      DO 260 IM=IM1,IML                                                 PRECA332
      IMLP = IMLP+1                                                     PRECA333
      ZMR(IMLP) = MV(IM)                                                PRECA334
      BETIM = (BETAV(IM,1)+BETAV(IM,2))/2./DEGRAD                       PRECA335
      RHOWIM = WTFL/BEF(IM)/RM(IM)/(TV(IM,2)-TV(IM,1))/COS(BETIM)       PRECA336
      RHOIPL = RHOIP*(1.-PLOSIM(IM))                                    PRECA337
      TWLMR = TWL-(OMEGA*RM(IM))**2                                     PRECA338
      LER(1) = 4                                                        PRECA339
C     DENSTY CALL NO. 4                                                 PRECA340
      NERT = NER(1)                                                     PRECA341
      JZ = 1                                                            PRECA342
      IF (IM.GE.IMS1.AND.IM.LE.IMS2) JZ=2                               PRECA343
      CALL DENSTY(RHOWIM,RHOIM,WIM,TWLMR,CPTIP,EXPON,RHOIPL,GAM,AR,TIP, PRECA344
     1   JZ)                                                            PRECA345
      IF (NERT.NE.NER(1)) WRITE(NWRIT,1024) MV(IM),IM                   PRECA346
      ENTHF = CPTIP-WIM**2-TWLMR                                        PRECA347
      ENTHRE = CPTIP-(WIM**2+TWLMR)*REDFAC**2                           PRECA348
  260 BEZMR(IMLP) = BEF(IM)*(ENTHF/ENTHRE)**EXPON                       PRECA349
  270 CONTINUE                                                          PRECA350
C  CALCULATE REDUCED BESP DOWNSTREAM                                    PRECA351
      DO 280 IM=MBOP1,MM                                                PRECA352
      IMLP ■ IMLP+1                                                     PRECA353
      ZMR(IMLP) = MV(IM)                                                PRECA354
      WTHTWL = (RVTHO/RM(IM))**2+2.*OMEGA*(LAMBDA-RVTHO)                PRECA355
      RHOWM = WTFL/RM(IM)/PITCH/BEF(IM)                                 PRECA356
      RHOIPL = RHOIP*(1.-PLOSIM(IM))                                    PRECA357
      LER(1) = 5                                                        PRECA358
C     DENSTY CALL NO. 5                                                 PRECA359
      NERT = NER(1)                                                     PRECA360
      JZ = 1                                                            PRECA361
      CALL DENSTY(RHOWM,RHOIM,WMIM,WTHTWL,CPTIP,EXPON,RHOIPL,GAM,AR,TIP,PRECA362
     1   JZ)                                                            PRECA363
      IF (NERT.NE.NER(1)) WRITE(NWRIT,1024) MV(IM),IM                   PRECA364
      ENTHF = CPTIP-WMIM**2-WTHTWL                                      PRECA365
      ENTHRE = CPTIP-(WMIM**2+WTHTWL)*REDFAC**2                         PRECA366
  280 BEZMR(IMLP) = BEF(IM)*(ENTHF/ENTHRE)**EXPON                       PRECA367
      NZMR = IMLP                                                       PRECA368
  290 CALL SPLINT(ZMR,BEZMR,NZMR,MV,MM,BE,DBDM,AAA)                     PRECA369
C                                                                       PRECA370
C  CALCULATE BEH ARRAY                                                  PRECA371
C                                                                       PRECA372
  300 DO 320 SURF=1,2                                                   PRECA373
      IF (REDFAC.NE.1.) CALL SPLINT(ZMR,BEZMR,NZMR,MH(1,SURF),IMS(SURF),PRECA374
     1   BEH(1,SURF),AAA,BBB)                                           PRECA375
      IF (REDFAC.EQ.1.) CALL SPLINT(MR,BESP,NRSP,MH(1,SURF),IMS(SURF),  PRECA376
     1   BEH(1,SURF),AAA,BBB)                                           PRECA377
      IMSS = IMS(SURF)                                                  PRECA378
      IF (IMSS.LT.1) GO TO 320                                          PRECA379
      DO 310 IHS=1,IMSS                                                 PRECA380
  310 IF (BEH(IHS,SURF).LE.0.) NEGBE = 2                                PRECA381
  320 CONTINUE                                                          PRECA382
C                                                                       PRECA383
C **********************************************************************PRECA384
C  NOTE ** WTFL, OMEGA, AND LAMBDA ARE ALL REDUCED AT THIS POINT,       PRECA385
C  AND REMAIN REDUCED FOR THE REST OF THE PROGRAM, EXCEPT THAT          PRECA386
C  LAMBDA IS RESTORED TO FULL VALUE IN TVELCY                           PRECA387
C                                                                       PRECA388
      ACTWT = WTFL                                                      PRECA389
      ACTOMG = OMEGA                                                    PRECA390
      ACTLAM = LAMBDA                                                   PRECA391
      WTFL = REDFAC*WTFL                                                PRECA392
      OMEGA = REDFAC*OMEGA                                              PRECA393
      LAMBDA = REDFAC*LAMBDA                                            PRECA394
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      TWL ■ 2.*OMEGA*LAMBDA                                             PRECA395
      TWW = 2.*OMEGA/WTFL                                               PRECA396
C                                                                       PRECA397
C  WRITE OUTPUT CALCULATED BY PRECAL                                    PRECA398
C                                                                       PRECA399
      WRITE(NWRIT,1030) WI,WMI,WCRI,BTAIN,WO,WMO,WCRO,BTAOUT,FSMI,FSMO  PRECA400
      WOSV=WO                                                           PRECA401
      WISV=WI                                                           PRECA402
      WRITE(NWRIT,1040) PITCH,HT,HM1                                    PRECA403
      WRITE(NWRIT,1050) ITMIN,ITMAX,ACTLAM,RVTHO,WTFL,NIP   .           PRECA404
      WRITE(NWRIT,1060) (IMOP(I),WIMOP(I),WWCR(I),BETAIM(I),I=1,4)      PRECA405
      GO TO 5000                                                        PRECA406
      WRITE(NWRIT,1070)                                                 PRECA407
      WRITE(NWRIT,1080) (MV(IM),RM(IM),TV(IM,1),DTDMV(IM,1),CURV(IM,1), PRECA408
     1   TV(IM,2),DTDMV(IM,2),CURV(IM,2),IM=MBI,MBO)                    PRECA409
      WRITE(NWRIT,1085) DISTLE,IM1,DISTTE,IML                           PRECA410
      WRITE(NWRIT,1090) (IM,MV(IM),RM(IM),SAL(IM),BE(IM),DBDM(IM),      PRECA411
     1BEF(IM),DBFDM(IM),IM=1,MM)                                        PRECA412
      WRITE(NWRIT,1120)                                                 PRECA413
      DO 330 SURF=1,2                                                   PRECA414
      IMSS = IMS(SURF)                                                  PRECA415
  330 WRITE(NWRIT,1130) SURF,(MH(IM,SURF),RMH(IM,SURF),BEH(IM,SURF),    PRECA416
     1   BETAH(IM,SURF),DTDMH(IM,SURF),IM=1,IMSS)                       PRECA417
      WRITE(NWRIT,1110)  (IM,IV(IM),(ITV(IM,SURF),SURF=1,2),IM=1,MM)    PRECA418
      WRITE(NWRIT,1140)                                                 PRECA419
 5000 CONTINUE                                                          PRECA420
      IT ■ ITMIN                                                        PRECA421
  340 IF (IT.GT.ITMAX) GO TO 350                                        PRECA422
      TH ■ FLOAT(IT)*HT                                                 PRECA423
C     WRITE(NWRIT,1010) IT,TH                                           PRECA424
      IT ■ IT+1                                                         PRECA425
      GO TO 340                                                         PRECA426
C                                                                       PRECA427
C  STOP PROGRAM IF FATAL ERROR HAS OCCURRED IN PRECAL                   PRECA428
C                                                                       PRECA429
  350 IF(NIP.GT.2500) STOP                                              PRECA430
      IF(IMSMAX.GT.100) STOP                                            PRECA431
      IF(IERROR.NE.0) STOP                                              PRECA432
      IF(NER(1).NE.0) STOP                                              PRECA433
      IF(NEGBE.NE.0) STOP                                               PRECA434
      WRITE(NWRIT,1000)                                                 PRECA435
      RETURN                                                            PRECA436
C                                                                       PRECA437
C  FORMAT STATEMENTS                                                    PRECA438
C                                                                       PRECA439
 1000 FORMAT (1H1)                                                      PRECA440
 1010 FORMAT (4X,I4,G16.5)                                              PRECA441
 1020 FORMAT(60H0INPUT WEIGHT FLOW (WTFL) IS TOO LARGE AT BLADE LEADING PRECA442
     1EDGE)                                                             PRECA443
 1022 FORMAT(61H0INPUT WEIGHT FLOW (WTFL) IS TOO LARGE AT BLADE TRAILINGPRECA444
     1 EDGE)                                                            PRECA445
 1024 FORMAT(45H0INPUT WEIGHT FLOW (WTFL) IS TOO LARGE AT M =,G15.5,7H (PRECA446
     1IM = ,I3,1H))                                                     PRECA447
 1026 FORMAT(97H0INPUT WEIGHT FLOW (WTFL) IS TOO LARGE ONE-HALF MESH SPAPRECA448
     1CE INSIDE UPSTREAM OR DOWNSTREAM BOUNDARY)                        PRECA449
 1030 FORMAT(1H1,10X,8HRELATIVE,11X,10HMERIDIONAL,11X,8HCRITICAL,       PRECA450
     1   11X,9HREL. FLOW/11X,3(8HVELOCITY,12X),6H ANGLE/                PRECA451
     2   3(9X,11HAT M = FSMI),7X,16HAT UPSTREAM BDY./1X,4G20.5/         PRECA452
     3   3(9X,11HAT M = FSMO),6X,18HAT DOWNSTREAM BDY./1X,4G20.5//      PRECA453
     4   9X,6HFSMI =,G14.5/9X,6HFSMO =,G14.5)                           PRECA454
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1040 FORMAT(//30H  CALCULATED PROGRAM CONSTANTS//5X,5HPITCH,13X,        PRECA455
   1   2HHT,13X,3HHM1/1X,5G16.7)                                         PRECA456
1050 FORMAT (/5X,5HITMIN,10X,5HITMAX/4X,I5,10X,I5//5X,6HLAMBDA,12X,     PRECA457
   1   29H  DOWNSTREAM WHIRL (RVTHO)   /1X,G16.7,12X,G16.7/26H0    REDPRECA458
   2UCED WEIGHT FLOW =,G16.7/38H0    NUMBER OF INTERIOR MESH POINTS = PRECA459
   3,I5)                                                              PRECA460
1060 FORMAT(40H0CALCULATED VELOCITY DIAGRAM INFORMATION/24X,2HIM,9X,1HWPRECA461
   1,17X,5HW/WCR,16X,4HBETA/1X,17HUPSTREAM BOUNDARY,5X,I3,3G20.5/1X,  PRECA462
   212HLEADING EDGE,10X,I3,3G20.5/1X,13HTRAILING EDGE,9X,I3,3G20.5/   PRECA463
   31X,19HDOWNSTREAM BOUNDARY,3X,I3,3G20.5)                           PRECA464
1070 FORMAT (1H1,6X,62HBLADE DATA AT INTERSECTIONS OF VERTICAL MESH LINPRECA465
   1ES WITH BLADES)                                                   PRECA466
1080 FORMAT (/37X,15HBLADE SURFACE 1,30X,15HBLADE SURFACE 2/7X,1HM,14X,PRECA467
   1   1HR,14X,2HTV,11X,5HDTDMV,11X,4HCURV,12X,2HTV,11X,5HDTDMV,11X,  PRECA468
   2   4HCURV/(8G15.5))                                               PRECA469
1085 FORMAT(38H0FAIRING DISTANCE FROM LEADING EDGE IS,G20.5,8H (IM1 = ,PRECA470
   1I3,1H)/39H FAIRING DISTANCE FROM TRAILING EDGE IS,G20.5,8H (IML = PRECA471
   2,I3,1H))                                                          PRECA472
1090 FORMAT (1H1,13X,44HSTREAM SHEET COORDINATES AND THICKNESS TABLE / PRECA473
   1   2X,2HIM,7X,1HM,14X,1HR,13X,3HSAL,13X,1HB,12X,5HDB/DM,14X,2HBF, PRECA474
   211X,6HDBF/DM/(1X,I3,7G15.5))                                      PRECA475
1100 FORMAT(34HLONE OF THE MH ARRAYS IS TOO LARGE/7H IT HAS,I5, 8H  POIPRECA476
   1NTS)                                                              PRECA477
1110 FORMAT (4H1 IM,9X,8HIV ARRAY,25X,9HITV ARRAY/38X,5HBLADE/37X,7HSURPRECA478
   1FACE,3X,1H1,5X,1H2/39X,3HNO./(1X,I3,5X,I10,25X,2(I4,2X)))         PRECA479
1120 FORMAT (67H1M COORDINATES OF INTERSECTIONS OF HORIZONTAL MESH LINEPRECA480
   1S WITH BLADE)                                                     PRECA481
1130 FORMAT (25H0MH ARRAY - BLADE SURFACE,I2//15X,2HMH,19X,3HRMH,19X,  PRECA482
   1   3HBEH,18X,5HBETAH,17X,5HDTDMH/(5G22.4))                        PRECA483
1140 FORMAT (43H1THETA COORDINATES OF HORIZONTAL MESH LINES//6X,2HIT,  PRECA484
   15X,5HTHETA)                                                       PRECA485
1150 FORMAT(48H0THE NUMBER OF INTERIOR MESH POINTS EXCEEDS 2500)       PRECA486
1160 FORMAT(80H0THE INPUT BESP ARRAY RESULTED IN A NEGATIVE VALUE OF BEPRECA487
   1 AT A VERTICAL MESH LINE/5X,47HTHE PROGRAM WILL TERMINATE AT THE EPRECA488
   2ND OF PRECAL)                                                     PRECA489
1170 FORMAT(82H0THE INPUT BESP ARRAY RESULTED IN A NEGATIVE VALUE OF BEPRECA490
   1 AT A HORIZONTAL MESH LINE/5X,47HTHE PROGRAM WILL TERMINATE AT THEPRECA491
   2 END OF PRECAL)                                                   PRECA492
      END                                                             PRECA493
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      SUBROUTINE PLOTER (KK1,KK2,KK3,KK4)                               PLOTER 2
      ENTRY BLDPLT                                                      PLOTER 3
      RETURN                                                            PLOTER 4
      ENTRY VEPLOT                                                      PLOTER 5
      RETURN                                                            PLOTER 6
      ENTRY TVPLOT                                                      PLOTER 7
      RETURN                                                            PLOTER 8
      END                                                               PLOTER 9
      SUBROUTINE COEF                                                   COEF   2
C                                                                       COEF   3
C  COEF CALCULATES FINITE DIFFERENCE COEFFICIENTS, A, AND CONSTANTS, K, COEF   4
C  AT ALL UNKNOWN MESH POINTS FOR THE ENTIRE REGION                     COEF   5
C                                                                       COEF   6
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)                        COEF   7
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,      COEF   8
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,     COEF   9
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,    COEF  10
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),      COEF  11
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),        COEF  12
     5   PLOSS(50),MSP(50,2),THSP(50,2)                                 COEF  13
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1, COEF  14
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,   COEF  15
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),     COEF  16
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),        COEF  17
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),   COEF  18
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),            COEF  19
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),   COEF  20
     7   BEH(100,2),PLOSMH(100,2)                                       COEF  21
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)               COEF  22
      LEVEL 2,  A,U,K,RHO                                               COEF  23
      COMMON /HRBAAK/H(4),R(4),B(4),KAK(4),KA(4),RZ,BZ,IH(4)            COEF  24
      COMMON /TBBC/ TBIBC,TBOBC                                         COEF  25
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,    COEF  26
     1   UPPER,S1,ST                                                    COEF  27
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1                 COEF  28
C  INITIALIZE ARRAYS                                                    COEF  29
      IH(1) = 1                                                         COEF  30
      IH(2) = 0                                                         COEF  31
C  INCOMPRESSIBLE CASE                                                  COEF  32
      IF (GAM.NE.1.5.OR.AR.NE.1000..OR.TIP.NE.1.E6) GO TO 20            COEF  33
      IEND = 1                                                          COEF  34
      GO TO 40                                                          COEF  35
C  ADJUSTMENT OF PRINTING CONTROL VARIABLES                             COEF  36
   20 IF(ITER.NE.1.AND.ITER.NE.2) GO TO 30                              COEF  37
      AANDK ■ AANDK-1                                                   COEF  38
      ERSOR = ERSOR-1                                                   COEF  39
      STRFN = STRFN-1                                                   COEF  40
      SLCRD ■ SLCRD-1                                                   COEF  41
      INTVL = INTVL-1                                                   COEF  42
      SURVL = SURVL-1                                                   COEF  43
   30 IF(IEND.NE.0) GO TO 40                                            COEF  44
      AANDK ■ AANDK+2                                                   COEF  45
      ERSOR = EPSOR+2                                                   COEF  46
      STRFN = STRFN+2                                                   COEF  47
      SLCRD = SLCRD+2                                                   COEF  48
      INTVL = INTVL+2                                                   COEF  49
      SURVL ■ SURVL+2                                                   COEF  50
C                                                                       COEF  51
C  FIRST VERTICAL MESH LINE                                             COEF  52
C                                                                       COEF  53
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   40 DO 50 IP=1,NBBI
      A(IP,1) = 0.
      A(IP,2) = 0.
      A(IP,3) = 0.
      A(IP,4) = 1.
   50 K(IP) = HM1*TBIBC/PITCH*2./(RM(1)+RM(2))
C
C   UPSTREAM OF BLADE, EXCEPT FOR FIRST VERTICAL MESH LINE
C
      IF (2.GT.MBIM1) GO TO 70
      DO 60 IM=2,MBIM1
   60 CALL COEFP(IM)
C
C   BETWEEN BLADES
C
   70 DO 80 IM=MBI,MBO
   80 CALL COEFB(IM)
C
C  DOWNSTREAM OF BLADES EXCEPT FOR FINAL MESH LINE
C
  150 IF (MBOP1.GT.MMM1) GO TO 170
      DO 160 IM=MBOP1,MMM1
  160 CALL COEFP(IM)
C
C  FINAL VERTICAL MESH LINE
C
  170 IVMM = IV(MM)
      DO 180 IP=IVMM,NIP
      A(IP,1) = 0.
      A(IP,2) = 0.
      A(IP,3) = 1.
      A(IP,4) = 0.
  180 K(IP) = -HM1*TBOBC/PITCH*2./(RM(MM)+RM(MM-1))
C
C  TAKE CARE OF POINTS ADJACENT TO B, AND CASES WHEN POINTS J,C,E, OR F
C  ARE GRID POINTS
C
C  POINT B
      IP = IV(MBIM1)
      A(IP,4) = 0.
C  POINT C
      IF (ITV(MBO,1)-ITV(MBO,2)+NBBI.NE.2) RETURN
      IT = ITV(MBO,1)-1
      IP = IPF(MBOP1,IT)
      A(IP,3) = 0.
      RETURN
      END
      SUBROUTINE COSUB (IM)
C
C  COSUB CALCULATES FINITE DIFFERENCE COEFFICIENTS, A, AND CONSTANTS, K
C  ALONG ALL VERTICAL MESH LINES WHICH INTERSECT BLADES
C
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),
     5   PLOSS(50),MSP(50,2),THSP(50,2)
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,THW,CPTIP,TGROG,TBI,TBO,TWL,
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),
     7   BEH(100,2),PLOSMH(100,2)
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)
      LEVEL 2,  A,U,K,RHO
      COMMON /HRBAAK/H(4),R(4),B(4),KAK(4),KA(4),RZ,BZ,IH(4)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,
     1   UPPER,S1,ST
      INTEGER DUMM
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1
      DATA IAOVER/0/
C
C  COEFB CALCULATES FINITE DIFFERENCE COEFFICIENTS, A, AND CONSTANTS, K,
C  ALONG VERTICAL MESH LINES WHICH INTERSECT BLADES
C
      ENTRY COEFB
      IF (IT,V(IM,1).GT.ITV(IM,2)) RETURN
      ITVU = ITV(IM,1)
      IT = ITVU - 1
      ITVL = ITV(IM,2)
      IPU = IPF(IM,ITVU)
      IPL = IPU+ITVL-ITVU
      DO 90 IP=IPU,IPL
      IT = IT+1
      CALL HRB (DUMM,IM,DUMM,IT,IP)
      DO 10 I=1,4
      KAK(I) = 0.
   10 KA(I) = 0
C  FIX HRB VALUES FOR CASES WHERE MESH LINES INTERSECT BLADES
   60 IF (IT.EQ.ITV(IM,1)) CALL BDRY12(1,IM,DUMM,IT)
      IF (IT.EQ.ITV(IM,2)) CALL BDRY12(2,IM,DUMM,IT)
      ITVM1 = ITV(IM-1,1)
      ITVP1 = ITV(IM+1,1)
      IF (IT.LT.ITVM1) CALL BDRY34(3,IM,1)
      IF (IT.LT.ITVP1) CALL BDRY34(4,IM,1)
      IF (IT.GT.ITV(IM-1,2)) CALL BDRY34(3,IM,2)
      IF (IT.GT.ITV(IM+1,2)) CALL BDRY34(4,IM,2)
C  COMPUTE A AND K COEFFICIENTS
   80 CALL AAK (DUMM,IM,DUMM,DUMM,IP)
      DO 90 I=1,4
      K(IP) = K(IP)+KAK(I)*A(IP,I)
      IF (KA(I).EQ.1) A(IP,I) = 0.
      IF (ABS(A(IP,I)).LE.1.) GO TO 90
      A(IP,I) = SIGN(1.,A(IP,I))
      IAOVER = IAOVER+1
      IF (IAOVER.LT.50) GO TO 90
      WRITE(NWRIT,1000)
      STOP
   90 CONTINUE
      RETURN
C
C  COEFP CALCULATES FINITE DIFFERENCE COEFFICIENTS, A, AND CONSTANTS, K,
C  ALONG ALL VERTICAL MESH LINES WHICH DO NOT INTERSECT BLADES
C
      ENTRY COEFP
      ITVU = ITV(IM,1)
      IT = ITVU-1
      ITVL = ITV(IM,2)
      IPL = IV(IM+1)-1
      IPU = IV(IM)
      DO 100 IP=IPU,IPL
      IT = IT+1
      CALL HRB (DUMM,IM,DUMM,IT,IP)
      IF (IT.EQ.ITVU) R(1) = RHO(IPL)
      IF (IT.EQ.ITVL) R(2) = RHO(IPU)
      CALL AAK (DUMM,IM,DUMM,DUMM,IP)
      DO 100 I=1,4
      IF(ABS(A(IP,I)).LE.1.) GO TO 100
      A(IP,I) = SIGN(1.,A(IP,I))
      IAOVER = IAOVER+1
      IF(IAOVER.LT.50) GO TO 100
      WRITE(NWRIT,1000)
      STOP
  100 CONTINUE
      K(IPL) = K(IPL)+A(IPL,2)
      K(IPU) = K(IPU)-A(IPU,1)
      RETURN
 1000 FORMAT (1H1,5X,81HPROGRAM HAS BEEN STOPPED BECAUSE 50 OF THE  A  C
     1OEFFICIENTS ARE GREATER THAN 1.0./6X,62HLOCAL SUPERSONIC FLOW MAY
     2BE THE CAUSE.  TRY A SMALLER REDFAC.)
      END
      SUBROUTINE HRBAK (I,IM,SURF,IT,IP)
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),
     7   BEH(100,2),PLOSMH(100,2)
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)
      LEVEL 2,  A,U,K,RHO
      COMMON /HRBAAK/H(4),R(4),B(4),KAK(4),KA(4),RZ,BZ,IH(4)
      COMMON /VARCOM/ RHOHB(100,2),RHOVB(100,2),WMB(100,2),WTB(100,2),
     1   WWCRM(100,2),LABEL(1,100)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,
     1   UPPER,S1,ST
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1
C
C  HRB CALCULATES MESH SPACING, H, DENSITIES, RZ AND R, AT GIVEN AND
C  ADJACENT POINTS, AND STREAM SHEET THICKNESSES, BZ AND B, AT GIVEN
C  AND ADJACENT POINTS
C
      ENTRY HRB
      H(1) = HT*RM(IM)
      H(2) = HT*RM(IM)
      H(3) = MV(IM) - MV(IM-1)
      H(4) = MV(IM+1)-MV(IM)
      RZ = RHO(IP)
      IP3 = IPF(IM-1,IT)
      IP4 = IPF(IM+1,IT)
      R(1) = RHO(IP-1)
      R(2) = RHO(IP+1)
      R(3) = RHO(IP3)
      R(4) = RHO(IP4)
      BZ = BE(IM)
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```
      B(3) = BE(IM-1)
      B(4) = BE(IM+1)
      RETURN
C
C  AAK CALCULATES FINITE DIFFERENCE COEFFICIENTS, A, AND CONSTANT, K,
C  AT A SINGLE MESH POINT
C
      ENTRY AAK
      A12 = 2./H(1)/H(2)
      A34 = 2./H(3)/H(4)
      AZ = A12+A34
      B12 = (R(2)-R(1))/RZ/(H(1)+H(2))
      B34 = (B(4)*R(4)-B(3)*R(3))/BZ/RZ/(H(3)+H(4))-SAL(IM)/RM(IM)
      A(IP,1) = (2./H(1)+B12)/AZ/(H(1)+H(2))
      A(IP,2) = A12/AZ-A(IP,1)
      A(IP,3) = (2./H(3)+B34)/AZ/(H(3)+H(4))
      A(IP,4) = A34/AZ-A(IP,3)
      K(IP) = -TWW*BZ*RZ*SAL(IM)/AZ
      RETURN
C
C  BDRY12 CORRECTS VALUES COMPUTED BY HRB WHEN A VERTICAL MESH LINE
C  INTERSECTS A BLADE
C
      ENTRY BDRY12
      H(I) = ABS(FLOAT(IT)*HT-TV(IM,I))*RM(IM)
      R(I) = RHOVB(IM,I)
      KAK(I) = BV(I)
      KA(I) = 1
      RETURN
C
C  BDRY34 CORRECTS VALUES COMPUTED BY HRB WHEN A HORIZONTAL MESH LINE
C  INTERSECTS A BLADE
C
      ENTRY BDRY34
      IH(SURF) = IH(SURF)+1
      IHS = IH(SURF)
      H(I) = ABS(MV(IM)-MH(IHS,SURF))
      R(I) = RHOHB(IHS,SURF)
      B(I) = BEH(IHS,SURF)
      KAK(I) = BV(SURF)
      KA(I) = 1
      RETURN
      END
      SUBROUTINE SOR
C
C  SOR SOLVES THE SET OF SIMULTANEOUS EQUATIONS FOR THE STREAM FUNCTION
C  USING THE METHOD OF SUCCESSIVE OVER-RELAXATION
C
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),
     5   PLOSS(50),MSP(50,2),THSP(50,2)
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),
     3   THLE(2),RMI(2),PMO(2),BESP(50),MV(100),RM(100),BE(100),
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),
     7   BEH(100,2),PLOSMH(100,2)
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)
      LEVEL 2,  A,U,K,RHO
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,
     1   UPPER,S1,ST
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1
      AATEMP = AANDK
      IF (ORF.GE.2.) ORF=0.
      ICOUNT = 0
      IF (ORF.GT.1.) GO TO 50
      ORF = 1.
      ORFOPT = 2.
   40 ORFTEM = ORFOPT
      LMAX = 0.
   50 IF (AATEMP.GT.0) WRITE(NWRIT,1010)
      ERROR = 0.
      ICOUNT = ICOUNT+1
C
C  SOLVE MATRIX EQUATION BY SOR, OR CALCULATE OPTIMUM OVERRELAXATION
C  FACTOR
C
      IP = 0
      DO 120 IM=1,MM
      IPU = IV(IM)
      IPL = IV(IM+1)-1
      IT ▣ ITV(IM,1)
      IF (AATEMP.GT.0) WRITE(NWRIT,1020) IM,IT
      DO 120 IP=IPU,IPL
      IP1 = IP-1
      IP2 = IP+1
C  CORRECT IP1 AND IP2 ALONG PERIODIC BOUNDARIES
      IF (IM.GE.MBI.AND.IM.LE.MBO) GO TO 60
      IF (IT.EQ.ITV(IM,1)) IP1=IP1+NBBI
      IF (IT.EQ.ITV(IM,2)) IP2=IP2-NBBI
   60 IT3 = IT
      IT4 = IT
  100 IP3 = IPF(IM-1,IT3)
      IP4 = IPF(IM+1,IT4)
      IF (ORF.GT.1.) GO TO 110
C  CALCULATE NEW ESTIMATE FOR LMAX
      UNEW = A(IP,1)*U(IP1)+A(IP,2)*U(IP2)+A(IP,3)*U(IP3)+A(IP,4)*U(IP4)
      IF (UNEW.LT.1.E-25) U(IP)=0.
      IF (U(IP).EQ.0.) GO TO 115
      RATIO = UNEW/U(IP)
      LMAX = AMAX1(RATIO,LMAX)
      U(IP) = UNEW
      GO TO 115
C  CALCULATE NEW ESTIMATE FOR STREAM FUNCTION BY SOR
  110 CHANGE = ORF*(K(IP)-U(IP)+A(IP,1)*U(IP1)+A(IP,2)*U(IP2)+A(IP,3)*
     1   U(IP3)+A(IP,4)*U(IP4))
      ERROR = AMAX1(ERROR,ABS(CHANGE))
      U(IP) = U(IP)+CHANGE
  115 IF (AATEMP.LE.0) GO TO 120
      WRITE(NWRIT,1030) IT,IP,IP1,IP2,IP3,IP4,(A(IP,I),I=1,4),K(IP)
  120 IT = IT+1
      AATEMP = 0
      IF (ORF.GT.1.) GO TO 130
      ORFOPT ▣ 2./(1.+SQRT(ABS(1.-LMAX)))
      IF (ICOUNT.EQ.(ICOUNT/1000)*1000) WRITE(NWRIT,1000) ORFOPT
      IF (ORFTEM-ORFOPT.GT..00001.OR.ORFOPT.GT.1.99) GO TO 40
      WRITE(NWRIT,1000) ORFOPT
      WRITE(NWRIT,1070) IT
      ORF = ORFOPT
      ICOUNT = 0
      GO TO 50
  130 IF (ERSOR.GT.0) WRITE(NWRIT,1040) ERROR
      IF (ICOUNT.EQ.(ICOUNT/1000)*1000) WRITE(NWRIT,1080) ERROR,ICOUNT
      IF (ERROR.GT..00003) GO TO 50
      IF (STRFN.LE.0) RETURN
C
C  PRINT STREAM FUNCTION VALUES FOR THIS ITERATION
C
      IF (REDFAC.LT.1.) WRITE(NWRIT,1050)
      IF (REDFAC.EQ.1.) WRITE(NWRIT,1055)
      DO 140 IM=1,MM
      IPU ▣ IV(IM)
      IPL ▣ IV(IM+1)-1
      ITVU = ITV(IM,1)
      WRITE(NWRIT,1020) IM,ITVU
  140 WRITE(NWRIT,1060) (U(IP),IP=IPU,IPL)
      RETURN
C
C  FORMAT STATEMENTS
C
 1000 FORMAT (24H ESTIMATED OPTIMUM ORF =,F9.6)
 1010 FORMAT (82H1  IT   IP    IP1   IP2   IP3   IP4    A(1)      A(2)
     1    A(3)       A(4)        K)
 1020 FORMAT (5HKIM =,I4,6X,6HIT1 = ,I4)
 1030 FORMAT (1X,I4,5I6,5F10.5)
 1040 FORMAT (8H ERROR =,F11.8)
 1050 FORMAT (1H1,10X,44HSTREAM FUNCTION VALUES FOR REDUCED MASS FLOW)
 1055 FORMAT (1H1,10X,41HSTREAM FUNCTION VALUES FOR FULL MASS FLOW)
 1060 FORMAT (2X,10F13.8)
 1070 FORMAT(1H ,*  IT = *,I6)
 1080 FORMAT (8H ERROR =,G14.4,7H AFTER ,I6,11H ITERATIONS)
      END
      SUBROUTINE VELMER
C
C  VELMER CALLS VELPM AND VELBM TO CALCULATE RHO*W-SUB-M THROUGHOUT THE
C  REGION AND ON THE BLADE SURFACES
C
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),
     5   PLOSS(50),MSP(50,2),THSP(50,2)
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),
     7   BEH(100,2),PLOSMH(100,2)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,
     1   UFPER,S1,ST
      REAL K,KAK,LAMPDA,LMAX,MH,MLE,MP,MSL,MSP,MV,MVIM1
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C                                                                         VELMER24
C  CALL VELPM AND VELBM THROUGHOUT THE REGION                             VELMER25
C                                                                         VELMER26
      ITVU = ITV(1,1)                                                     VELMER27
      ITVL = ITV(1,2)                                                     VELMER28
      DO 10 IM=1,MBIM1                                                    VELMER29
   10 CALL VELPM(IM,ITVU,ITVL)                                            VELMER30
      DO 20 IM=MBI,MBO                                                    VELMER31
      I = 0                                                               VELMER32
   20 CALL VELBM(IM)                                                      VELMER33
      ITVU = ITV(MBOP1,1)                                                 VELMER34
      ITVL = ITV(MBOP1,2)                                                 VELMER35
      DO 30 IM=MBOP1,MM                                                   VELMER36
   30 CALL VELPM(IM,ITVU,ITVL)                                            VELMER37
      RETURN                                                              VELMER38
      END                                                                 VELMER39
      SUBROUTINE VELSUB (IM,ITVU,ITVL)                                    VELSUB 2
C                                                                         VELSUB 3
C  VELSUB CALCULATES RHO*W-SUB-M THROUGHOUT THE REGION AND ON THE BLADE VELSUB 4
C  SURFACES, AND CALCULATES THE STREAMLINE LOCATIONS                      VELSUB 5
C                                                                         VELSUB 6
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)                          VELSUB 7
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,        VELSUB 8
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,       VELSUB 9
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,      VELSUB10
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),        VELSUB11
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),          VELSUB12
     5   PLOSS(50),MSP(50,2),THSP(50,2)                                   VELSUB13
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,   VELSUB14
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,     VELSUB15
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),       VELSUB16
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),          VELSUB17
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),     VELSUB18
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),              VELSUB19
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),     VELSUB20
     7   BEH(100,2),PLOSMH(100,2)                                         VELSUB21
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)                 VELSUB22
      LEVEL 2,  A,U,K,RHO                                                 VELSUB23
      COMMON /VARCOM/ RHOHB(100,2),RHOVB(100,2),WMB(100,2),WTB(100,2),    VELSUB24
     1   WWCRM(100,2),LABEL(1,100)                                        VELSUB25
      DIMENSION W(2500),BETA(2500),DUDT(2500),DUDTT(2500),AAP(2500),      VELSUB26
     1   BBP(2500)                                                        VELSUB27
      LEVEL 2,  W,BETA,DUDT,DUDTT,AAP,BBP                                 VELSUB28
      EQUIVALENCE (A,W),(A(1,2),BETA),(A(1,3),DUDT),(A(1,4),DUDTT),       VELSUB29
     1   (K,AAP),(RHO,BBP)                                                VELSUB30
      COMMON /SLCOM/ USL(100,11),TSL(100,11)                              VELSUB31
      LEVEL 2,  USL,TSL                                                   VELSUB32
      COMMON /PLTCOM/ TSLPT(1100),XDOWN(400),YACROS(400)                  VELSUB33
      LEVEL 2,  TSLPT,XDOWN,YACROS                                        VELSUB34
      DIMENSION TSP(51),USP(51),DDT(51),UINT(11),TINT(11)                 VELSUB35
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,      VELSUB36
     1   UPPER,S1,ST                                                      VELSUB37
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1                   VELSUB38
C                                                                         VELSUB39
C  VELPM CALCULATES ALONG VERTICAL MESH LINES WHICH DO NOT                VELSUB40
C  INTERSECT BLADES                                                       VELSUB41
C                                                                         VELSUB42
      ENTRY VELPM                                                         VELSUB43
    5 NSL = 5                                                             VELSUB44
      NSLM1 = NSL-1                                                       VELSUB45
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      LOC ■ 0                                                             VELSUB46
      NSP = ITVL-ITVU+2                                                   VELSUB47
      IP = IV(IM)-1                                                       VELSUB48
      DO 10 IT=1,NSP                                                      VELSUB49
      IP = IP+1                                                           VELSUB50
      TSP(IT) = FLOAT(IT+ITVU-1)*HT                                       VELSUB51
   10 USP(IT) = U(IP)                                                     VELSUB52
      USP(NSP) = USP(1)+1.                                                VELSUB53
      IP = IV(IM)                                                         VELSUB54
      INTU = INT(U(IP)*FLOAT(NSLM1))                                      VELSUB55
      IF (U(IP).GT.0.) INTU=INTU+1                                        VELSUB56
      DO 20 J=1,NSLM1                                                     VELSUB57
      UINT(J) = FLOAT(INTU)/FLOAT(NSLM1)                                  VELSUB58
   20 INTU = INTU+1                                                       VELSUB59
      UINT(NSL) = UINT(1)                                                 VELSUB60
      CALL SPLIPR(HT,USP,NBBI,DDT,AAA)                                    VELSUB61
      GO TO 100                                                           VELSUB62
C                                                                         VELSUB63
C  VELBM CALCULATES ALONG VERTICAL MESHLINES WHICH INTERSECT BLADES       VELSUB64
C                                                                         VELSUB65
      ENTRY VELBM                                                         VELSUB66
      LOC = 1                                                             VELSUB67
      ITVUP1 = ITV(IM,1)                                                  VELSUB68
      ITVLM1 = ITV(IM,2)                                                  VELSUB69
      ITVU ■ ITVUP1-1                                                     VELSUB70
      ITVL = ITVLM1+1                                                     VELSUB71
      NSP = ITVL-ITVU+1                                                   VELSUB72
      TSP(1) = TV(IM,1)                                                   VELSUB73
      TSP(NSP) ■ TV(IM,2)                                                 VELSUB74
      USP(1) = BV(1)                                                      VELSUB75
      USP(NSP) = BV(2)                                                    VELSUB76
      IP = IV(IM)-1                                                       VELSUB77
      NSPM1 = NSP-1                                                       VELSUB78
      IF (2.GT.NSPM1) GO TO 70                                            VELSUB79
      DO 60 IT=2,NSPM1                                                    VELSUB80
      IP = IP+1                                                           VELSUB81
      TSP(IT) = FLOAT(IT+ITVU-1)*HT                                       VELSUB82
   60 USP(IT) = U(IP)                                                     VELSUB83
   70 DO 80 I=1,NSL                                                       VELSUB84
   80 UINT(I) = FLOAT(I-1)/FLOAT(NSLM1)                                   VELSUB85
      CALL SPLINE(TSP,USP,NSP,DDT,AAA)                                    VELSUB86
C                                                                         VELSUB87
C  FOR VELPM AND VELBM, CALCULATE RHO*W-SUB-M IN THE REGION               VELSUB88
C  FOR VELBM, CALCULATE RHO*W AT VERTICAL MESH LINE INTERSECTIONS WITH    VELSUB89
C  BLADE SURFACES                                                         VELSUB90
C                                                                         VELSUB91
  100 CONTINUE                                                            VELSUB92
      IT = LOC                                                            VELSUB93
      IPU = IV(IM)                                                        VELSUB94
      IPL = IV(IM+1)-1                                                    VELSUB95
      DO 110 IP=IPU,IPL                                                   VELSUB96
      IT = IT+1                                                           VELSUB97
      DUDT(IP) = DDT(IT)                                                  VELSUB98
  110 DUDTT(IP) = AAA(IT)                                                 VELSUB99
  120 IF (LOC.EQ.0) GO TO 130                                             VELSU100
      WMB(IM,1) = DDT(1)*WTFL/BE(IM)/RM(IM)                               VELSU101
      WMB(IM,2) = DDT(NSP)*WTFL/BE(IM)/RM(IM)                             VELSU102
      RMDTU2 ■ (RM(IM)*DTDMV(IM,1))**2                                    VELSU103
      RMDTL2 = (RM(IM)*DTDMV(IM,2))**2                                    VELSU104
      IF (RMDTU2.GT.10000.) WMB(IM,1) = 0.                                VELSU105
      IF (RMDTL2.GT.10000.) WMB(IM,2) = 0.                              VELSU106
      WMB(IM,1) = WMB(IM,1)*SQRT(1.+RMDTU2)                             VELSU107
      WMB(IM,2) = WMB(IM,2)*SQRT(1.+RMDTL2)                             VELSU108
  130 IF (SLCPD.LE.0) RETURN                                            VELSU109
      CALL SPLINT(USP,TSP,NSP,UINT,NSL,TINT,AAA,BBB)                    VELSU110
      DO 140 J=1,NSL                                                    VELSU111
      USL(IM,J) = UINT(J)                                               VELSU112
      TSL(IM,J) = TINT(J)                                               VELSU113
      L = (J-1)*MM+IM                                                   VELSU114
  140 TSLPT(L) = TINT(J)                                                VELSU115
      RETURN                                                            VELSU116
      END                                                               VELSU117
      SUBROUTINE VELTAN                                                 VELTAN 2
C                                                                       VELTAN 3
C  VELTAN CALCULATES RHO*W-SUB-THETA AND THEN RHO*W THROUGHOUT THE      VELTAN 4
C  REGION AND ON THE BLADE SURFACES,  AND CALCULATES BETA               VELTAN 5
C  THROUGHOUT THE REGION                                                VELTAN 6
C                                                                       VELTAN 7
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)                        VELTAN 8
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,      VELTAN 9
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,     VELTAN10
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,    VELTAN11
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),      VELTAN12
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),        VELTAN13
     5   PLOSS(50),MSP(50,2),THSP(50,2)                                 VELTAN14
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1, VELTAN15
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,   VELTAN16
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),     VELTAN17
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),        VELTAN18
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),   VELTAN19
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),            VELTAN20
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),   VELTAN21
     7   BEH(100,2),PLOSMH(100,2)                                       VELTAN22
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)               VELTAN23
      LEVEL 2,  A,U,K,RHO                                               VELTAN24
      COMMON /VARCOM/ RHOHB(100,2),RHOVB(100,2),WMB(100,2),WTB(100,2),  VELTAN25
     1   WWCRM(100,2),LABEL(1,100)                                      VELTAN26
      DIMENSION W(2500),BETA(2500),DUDT(2500),DUDTT(2500),AAP(2500),    VELTAN27
     1   BBP(2500)                                                      VELTAN28
      LEVEL 2,  W,BETA,DUDT,DUDTT,AAP,BBP                               VELTAN29
      EQUIVALENCE (A,W),(A(1,2),BETA),(A(1,3),DUDT),(A(1,4),DUDTT),     VELTAN30
     1   (K,AAP),(RHO,BBP)                                              VELTAN31
      DIMENSION SPM(100),USP(100),DDT(100),DUDM(100),DUDMM(100),        VELTAN32
     1   DUDTM(100),DWDM(100),WIP(100)                                  VELTAN33
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,    VELTAN34
     1   UPPER,S1,ST                                                    VELTAN35
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1                 VELTAN36
      EXTERNAL BL1,BL2                                                  VELTAN37
C                                                                       VELTAN38
C  PERFORM CALCULATIONS ALONG ONE HORIZONTAL LINE AT A TIME             VELTAN39
C                                                                       VELTAN40
      IT = ITMIN                                                        VELTAN41
   10 IF (IT.GT.ITMAX) RETURN                                           VELTAN42
      S1 = 0                                                            VELTAN43
C                                                                       VELTAN44
C  ON THE GIVEN HORIZONTAL MESH LINE, FIND A FIRST POINT IN THE REGION  VELTAN45
C                                                                       VELTAN46
      IF (IT.GE.0.AND.IT.LT.NBBI) GO TO 60                              VELTAN47
      IM = MBIM1                                                        VELTAN48
   20 IM = IM+1                                                         VELTAN49
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      IF (IM.GT.MBOP1) GO TO 200                                        VELTAN50
      SURF = 1                                                          VELTAN51
      IF (IT.GE.ITV(IM,1).AND.IT.LT.ITV(IM-1,1)) GO TO 70               VELTAN52
      IF (IM.EQ.MBOP1.AND.IT.EQ.ITV(MBO,1)-1.AND.ITV(MBO,1)-ITV(MBO,2)  VELTAN53
     1   +NBBI.EQ.2) GO TO 70                                           VELTAN54
      SURF = 2                                                          VELTAN55
      IF (IT.LE.ITV(IM,2).AND.IT.GT.ITV(IM-1,2)) GO TO 70               VELTAN56
      GO TO 20                                                          VELTAN57
C                                                                       VELTAN58
C  FIRST POINT IS ON BOUNDARY A-H                                       VELTAN59
C                                                                       VELTAN60
   60 IM1 = 1                                                           VELTAN61
      IM = 1                                                            VELTAN62
      SPM(1) = MV(1)                                                    VELTAN63
      USP (1) = U(IT+1)                                                 VELTAN64
      GO TO 90                                                          VELTAN65
C                                                                       VELTAN66
C  FIRST POINT IS ON A BLADE SURFACE                                    VELTAN67
C                                                                       VELTAN68
   70 S1 = SURF                                                         VELTAN69
      IM1 = IM 1                                                        VELTAN70
      IM2 = IM                                                          VELTAN71
      TH = FLOAT(IT)*HT                                                 VELTAN72
      MVIM1 = MV(IM1)                                                   VELTAN73
      IF (IM.EQ.MBIP1) MVIM1 = MVIM1+(MV(IM2)-MVIM1)/1000.              VELTAN74
      LER(2) = 5                                                        VELTAN75
C     BLCD (VIA ROOT) CALL NO. 5                                        VELTAN76
      IF (S1.EQ.1.AND.IM1.NE.MBO) CALL ROOT(MVIM1,MV(IM2),TH,BL1,DTLR,  VELTAN77
     1   ANS,AAA)                                                       VELTAN78
      LER(2) = 6                                                        VELTAN79
C     BLCD (VIA ROOT) CALL NO. 6                                        VELTAN80
      IF (S1.EQ.2) CALL ROOT(MVIM1,MV(IM2),TH,BL2,DTLR,ANS,AAA)         VELTAN81
      IF (S1.EQ.1.AND.IM1.EQ.MBO) ANS = MV(MBO)                         VELTAN82
      SPM(IM1) = ANS                                                    VELTAN83
      USP(IM1) = BV(S1)                                                 VELTAN84
C                                                                       VELTAN85
C  MOVE ALONG HORIZONTAL MESH LINE UNTIL MESH LINE INTERSECTS BOUNDARY  VELTAN86
C                                                                       VELTAN87
   90 IF (IM.LT.MBI.OR.IM.GT.MBO) GO TO 120                             VELTAN88
      SURF = 1                                                          VELTAN89
      IF (IT.LT.ITV(IM,SURF).AND.IT.GE.ITV(IM-1,SURF)) GO TO 140        VELTAN90
      SURF = 2                                                          VELTAN91
      IF (IT.GT.ITV(IM,SURF).AND.IT.LE.ITV(IM-1,SURF)) GO TO 140        VELTAN92
  120 SPM(IM) = MV(IM)                                                  VELTAN93
      IP = IPF(IM,IT)                                                   VELTAN94
      USP(IM) = U(IP)                                                   VELTAN95
      IF (IM.EQ.MM) GO TO 130                                           VELTAN96
      IM = IM+1                                                         VELTAN97
      GO TO 90                                                          VELTAN98
C                                                                       VELTAN99
C   FINAL POINT IS ON BOUNDARY D-E                                      VELTA100
C                                                                       VELTA101
  130 IMT = MM                                                          VELTA102
      GO TO 150                                                         VELTA103
C                                                                       VELTA104
C  FINAL POINT IS ON A BLADE SURFACE                                    VELTA105
C                                                                       VELTA106
  140 ST = SURF                                                         VELTA107
      IMT = IM                                                          VELTA108
      IMTM1 = IMT-1                                                     VELTA109
      TH = FLOAT(IT)*HT                                                 VELTA110
      MVIM1 ,= MV(IMTM1)                                                VELTA111
      IF (IM.EQ.MBIP1) MVIM1 = MVIM1+(MV(IMT)-MVIM1)/1000.              VELTA112
      LER(2) = 7                                                        VELTA113
C     BLCD (VIA ROOT) CALL NO. 7                                        VELTA114
      IF (ST.EQ.1.AND.IMT.NE.MBI) CALL ROOT(MVIM1,MV(IMT),TH,BL1,       VELTA115
     1   DTLR,ANS,AAA)                                                  VELTA116
      LER(2) = 8                                                        VELTA117
C     BLCD (VIA ROOT) CALL NO. 8                                        VELTA118
      IF (ST.EQ.2) CALL ROOT(MVIM1,MV(IMT),TH,BL2,DTLR,ANS,AAA)         VELTA119
      IF (ST.EQ.1.AND.IMT.EQ.MBI) ANS=MV(MBI)                           VELTA120
      SPM(IMT) = ANS                                                    VELTA121
      USP(IMT) = BV(ST)                                                 VELTA122
  150 NSP = IMT-IM1+1                                                   VELTA123
      CALL SPLINE(SPM(IM1),USP(IM1),NSP,DUDM(IM1),DUDMM(IM1))           VELTA124
C                                                                       VELTA125
C  CALCULATE RHO*W ON THE BLADE SURFACES                                VELTA126
C                                                                       VELTA127
      FIRST = 1                                                         VELTA128
      LAST = MM                                                         VELTA129
      IF (IM1.EQ.1) GO TO 160                                           VELTA130
      FIRST = IM2                                                       VELTA131
      CALL SEARCH (SPM(IM1),S1,IHS)                                     VELTA132
      ANS = DUDM(IM1)*WTFL/BEH(IHS,S1)                                  VELTA133
      IF (S1.EQ.2) ANS=-ANS                                             VELTA134
      WTB(IHS,S1) = ANS*SQRT(1.+1./(RMH(IHS,S1)*DTDMH(IHS,S1))**2)      VELTA135
      DDT(IM1) = -DUDM(IM1)/DTDMH(IHS,S1)                               VELTA136
      WIP(IM1) = WTB(IHS,S1)/RHOHB(IHS,S1)                              VELTA137
  160 IF (IMT.EQ.MM) GO TO 170                                          VELTA138
      LAST = IMTM1                                                      VELTA139
      CALL SEARCH (SPM(IMT),ST,IHS)                                     VELTA140
      ANS = DUDM(IMT)*WTFL/BEH(IHS,ST)                                  VELTA141
      IF (ST.EQ.1) ANS=-ANS                                             VELTA142
      WTB(IHS,ST) = ANS*SQRT(1.+1./(RMH(IHS,ST)*DTDMH(IHS,ST))**2)      VELTA143
      DDT(IMT) = -DUDM(IMT)/DTDMH(IHS,ST)                               VELTA144
      WIP(IMT) = WTB(IHS,ST)/RHOHB(IHS,ST)                              VELTA145
C                                                                       VELTA146
C  CALCULATE RHO*W-SUB-THETA AND THEN RHO*W AND BETA IN THE REGION      VELTA147
C                                                                       VELTA148
  170 IF (FIRST.GT.LAST) GO TO 190                                      VELTA149
      DO 180 I=FIRST,LAST                                               VELTA150
      IP = IPF(I,IT)                                                    VELTA151
      DDT(I) = DUDT(IP)                                                 VELTA152
      RWM = DDT(I)/RM(I)                                                VELTA153
      RWT = -DUDM(I)                                                    VELTA154
      W(IP) = SQRT(RWT**2+RWM**2)/BE(I)*WTFL                            VELTA155
      THLMR = 2.*OMEGA*LAMBDA-(OMEGA*RM(I))**2                          VELTA156
      RHOIPL = RHOIP*(1.-PLOSIM(I))                                     VELTA157
      LER(1) = 6                                                        VELTA158
C     DENSTY CALL NO. 6                                                 VELTA159
      RHOTEM=RHO(IP)                                                    VELTA160
      WTEM=W(IP)                                                        VELTA161
      CALL DENSTY(WTEM,RHOTEM,ANS,THLMR,CPTIP,EXPON,RHOIPL,GAM,AR,TIP,  VELTA162
     1    JZ)                                                           VELTA163
      RHO(IP)=RHOTEM                                                    VELTA164
      W(IP)=WTEM                                                        VELTA165
      W(IP) = ANS                                                       VELTA166
      WIP(I) = W(IP)                                                    VELTA167
      BETA(IP) = ATAN2(RWT,RWM)*57.295779                               VELTA168
  180 CONTINUE                                                          VELTA169
      IF (IEND.LT.0) GO TO 190                                          VELTA170
      CALL SPLINE (SPM(IM1),DDT(IM1),NSP,DUDTM(IM1),AAA(IM1))           VELTA171
      CALL SPLINE (SPM(IM1),WIP(IM1),NSP,DWDM(IM1),AAA(IM1))            VELTA172
      DO 185 I=FIRST,LAST                                               VELTA173
      IP = IPF(I,IT)                                                    VELTA174
      SBETA = SIN(BETA(IP)/57.295779)                                   VELTA175
      CBETA ■ SQRT(1.-SBETA**2)                                         VELTA176
      AAP(IP) = SBETA**2*(2.*DUDTM(I)/DUDM(I)-DUDT(IP)/DUDM(I)**2*      VELTA177
     1   DUDMM(I)-DUDTT(IP)/DUDT(IP))+SAL(I)*SBETA/CBETA*(1.+CBETA**2)  VELTA178
      BBP(IP) = RM(I)/CBETA*(2.*ACTOMG*SAL(I)+SBETA*DWDM(I)/REDFAC)     VELTA179
  185 CONTINUE                                                          VELTA180
  190 CONTINUE                                                          VELTA181
      IF (IMT.NE.MM) GO TO 20                                           VELTA182
  200 IT = IT+1                                                         VELTA183
     ·GO TO 10                                                          VELTA184
      END                                                               VELTA185
      SUBROUTINE SEARCH (DIST,SURF,IS)                                  SEARCH 2
C                                                                       SEARCH 3
C  SEARCH LOCATES THE POSITION OF A GIVEN VALUE OF M IN THE MH ARRAY    SEARCH 4
C                                                                       SEARCH 5
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)                        SEARCH 6
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1, SEARCH 7
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,   SEARCH 8
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),     SEARCH 9
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),        SEARCH10
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),   SEARCH11
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),            SEARCH12
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),   SEARCH13
     7   BEH(100,2),PLOSMH(100,2)                                       SEARCH14
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,    SEARCH15
     1   UPPER,S1,ST                                                    SEARCH16
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1                 SEARCH17
      DO 10 I=1,100                                                     SEARCH18
      IF (ABS(MH(I,SURF)-DIST).GT.DMLR) GO TO 10                        SEARCH19
      IS = I                                                            SEARCH20
      RETURN                                                            SEARCH21
   10 CONTINUE                                                          SEARCH22
      WRITE(NWRIT,1000) DIST,SURF                                       SEARCH23
      STOP                                                              SEARCH24
 1000 FORMAT (38HL SEARCH CANNOT FIND M IN THE MH ARRAY/7H DIST =,G14.6,SEARCH25
     110X,6HSURF =,G14.6)                                               SEARCH26
      END                                                               SEARCH27
      SUBROUTINE STRLIN                                                 STRLIN 2
C                                                                       STRLIN 3
C  STRLIN CALCULATES, PRINTS, AND PLOTS THE STREAMLINE OUTPUT DATA      STRLIN 4
C                                                                       STRLIN 5
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)                        STRLIN 6
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,      STRLIN 7
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,     STRLIN 8
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,    STRLIN 9
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),      STRLIN10
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),        STRLIN11
     5   PLOSS(50),MSP(50,2),THSP(50,2)                                 STRLIN12
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1, STRLIN13
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,   STRLIN14
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),     STRLIN15
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),        STRLIN16
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),   STRLIN17
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),            STRLIN18
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),   STRLIN19
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    7   BEH(100,2),PLOSMH(100,2)                                         STRLIN20
      COMMON /SLCOM/ USL(100,11),TSL(100,11)                             STRLIN21
      LEVEL 2,  USL,TSL                                                  STRLIN22
      COMMON /PLTCOM/ TSLPT(1100),XDOWN(400),YACROS(400)                 STRLIN23
      LEVEL 2,  TSLPT,XDOWN,YACROS                                       STRLIN24
      COMMON /DUM1/ MSL(100)                                             STRLIN25
      LEVEL 2,  MSL                                                      STRLIN26
      DIMENSION DTDM(100),D2TDM2(100),KKK(24),P(11)                      STRLIN27
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,     STRLIN28
     1   UPPER,S1,ST                                                     STRLIN29
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1                  STRLIN30
      DATA KKK(4)/1H*/,KKK(6)/1H*/,KKK(8)/1H*/,KKK(10)/1H*/,KKK(12)/1H*/STRLIN31
     1   ,KKK(14)/1H*/,KKK(16)/1H*/,KKK(18)/1H*/,KKK(20)/1H*/,           STRLIN32
     2   KKK(22)/1H*/,KKK(24)/1H*/                                       STRLIN33
C                                                                        STRLIN34
C  CALCULATE AND PRINT STREAMLINE OUTPUT DATA                            STRLIN35
C                                                                        STRLIN36
      IF (SLCRD.LE.0) RETURN                                             STRLIN37
      NSL = 5                                                            STRLIN38
      MMBL = MBO-MBI+1                                                   STRLIN39
      RADDEG = 180./3.1415927                                            STRLIN40
      IF (REDFAC.LT.1.) WRITE(NWRIT,1000)                                STRLIN41
      IF (REDFAC.EQ.1.) WRITE(NWRIT,1010)                                STRLIN42
      DO 70 J=1,NSL                                                      STRLIN43
      TSLTEM=TSL(MBI,J)                                                  STRLIN44
      CALL SPLINE(MV(MBI),TSLTEM,MMBL,DTDM(MBI),D2TDM2(MBI))             STRLIN45
      TSL(MBI,J)=TSLTEM                                                  STRLIN46
      WRITE(NWRIT,1020) J                                                STRLIN47
      DO 40 IM=1,MBIM1                                                   STRLIN48
   40 WRITE(NWRIT,1030) IM,MV(IM),RM(IM),USL(IM,J),TSL(IM,J)             STRLIN49
      DO 50 IM=MBI,MBO                                                   STRLIN50
      BETASL = ATAN(RM(IM)*DTDM(IM))*RADDEG                              STRLIN51
      CURVSL = (RM(IM)*D2TDM2(IM)+SAL(IM)*DTDM(IM))/(1.+(RM(IM)*         STRLIN52
     1   DTDM(IM))**2)**1.5                                              STRLIN53
      IF (DTDM(IM).NE.0.) DTDMN=-1./RM(IM)**2/DTDM(IM)                   STRLIN54
      IF (DTDM(IM).EQ.0.) DTDMN=1.E10                                    STRLIN55
   50 WRITE(NWRIT,1040) IM,MV(IM),RM(IM),USL(IM,J),TSL(IM,J),DTDM(IM),   STRLIN56
     1   DTDMN,BETASL,CURVSL                                             STRLIN57
      DO 60 IM=MBOP1,MM                                                  STRLIN58
   60 WRITE(NWRIT,1030) IM,MV(IM),RM(IM),USL(IM,J),TSL(IM,J)             STRLIN59
   70 CONTINUE                                                           STRLIN60
C                                                                        STRLIN61
C  PLOT STREAMLINES                                                      STRLIN62
C                                                                        STRLIN63
      KKK(1) = 7                                                         STRLIN64
      KKK(2) = NSL                                                       STRLIN65
      KKK(3) = MM                                                        STRLIN66
      P(1) = 1.                                                          STRLIN67
      P(3) = 0.                                                          STRLIN68
      P(4) = 0.                                                          STRLIN69
      DO 80 IM=1,MM                                                      STRLIN70
   80 MSL(IM) = MV(IM)                                                   STRLIN71
      IF (REDFAC.LT.1.) WRITE(NWRIT,1050)                                STRLIN72
      IF (REDFAC.EQ.1.) WRITE(NWRIT,1060)                                STRLIN73
      CALL PLOTMY(MSL,TSLPT,KKK,P)                                       STRLIN74
      WRITE(NWRIT,1070)                                                  STRLIN75
      RETURN                                                             STRLIN76
C                                                                        STRLIN77
C  FORMAT STATEMENTS                                                     STRLIN78
C                                                                        STRLIN79
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 1000 FORMAT (1H1,2X,44HSTREAMLINE COORDINATES FOR REDUCED MASS FLOW)    STRLIN80
 1010 FORMAT (1H1,2X,41HSTREAMLINE COORDINATES FOR FULL MASS FLOW)       STRLIN91
 1020 FORMAT (////4X,14HSTREAMLINE NO.,I3,23H  - WITHIN BLADE REGION//   STRLIN82
     1   8X,2HIM,8X,1HM,14X,1HR,13X,3HUSL,12X,3HTSL,12X,4HDTDM,10X,      STRLIN83
     2   5HDTDMN,10X,6HBETASL,9X,6HCURVSL)                               STRLIN84
 1030 FORMAT (7X,I3,2G15.5,3X,F7.3,5X,G15.5)                             STRLIN85
 1040 FORMAT (7X,I3,2G15.5,3X,F7.3,5X,3G15.5,3X,F7.2,5X,G15.5)           STRLIN86
 1050 FORMAT (1H1,50X,38HSTREAMLINE PLOTS FOR REDUCED MASS FLOW)         STRLIN87
 1060 FORMAT (1H1,50X,35HSTREAMLINE PLOTS FOR FULL MASS FLOW)            STRLIN88
 1070 FORMAT (    /40X,70HSTREAMLINES ARE PLOTTED WITH THETA ACROSS THE STRLIN89
     1PAGE AND M DOWN THE PAGE)                                          STRLIN90
      END                                                                STRLIN91
      SUBROUTINE OUTPUT                                                  OUTPUT 2
C                                                                        OUTPUT 3
C  OUTPUT CALLS SUBROUTINES TO CALCULATE DENSITIES AND VELOCITIES        OUTPUT 4
C  THROUGHOUT THE REGION AND ON THE BLADE SURFACES, AND IT PLOTS         OUTPUT 5
C  THE SURFACE VELOCITIES                                                OUTPUT 6
C                                                                        OUTPUT 7
      DIMENSION PRES(100,2),PRATIO(100,2),XVDIM(100),CPT(100,2)          OUTPUT 8
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)                         OUTPUT 9
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,       OUTPUT10
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,      OUTPUT11
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,     OUTPUT12
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),       OUTPUT13
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),         OUTPUT14
     5   PLOSS(50),MSP(50,2),THSP(50,2)                                  OUTPUT15
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,  OUTPUT16
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,    OUTPUT17
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),      OUTPUT18
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),         OUTPUT19
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),    OUTPUT20
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),             OUTPUT21
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),    OUTPUT22
     7   BEH(100,2),PLOSMH(100,2)                                        OUTPUT23
      COMMON /VARCOM/ RHOHB(100,2),RHOVB(100,2),WMB(100,2),WTB(100,2),   OUTPUT24
     1   WHCRM(100,2),LABEL(1,100)                                       OUTPUT25
      COMMON /PLTCOM/ TSLPT(1100),XDOWN(400),YACROS(400)                 OUTPUT26
      LEVEL 2,  TSLPT,XDOWN,YACROS                                       OUTPUT27
      DIMENSION KKK(14)                                                  OUTPUT28
      DIMENSION P(11)                                                    OUTPUT29
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,     OUTPUT30
     1   UPPER,S1,ST                                                     OUTPUT31
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1                  OUTPUT32
      DATA KKK(4)/1H*/,KKK(6)/1H0/,KKK(8)/1H+/,KKK(10)/1HX/              OUTPUT33
C                                                                        OUTPUT34
C  CALL VELP, VELB, AND VELSUR THROUGHOUT THE REGION                     OUTPUT35
C                                                                        OUTPUT36
      IF (INTVL.GT.0) CALL VELP(1,MBIM1)                                 OUTPUT37
      CALL VELB(MBI,MBO)                                                 OUTPUT38
   20 IF (INTVL.GT.0) CALL VELP(MBOP1,MM)                                OUTPUT39
      CALL VELSUR                                                        OUTPUT40
C                                                                        OUTPUT41
C  PREPARE INPUT ARRAYS FOR PLOT OF VELOCITIES                           OUTPUT42
C                                                                        OUTPUT43
      IF (SURVL.LE.0) RETURN                                             OUTPUT44
      NP2 = 0                                                            OUTPUT45
C                                                                        OUTPUT46
C   TANGENTIAL COMPONENTS                                                OUTPUT47
      DO 50 SURF=1,2                                                     OUTPUT48
      NP1 = NP2                                                          OUTPUT49
      IMSS = IMS(SURF)
      IF (IMSS.LT.1) GO TO 40
      DO 30 IHS=1,IMSS
      IF (ABS(DTDMH(IHS,SURF)*RMH(IHS,SURF)).LT..57735) GO TO 30
      NP1 = NP1+1
      YACROS(NP1) ■ WTB(IHS,SURF)
      XDOWN(NP1) = MH(IHS,SURF)
   30 CONTINUE
   40 KKK(2*SURF+1) = NP1-NP2
   50 NP2 = NP1
C
C  MERIDIONAL COMPONENTS
      DO 80 SURF=1,2
      NP1 = NP2
      DO 60 IM=MBIP1,MBOM1
      IF (ABS(DTDMV(IM,SURF)*RM(IM)).GT.1.7321) GO TO 60
      NP1 = NP1+1
      YACROS(NP1) = WMB(IM,SURF)
      XDOWN(NP1) = MV(IM)
   60 CONTINUE
   70 KKK(2*SURF+5) = NP1-NP2
   80 NP2 = NP1
C
C  PLOT VELOCITIES
C
      KK1 = KKK(3)
      KK2 = KKK(5)
      KK3 = KKK(7)
      KK4 = KKK(9)
      IF (BLDAT.GE.2) CALL VEPLOT(KK1,KK2,KK3,KK4)
      KKK(1) = 1
      KKK(2) = 4
      P(1)   = 5.
      IF (REDFAC.LT.1.) WRITE(NWRIT,1000)
      IF (REDFAC.EQ.1.) WRITE(NWRIT,1020)
      CALL PLOTMY(XDOWN,YACROS,KKK,P)
      WRITE(NWRIT,1010)
      PTOTAL = RHOIP*AR*TIP
      DO 90 IS= 1,2
      PRESIN = PTOTAL
      DO 90 IM = MBI,MBO
      XVDIM(IM)=MV(IM)/MV(MBO)
      TWLMI  ■ 2.*OMEGA*LAMBDA - (OMEGA*RM(IM))**2
      PRES(IM,IS) = PTOTAL*(1.-PLOSIM(IM))*(1.-(WMB(IM,IS)**2+TWLMI)/
     1         CPTIP)**(GAM/(GAM-1.))
      PRATIO(IM,IS)=PRES(IM,IS)/PRESIN
      CPT(IM,IS)=PRATIO(IM,IS)-1.
   90 CONTINUE
      IF(REDFAC.LT.1.) WRITE (NWRIT,998)
      IF(REDFAC.EQ.1.) WRITE (NWRIT,999)
      WRITE(6,1100)
      DO 91 IM ■ MBI,MBO
      WRITE (6,1001)IM,MV(IM),XVDIM(IM),PRATIO(IM,1),PRATIO(IM,2),CPT(
     1IM,1),CPT(IM,2)
   91 CONTINUE
      MB2=MBI+1
      IND=MBI+MBO
      IF (IEND.LE.0) RETURN
      WRITE (9,1003) TITLEI
      W?ITE (9,1002) (XVDIM(IND-IM),IM=MBI,MBO),(XVDIM(IM),IM=MB2,MBO)
      WRITE (9,1002) (   CPT(IND-IM,2),IM=MBI,MBO),
     1               (   CPT(IM,1),IM=MB2,MBO)
  998 FORMAT (1H1,50X,47HBLADE SURFACE PRESSURES FOR REDUCED WEIGHT FLOW
     1 /)
  999 FORMAT (1H1,50X,44HBLADE SURFACE PRESSURES FOR FULL WEIGHT FLOW /)
 1100 FORMAT (1H ,7X,3HIM ,8X,7H  M     ,8X,7H  M/MC  ,8X,7HP(1)/PT,
     18X,7HP(2)/PT,8X,7HCPT(1) ,8X,7HCPT(2) ,/)
 1001 FORMAT(5X,I5,6(6X,G10.4))
 1002 FORMAT (8F10.6)
 1003 FORMAT (20A4)
      RETURN
C
C  FORMAT STATEMENTS
C
 1000 FORMAT(1H1,50X48HBLADE SURFACE VELOCITIES FOR REDUCED WEIGHT FLOW)
 1010 FORMAT ( 39X    ,63HVELOCITY(W) VS. MERIDIONAL STREAMLINE DISTANCE
     1(M) DOWN THE PAGE  //
     2   52X,50H+ - BLADE SURFACE 1, BASED ON MERIDIONAL COMPONENT/
     3   52X,50H* - BLADE SURFACE 1, BASED ON TANGENTIAL COMPONENT/
     4   52X,50HX - BLADE SURFACE 2, BASED ON MERIDIONAL COMPONENT/
     5   52X,50HO - BLADE SURFACE 2, BASED ON TANGENTIAL COMPONENT)
 1020 FORMAT(1H1,50X,45HBLADE SURFACE VELOCITIES FOR FULL WEIGHT FLOW)
      END
      SUBROUTINE VEL (FIRST,LAST)
C
C  VEL CALCULATES DENSITIES AND VELOCITIES FROM THE PRODUCT OF
C  DENSITY TIMES VELOCITY
C
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),
     5   PLOSS(50),MSP(50,2),THSP(50,2)
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),
     7   BEH(100,2),PLOSMH(100,2)
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)
      LEVEL 2,  A,U,K,RHO
      COMMON /VARCOM/ RHOHB(100,2),RHOVB(100,2),WMB(100,2),WTB(100,2),
     1   WWCRM(100,2),LABEL(1,100)
      DIMENSION W(2500),BETA(2500),DUDT(2500),DUDTT(2500),AAP(2500),
     1   BBP(2500)
      LEVEL 2,  W,BETA,DUDT,DUDTT,AAP,BBP
      EQUIVALENCE (A,W),(A(1,2),BETA),(A(1,3),DUDT),(A(1,4),DUDTT),
     1   (K,AAP),(RHO,BBP)
      DIMENSION WWCRT(100,2),SURFL(100,2)
C
C  VELP WRITES OUTPUT ALONG VERTICAL MESH LINES WHICH DO NOT
C  INTERSECT BLADES
C
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,
     1   UPPER,S1,ST
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1
      DATA REDFUL/7HREDUCED/,FULL/6H  FULL/
      ENTRY VELP
      IF (REDFAC.EQ.1) REDFUL=FULL
      IF (FIRST.GT.LAST) RETURN
      IF (FIRST.EQ.1) WRITE(NWRIT,1000) REDFUL
      DO 20 IM=FIRST,LAST
      IPU = IV(IM)
      IPL = IPU+NBBI-1
      WRITE(NWRIT,1010) IM,(W(IP),BETA(IP),IP=IPU,IPL)
   20 CONTINUE
      RETURN
C
C  VELB CALCULATES ALONG VERTICAL MESH LINES WHICH INTERSECT BLADES
C
      ENTRY VELB
      IF (FIRST.GT.LAST) RETURN
      IF (FIRST.NE.MBI) GO TO 30
      RELER =  0.
      RELERA = 0.
      ZMREL = 0.
      IMREL = 0
      ITREL = 0
      ISREL = 0
      ICOUNT = 0
      SURFL(MBI,1) = 0.
      SURFL(MBI,2) ■ 0.
   30 DO 75 IM=FIRST,LAST
      ITVU ■ ITV(IM,1)
      ITVL ■ ITV(IM,2)
      IPUP1 = IPF(IM,ITVU)
      IPLM1 = IPF(IM,ITVL)
      TWLMR = 2.*OMEGA*LAMBDA-(OMEGA*RM(IM))**2
      WCR = SQRT(TGROG*TIP*(1.-TWLMR/CPTIP))
      IF (ITVL.LT.ITVU) GO TO 50
C  ALONG THE LINE BETWEEN BLADES
      IF (INTVL.LE.0) GO TO 50
      WRITE(NWRIT,1010) IM,(W(IP),BETA(IP),IP=IPUP1,IPLM1)
C  ON THE UPPER SURFACE
   50 RHOB = RHOVB(IM,1)
      RHOIPL = RHOIP*(1.-PLOSIM(IM))
      LER(1) = 7
C     DENSTY CALL NO. 7
      CALL DENSTY(WMB(IM,1),RHOVB(IM,1),ANS,TWLMR,CPTIP,EXPON,RHOIPL,
     1   GAM,AR,TIP,JZ)
      WMB(IM,1) = ANS
      WWCRM(IM,1) = WMB(IM,1)/WCR
      IF (IM.EQ.MBI) GO TO 60
      DELTV ■ TV(IM-1,1)-TV(IM,1)
      SURFL(IM,1) = SURFL(IM-1,1)+SQRT((MV(IM)-MV(IM-1))**2+
     1   (DELTV*(RM(IM)+RM(IM-1))/2.)**2)
   60 ERR = ABS((RHOB-RHOVB(IM,1))/RHOVB(IM,1))
      RELER = AMAX1(RELER,ERR)
      RELERA = RELERA+ERR
      IF (RELER.NE.ERR) GO TO 65
      IMREL = IM
      ISREL = 1
      ZMREL = MV(IM)
   65 IF (ERR.GE.DENTOL) ICOUNT=ICOUNT+1
C  ON THE LOWER SURFACE
      RHOB = RHOVB(IM,2)
      RHOIPL = RHOIP*(1.-PLOSIM(IM))
      LER(1) = 8
C     DENSTY CALL NO. 8
      CALL DENSTY(WMB(IM,2),RHOVB(IM,2),ANS,TWLMR,CPTIP,EXPON,RHOIPL,
     1   GAM,AR,TIP,JZ)
      WMB(IM,2) = ANS
      WWCRM(IM,2) = WMB(IM,2)/WCR
      IF (IM.EQ.MBI) GO TO 70
      DELTV = TV(IM-1,2)-TV(IM,2)
      SURFL(IM,2) = SURFL(IM-1,2)+SQRT((MV(IM)-MV(IM-1))**2+
     1   (DELTV*(RM(IM)+RM(IM-1))/2.)**2)
   70 ERR = ABS((RHOB-RHOVB(IM,2))/RHOVB(IM,2))
      RELER = AMAX1(RELER,ERR)
      RELERA = RELERA+ERR
      IF (RELER.NE.ERR) GO TO 75
      IMREL = IM
      ISREL = 2
      ZMREL = MV(IM)
   75 IF (ERR.GE.DENTOL) ICOUNT=ICOUNT+1
      RETURN
C
C  VELSUR CALCULATES WHERE HORIZONTAL MESH LINES INTERSECT THE BLADES
C
      ENTRY VELSUR
      ITERMX = 10
      DO 90 SURF=1,2
      IMSS = IMS(SURF)
      IF (IMSS.EQ.0) GO TO 90
      DO 80 IHS=1,IMSS
      TWLMR = 2.*OMEGA*LAMBDA-(OMEGA*RMH(IHS,SURF))**2
      WCR = SQRT(TGROG*TIP*(1.-TWLMR/CPTIP))
      RHOB = RHOHB(IHS,SURF)
      RHOIPL = RHOIP*(1.-PLOSMH(IHS,SURF))
      LER(1) = 9
C     DENSTY CALL NO. 9
      CALL DENSTY(WTB(IHS,SURF),RHOHB(IHS,SURF),ANS,TWLMR,CPTIP,
     1   EXPON,RHOIPL,GAM,AR,TIP,JZ)
      WTB(IHS,SURF) = ANS
      WWCRT(IHS,SURF) = WTB(IHS,SURF)/WCR
      ERR ■ ABS((RHOB-RHOHB(IHS,SURF))/RHOHB(IHS,SURF))
      RELER = AMAX1(RELER,ERR)
      RELERA = RELERA+ERR
      IF (RELER.NE.ERR) GO TO 80
      IMREL = 0
      IF (SURF.EQ.1) CALL BL1(MH(IHS,SURF),THET,DTDM,INF)
      IF (SURF.EQ.2) CALL BL2(MH(IHS,SURF),THET,DTDM,INF)
      ITREL = THET/HT+SIGN(.1,THET)
      ISREL = SURF
      ZMREL = MH(IHS,SURF)
   80 IF (ERR.GE.DENTOL) ICOUNT=ICOUNT+1
   90 CONTINUE
      IF (RELER.LT.DENTOL.OR.ITER.GE.ITERMX) IEND=IEND+1
      RELERA = RELERA/FLOAT(2*(MBO-MBI+1)+IMS(1)+IMS(2))
      WRITE(NWRIT,1080) ITER,RELER,IMREL,ITREL,ISREL,ZMREL,RELERA,ICOUNT
C
C   WRITE ALL BLADE SURFACE VELOCITIES
C
      IF (SURVL.LE.0) RETURN
      WRITE (NWRIT,1020) REDFUL
      WRITE(NWRIT,1040) (MV(IM),WMB(IM,1),BETAV(IM,1),SURFL(IM,1),
     1   WWCRM(IM,1),WMB(IM,2),BETAV(IM,2),SURFL(IM,2),WWCRM(IM,2),
     2   IM=MBI,MBO)
      WRITE (NWRIT,1050) REDFUL
      DO 100 SURF=1,2
      IMSS = IMS(SURF)
      IF (IMSS.LT.1) GO TO 100
      WRITE(NWRIT,1060) SURF
      WRITE(NWRIT,1070) (MH(IHS,SURF),WTB(IHS,SURF),BETAH(IHS,SURF),
     1   WWCRT(IHS,SURF), IHS=1,IMSS)
  100 CONTINUE
      RETURN
C
C  FORMAT STATEMENTS
C
 1000 FORMAT(1H1/40X,34HVELOCITIES AT INTERIOR MESH POINTS/45X,
     1   4HFOR ,A8,11HWEIGHT FLOW)
 1010 FORMAT(1HL,3HIM=,I3,5(24H   VELOCITY   ANGLE(DEG))/
     1(5X,5(G15.4,F9.2)))
 1020 FORMAT(1H1/16X,1H*,18X,52HSURFACE VELOCITIES BASED ON MERIDIONAL C
     1OMPONENTS - ,A8,11HWEIGHT FLOW,18X,1H*/16X,1H*,53X,1H*,53X,1H*/
     2   16X,1H*,19X,15HBLADE SURFACE 1,19X,1H*,20X,15HBLADE SURFACE 2,
     3   18X,1H*/7X,1HM,8X,1H*,2(3X,8HVELOCITY,3X,23HANGLE(DEG) SURF. LE
     4NGTH,5X,5HW/WCR,6X,1H*))
 1040 FORMAT((1H ,G13.4,3H  *,2(G12.4,F9.2,2G15.4,3H  *)))
 1050 FORMAT(1H1/3X,49HSURFACE VELOCITIES BASED ON TANGENTIAL COMPONENTS
     1   /18X,A8,11HWEIGHT FLOW)
 1060 FORMAT(//22X,15HBLADE SURFACE  ,I1/7X,1HM,10X,8HVELOCITY,3X,10HANG
     1LE(DEG),3X,5HW/WCR)
 1070 FORMAT(1H ,2G13.4,F9.2,G15.4)
 1080 FORMAT (///5X,14HITERATION  NO.,I4/5X,60HMAXIMUM RELATIVE CHANGE I
     1N DENSITY AT BLADE SURFACE POINTS =,G11.4,10H   AT IM =,I3,
     28H,   IT =,I3,10H,   SURF =,I2,7H,   M =,G11.4/5X,60HAVERAGE RELAT
     3IVE CHANGE IN DENSITY AT BLADE SURFACE POINTS =,G11.4/5X,49HNUMBER
     4 OF UNCONVERGED BLADE SURFACE MESH POINTS =,I4)
      END
      SUBROUTINE TVELCY
C
C  TVELCY SOLVES THE FULL MASS FLOW PROBLEM BY OBTAINING A
C  VELOCITY GRADIENT SOLUTION ALONG EACH VERTICAL MESH LINE
C
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),
     5   PLOSS(50),MSP(50,2),THSP(50,2)
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),
     7   BEH(100,2),PLOSMH(100,2)
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)
      LEVEL 2,  A,U,K,RHO
      COMMON /VARCOM/ RHOHB(100,2),RHOVB(100,2),WMB(100,2),WTB(100,2),
     1   WWCRM(100,2),LABEL(1,100)
      COMMON /PLTCOM/ TSLPT(1100),XDOWN(400),YACROS(400)
      LEVEL 2,  TSLPT,XDOWN,YACROS
      DIMENSION W(2500),BETA(2500),DUDT(2500),DUDTT(2500),AAP(2500),
     1   BBP(2500)
      LEVEL 2,  W,BETA,DUDT,DUDTT,AAP,BBP
      EQUIVALENCE (A,W),(A(1,2),BETA),(A(1,3),DUDT),(A(1,4),DUDTT),
     1   (K,AAP),(RHO,BBP)
      DIMENSION KKK(14)
      DIMENSION P(11)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,SURFBV,
     1FIRST,UPPER,UPPRBV,S1,ST
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1
C
C  CALL VELGRP AND VELGRB THROUGHOUT THE SOLUTION REGION
C
      LAMBDA ▣ ACTLAM
      IF (INTVL.GT.0) WRITE(NWRIT,1000)
      IF (1.GT.MBIM1) GO TO 20
      DO 10 IM=1,MBIM1
   10 CALL VELGRP(IM)
   20 DO 30 IM=MBIP1,MBOM1
   30 CALL VELGRB(IM)
      IF (MBOP1.GT.MM) GO TO 50
      DO 40 IM=MBOP1,MM
   40 CALL VELGRP(IM)
C
C  FIX VELOCITIES ON LEADING AND TRAILING EDGE LINES
C
   50 FIRST = IV(MBI)
      LAST = IV(MBIP1)-1
      DO 54 I=FIRST,LAST
   54 W(I) = W(I)/REDFAC
      FIRST = IV(MBO)
      LAST = IV(MBOP1)-1
      DO 56 I=FIRST,LAST
   56 W(I) = W(I)/REDFAC
C
C  WRITE SURFACE VELOCITIES
C
      IF (SURVL.LE.0) RETURN
      WRITE(NWRIT,1010)
      WRITE(NWRIT,1020)(MV(IM),WMB(IM,1),WWCRM(IM,1),LABEL(1,IM),
     1   WMB(IM,2),WWCRM(IM,2),LABEL(1,IM),IM=MBIP1,MBOM1)
C
C   PREPARE ARRAYS FOR PLOT OF SURFACE VELOCITIES
C
      DO 60 IM=MBIP1,MBOM1
      I ▣ IM-MBI
      I2 = I+MBOM1-MBI
      XDOWN(I) ▣ MV(IM)
      YACROS(I) ▣ WMB(IM,1)
   60 YACROS(I2) = WMB(IM,2)
      KKK(1) = 0
      KKK(2) = 2
      KKK(3) = MBOM1-MBI
      P(1)   = 1.
C
C   PLOT SURFACE VELOCITIES
C
      IF (BLDAT.GE.2) CALL TVPLOT
      WRITE(NWRIT,1030)
      CALL PLOTMY (XDOWN,YACROS,KKK,P)                                  TVELCY87
      WRITE(NWRIT,1040)                                                 TVELCY88
      RETURN                                                            TVELCY89
C                                                                       TVELCY90
C  FORMAT STATEMENTS                                                    TVELCY91
C                                                                       TVELCY92
 1000 FORMAT(1H1/40X,34HVELOCITIES AT INTERIOR MESH POINTS/44X,         TVELCY93
     1   27H(BASED ON FULL WEIGHT FLOW))                                TVELCY94
 1010 FORMAT(1H1/16X,1H*,13X,68HSURFACE VELOCITIES BASED ON MERIDIONAL CTVELCY95
     1OMPONENTS - FULL WEIGHT FLOW,30X,1H*/16X,1H*,55X,1H*,55X,1H*/16X, TVELCY96
     21H*,20X,15HBLADE SURFACE 1,20X,1H*,20X,15HBLADE SURFACE 2,20X,1H*/TVELCY97
     37X,1HM,8X,1H*,2(3X,8HVELOCITY,6X,5HW/WCR,33X,1H*))                TVELCY98
 1020 FORMAT((1X,G13.4,3H  *,2(2G13.4,A8,21X,1H*)))                     TVELCY99
 1030 FORMAT(1H1,51X,24HBLADE SURFACE VELOCITIES/51X,27H(BASED ON FULL WTVELC100
     1EIGHT FLOW))                                                      TVELC101
 1040 FORMAT(39X,63HVELOCITY(W) VS. MERIDIONAL STREAMLINE DISTANCE(M) DOTVELC102
     1WN THE PAGE//52X,19H* - BLADE SURFACE 1/52X,19H+ - BLADE SURFACE 2TVELC103
     2)                                                                 TVELC104
      END                                                               TVELC105
      SUBROUTINE VELGRA (IM)                                            VELGRA 2
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)                        VELGRA 3
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,      VELGRA 4
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,     VELGRA 5
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,    VELGRA 6
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),      VELGRA 7
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),        VELGRA 8
     5   PLOSS(50),MSP(50,2),THSP(50,2)                                 VELGRA 9
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1, VELGRA10
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,   VELGRA11
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),     VELGRA12
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),        VELGRA13
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),   VELGRA14
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),            VELGRA15
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),   VELGRA16
     7   BEH(100,2),PLOSMH(100,2)                                       VELGRA17
      COMMON /AUKRHO/ A(2500,4),U(2500),K(2500),RHO(2500)               VELGRA18
      LEVEL 2,  A,U,K,RHO                                               VELGRA19
      COMMON /VARCOM/ RHOHB(100,2),RHOVB(100,2),WMB(100,2),WTB(100,2),  VELGRA20
     1   WWCRM(100,2),LABEL(1,100)                                      VELGRA21
      COMMON /BCDCOM/ INIT(2),EM(50,2),D2TDM2(100,2)                    VELGRA22
      DIMENSION W(2500),BETA(2500),DUDT(2500),DUDTT(2500),AAP(2500),    VELGRA23
     1   BBP(2500)                                                      VELGRA24
      EQUIVALENCE (A,W),(A(1,2),BETA),(A(1,3),DUDT),(A(1,4),DUDTT),     VELGRA25
     1   (K,AAP),(RHO,BBP)                                              VELGRA26
      DIMENSION WGRAD(51),THETA(51),RWCB(51),CBETA(51),A2(51),B2(51)    VELGRA27
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,SURFBV,   VELGRA28
     1FIRST,UPPER,UPPRBV,S1,ST,CHOKED,BLANK                             VELGRA29
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1                 VELGRA30
      DATA CHOKED/6HCHOKED/,BLANK/1H /                                  VELGRA31
C                                                                       VELGRA32
C  VELGRP SOLVES IN THE PERIODIC REGION                                 VELGRA33
C                                                                       VELGRA34
      ENTRY VELGRP                                                      VELGRA35
      AORB = 1.                                                         VELGRA36
      IP = IV(IM)                                                       VELGRA37
      WGRAD(1) ■ W(IP)/REDFAC                                           VELGRA38
      IT1 = ITV(IM,1)                                                   VELGRA39
      IT = IT1                                                          VELGRA40
      NSP = NBBI+1                                                      VELGRA41
      GO TO 10                                                          VELGRA42
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C                                                                       VELGRA43
C  VELGRB SOLVES IN THE BLADE REGION                                    VELGRA44
C                                                                       VELGRA45
      ENTRY VELGRB                                                      VELGRA46
      IP = IV(IM)-1                                                     VELGRA47
      WGRAD(1) = WMB(IM,1)/REDFAC                                       VELGRA48
      NSP ■ IV(IM+1)-IV(IM)+2                                           VELGRA49
      AORB = 2.                                                         VELGRA50
      IT1 = ITV(IM,1)                                                   VELGRA51
      IT = IT1-1                                                        VELGRA52
   10 NSPM1 ■ NSP-1                                                     VELGRA53
      LABEL(1,IM) ■ BLANK                                               VELGRA54
      TORSAL = 2.*ACTOMG*RM(IM)*SAL(IM)                                 VELGRA55
      JZ = 1                                                            VELGRA56
      IF (IM.GE.IMS1.AND.IM.LE.IMS2) JZ=2                               VELGRA57
      TWLMR = 2.*ACTOMG*LAMBDA-(ACTOMG*RM(IM))**2                       VELGRA58
      WCR = SQRT(TGROG*TIP*(1.-TWLMR/CPTIP))                            VELGRA59
      DELMAX = WCR/ 10.                                                 VELGRA60
      TOLERC = WCR/ 100.                                                VELGRA61
      DO 20 I=1,NSPM1                                                   VELGRA62
      CBETA(I) = COS(BETA(IP)/57.295779)                                VELGRA63
      THETA(I) = HT*FLOAT(IT)                                           VELGRA64
      A2(I) = AAP(IP)                                                   VELGRA65
      B2(I) = BBP(IP)                                                   VELGRA66
      IT ■ IT+1                                                         VELGRA67
   20 IP ■ IP+1                                                         VELGRA68
      CBETA(NSP) = CBETA(1)                                             VELGRA69
      A2(NSP) = A2(1)                                                   VELGRA70
      B2(NSP) = B2(1)                                                   VELGRA71
      THETA(NSP) = HT*FLOAT(IT)                                         VELGRA72
      IF (AORB.LE.1.) GO TO 30                                          VELGRA73
      CBETA(1) = 1./SQRT(1.+(RM(IM)*DTDMV(IM,1))**2)                    VELGRA74
      SBETA1 = SQRT(1.-CBETA(1)**2)*SIGN(1.,DTDMV(IM,1))                VELGRA75
      A2(1) = (RM(IM)*CBETA(1))**2*D2TDM2(IM,1)+SAL(IM)*SBETA1/         VELGRA76
     1   CBETA(1)*(1.+CBETA(1)**2)                                      VELGRA77
      B2(1) = B2(2)+TORSAL*(1./CBETA(1)-1./CBETA(2))                    VELGRA78
      THETA(1) = TV(IM,1)                                               VELGRA79
      CBETA(NSP) ■ 1./SQRT(1.+(RM(IM)*DTDMV(IM,2))**2)                  VELGRA80
      SBETAN = SQRT(1.-CBETA(NSP)**2)*SIGN(1.,DTDMV(IM,2))              VELGRA81
      A2(NSP) = (RM(IM)*CBETA(NSP))**2*D2TDM2(IM,2)+SAL(IM)*SBETAN/     VELGRA82
     1   CBETA(NSP)*(1.+CBETA(NSP)**2)                                  VELGRA83
      B2(NSP) = B2(NSPM1)+TORSAL*(1./CBETA(NSP)-1./CBETA(NSPM1))        VELGRA84
      THETA(NSP) = TV(IM,2)                                             VELGRA85
   30 IND = 1                                                           VELGRA86
   40 CONTINUE                                                          VELGRA87
      DO 50 I=2,NSP                                                     VELGRA88
      WAS = WGRAD(I-1)+(A2(I-1)*WGRAD(I-1)+B2(I-1))*(THETA(I)-          VELGRA89
     1   THETA(I-1))                                                    VELGRA90
      WASS = WGRAD(I-1)+(A2(I)*WAS+B2(I))*(THETA(I)-THETA(I-1))         VELGRA91
   50 WGRAD(I) = (WAS+WASS)/2.                                          VELGRA92
      DO 60 I=1,NSP                                                     VELGRA93
      TTIP = 1.-(WGRAD(I)**2+TWLMR)/CPTIP                               VELGRA94
      IF (TTIP.GE..0) GO TO 55                                          VELGRA95
      WRITE(NWRIT,1010) IM                                              VELGRA96
      IF (AORB.GT.1.) WGRAD(1) ■ 0.                                     VELGRA97
      IF (AORB.GT.1.) WGRAD(NSP) = 0.                                   VELGRA98
      GO TO 70                                                          VELGRA99
   55 RHOT = RHOIP*(1.-PLOSIM(IM))*TTIP**EXPON                          VELGR100
   60 RWCB(I) = RHOT*WGRAD(I)*CBETA(I)                                  VELGR101
      CALL INTGRL (THETA,RWCB,NSP,AAA)                                  VELGR102
      WTFLES = BEF(IM)*RM(IM)*AAA(NSP)
      IF (IND.GE.6.AND.ABS(ACTWT-WTFLES).LE.ACTWT/1.E5) GO TO 70
      CALL CONTIN (WGRAD(1),WTFLES,IND,JZ,ACTWT,DELMAX)
      IF (IND.LT.10) GO TO 40
      AA = WTFLES/ACTWT
      IF (IND.EQ.10) WRITE(NWRIT,1030) IM,AA,IM
      IF (IND.EQ.10) GO TO 65
      WRITE(NWRIT,1020) IM
      IF (AORB.GT.1.) WGRAD(1) = 0.
      IF (AORB.GT.1.) WGRAD(NSP) = 0.
      GO TO 70
   65 LABEL(1,IM) = CHOKED
   70 CONTINUE
      FIRST = 1
      IF (AORB.GT.1.) FIRST = 2
      LAST = NSPM1
      IF (INTVL.GT.0) WRITE(NWRIT,1000) IM,IT1,(WGRAD(I),I=FIRST,LAST)
      IP = IV(IM)-1
      DO 80 I=FIRST,LAST
      IP = IP+1
   80 W(IP) = WGRAD(I)
      IF (AORB.LE.1.) RETURN
      WMB(IM,1) = WGRAD(1)
      WMB(IM,2) = WGRAD(NSP)
      WWCRM(IM,1) = WMB(IM,1)/WCR
      WWCRM(IM,2) = WMB(IM,2)/WCR
      RETURN
C
C  FORMAT STATEMENTS
C
 1000 FORMAT(5HKIM =,I3,10X,5HIT1 =,I3/(2X,10G13.4))
 1010 FORMAT (73HK  A VELOCITY GRADIENT SOLUTION CANNOT BE OBTAINED FOR
     1VERTICAL LINE IM =,I3)
 1020 FORMAT(92HK A VELOCITY GRADIENT SOLUTION COULD NOT BE OBTAINED IN
     150 ITERATIONS FOR VERTICAL LINE IM =,I3)
 1030 FORMAT(43HLACTWT EXCEEDS CHOKING WEIGHT FLOW FOR IM =,I3/22HKCHOKI
     1NG WEIGHT FLOW =,F6.3,3X,32H OF ACTUAL WEIGHT FLOW FOR IM = ,I3)
      END
      SUBROUTINE BLCD (M,THETA,DTDM,INF)
C
C  BLCD CALCULATES BLADE THETA COORDINATE AS A FUNCTION OF M
C
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)
      COMMON /INPUTT/ GAM,AR,TIP,RHOIP,WTFL,OMEGA,ORF,BETAI,BETAO,
     1   LAMBDA,RVTHO,REDFAC,DENTOL,FSMI,FSMO,SSM1,SSM2,MBI,MBO,MM,
     2   NBBI,NBL,NRSP,MOPT,LOPT,LRVB,BLDAT,AANDK,ERSOR,STRFN,SLCRD,
     3   INTVL,SURVL,CHORD(2),STGR(2),RI(2),RO(2),BETI(2),BETO(2),
     4   NSPI(2),TITLEI(20),MR(50),RMSP(50),BESPF(50),WOWCR(50),
     5   PLOSS(50),MSP(50,2),THSP(50,2)
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),
     7   BEH(100,2),PLOSMH(100,2)
      COMMON /BCDCOM/ INIT(2),EM(50,2),D2TDM2(100,2)
      DIMENSION DTDMI(2),DTDMO(2)
C
C  BL1 SOLVES FOR BLADE SURFACE 1
C
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,
     1   UPPER,S1,ST
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1
      REAL M,MMLE,MSPMM,MMMSP
      ENTRY BL1
      SURF = 1
      SIGN = 1.
      GO TO 10
C
C  BL2 SOLVES FOR BLADE SURFACE 2
C
      ENTRY BL2
      SURF= 2
      SIGN =-1.
   10 INF = 0
      IM = 1
      DO 15 I=MBI,MBO
   15 IF (ABS(MV(I)-M).LE.DMLR) IM=I
      NSP = NSPI(SURF)
      IF (INIT(SURF).EQ.1) GO TO 30
      INIT(SURF) = 1
C
C  INITIAL CALCULATION OF FIRST AND LAST SPLINE POINTS ON BLADE
C
      AA = BETI(SURF)/57.295779
      AA = SIN(AA)
      MSP(1,SURF) = RI(SURF)*(1.-SIGN*AA)
      BB = SQRT(1.-AA**2)
      THSP(1,SURF) = SIGN*BB*RI(SURF)/RMI(SURF)
      DTDMI(SURF) = AA/BB/RMI(SURF)
      AA = BETO(SURF)/57.295779
      AA = SIN(AA)
      MSP(NSP,SURF) = CHORD(SURF)-RO(SURF)*(1.+SIGN*AA)
      BB = SQRT(1.-AA**2)
      THSP(NSP,SURF) = STGR(SURF)+SIGN*BB*RO(SURF)/RMO(SURF)
      DTDMO(SURF) = AA/BB/RMO(SURF)
      DO 20 IA=1,NSP
      MSP(IA,SURF) = MSP(IA,SURF)+MLE(SURF)
   20 THSP(IA,SURF) = THSP(IA,SURF)+THLE(SURF)
      CALL SPLISL(MSP(1,SURF),THSP(1,SURF),NSP,DTDMI(SURF),DTDMO(SURF),
     1   AAA,EM(1,SURF))
      IF (BLDAT.LE.0) GO TO 30
      GO TO 5000
      IF (SURF.EQ.1) WRITE(NWRIT,1000)
      WRITE(NWRIT,1010) SURF
      WRITE(NWRIT,1020) (MSP(IA,SURF),THSP(IA,SURF),AAA(IA),EM(IA,SURF),
     1   IA=1,NSP)
 5000 CONTINUE
C
C  BLADE COORDINATE CALCULATION
C
   30 KK = 2
      IF (M.GT.MSP(1,SURF)) GO TO 50
C
C  AT LEADING EDGE RADIUS
C
      MMLE = M-MLE(SURF)
      IF (MMLE.LT.-DMLR) GO TO 90
      MMLE = AMAX1(0.,MMLE)
      THETA = SQRT(MMLE*(2.*RI(SURF)-MMLE))*SIGN
      IF (THETA.EQ.0.) GO TO 40
      RMM = RI(SURF)-MMLE
      DTDM = RMM/THETA/RMI(SURF)
      THETA = THETA/RMI(SURF)
      D2TDM2(IM,SURF) = (-THETA-RMM*DTDM)/(RMI(SURF)*THETA)**2
      THETA = THETA+THLE(SURF)
      RETURN
   40 INF = 1
      DTDM = 1.E10*SIGN
      THETA = THLE(SURF)
      D2TDM2(IM,SURF) = 0.
      RETURN
C
C  ALONG SPLINE CURVE
C
   50 IF (M.LE.MSP(KK,SURF)) GO TO 60
      IF (KK.GE.NSP) GO TO 70
      KK = KK+1
      GO TO 50
   60 S = MSP(KK,SURF)-MSP(KK-1,SURF)
      EMKM1 = EM(KK-1,SURF)
      EMK = EM(KK,SURF)
      MSPMM = MSP(KK,SURF)-M
      MMMSP = M-MSP(KK-1,SURF)
      THK = THSP(KK,SURF)/S
      THKM1 = THSP(KK-1,SURF)/S
      THETA = EMKM1*MSPMM**3/6./S+EMK*MMMSP**3/6./S+(THK-EMK*S/6.)*
     1   MMMSP + (THKM1-EMKM1*S/6.)*MSPMM
      DTDM = -EMKM1*MSPMM**2/2./S+EMK*MMMSP**2/2./S+THK-THKM1-(EMK-
     1   EMKM1)*S/6.
      D2TDM2(IM,SURF) = EMKM1*MSPMM/S+EMK*MMMSP/S
      RETURN
C
C  AT TRAILING EDGE RADIUS
C
   70 CMM = CHORD(SURF)+MLE(SURF)-M
      IF (CMM.LT.-DMLR) GO TO 90
      CMM = AMAX1(0.,CMM)
      THETA = SQRT(CMM*(2.*RO(SURF)-CMM))*SIGN
      IF (THETA.EQ.0.) GO TO 80
      RMM = RO(SURF)-CMM
      DTDM = -RMM/THETA/RMO(SURF)
      THETA = THETA/RMO(SURF)
      D2TDM2(IM,SURF) = (-THETA+RMM*DTDM)/(RMO(SURF)*THETA)**2
      THETA = THETA+STGR(SURF)+THLE(SURF)
      RETURN
   80 INF = 1
      DTDM = -1.E10*SIGN
      THETA = THLE(SURF)+STGR(SURF)
      D2TDM2(IM,SURF) = 0.
      RETURN
C
C  ERROR RETURN
C
   90 WRITE(NWRIT,1030) LER(2),M,SURF
      STOP
C
C  FORMAT STATEMENTS
C
 1000 FORMAT (1H1,13X,33HBLADE DATA AT INPUT SPLINE POINTS)
 1010 FORMAT(1HL,17X,16HBLADE    SURFACE,I4)
 1020 FORMAT (7X ,1HM,10X,5HTHETA,10X,10HDERIVATIVE,5X,10H2ND DERIV. /
     1  (4G15.5) )
 1030 FORMAT (14HLBLCD CALL NO.,I3/33H M COORDINATE IS NOT WITHIN BLADE/
     14H M =,G14.6,10X,6HSURF =,G14.6)
      END
      SUBROUTINE MHORIZ(MV,ITV,BL,MBI,MBO,ITO,HT,DTLR,KODE,J,MH,DTDMH,
     1MRTS)
C
C  MHORIZ CALCULATES M COORDINATES OF INTERSECTIONS OF ALL HORIZONTAL
C  MESH LINES WITH A BLADE SURFACE
C  KODE = 0 FOR UPPER BLADE SURFACE
C  KODE = 1 FOR LOWER BLADE SURFACE
C
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)
      DIMENSION MV(100),ITV(100),MH(100),DTDMH(100)
      INTEGER BLDAT,AANDK,ERSOR,STRFN,SLCRD,SURVL,AATEMP,SURF,FIRST,
     1   UPPER,S1,ST
      REAL K,KAK,LAMBDA,LMAX,MH,MLE,MR,MSL,MSP,MV,MVIM1,MVIM
      EXTERNAL BL
      IF (MBI.GE.MBO) RETURN
      IM = MBI
   10 ITIND = 0
   20 IF (ITV(IM+1)-ITV(IM)-ITIND) 30,40,50
   30 J = J+1
      TI = FLOAT(ITV(IM+1)-ITO-ITIND+KODE)*HT
      ITIND = ITIND-1
      MVIM = MV(IM)
      IF (MRTS.EQ.1) MVIM=MVIM+(MV(IM+1)-MVIM)/1000.
      CALL ROOT (MVIM,MV(IM+1),TI,BL,DTLR,MH(J),DTDMH(J))
      GO TO 20
   40 IM = IM+1
      MRTS = 0
      IF (IM.EQ.MBO) RETURN
      GO TO 10
   50 J = J+1
      TI = FLOAT(ITV(IM)-ITO+ITIND+KODE)*HT
      ITIND = ITIND+1
      MVIM = MV(IM)
      IF (MRTS.EQ.1) MVIM=MVIM+(MV(IM+1)-MVIM)/1000.
      CALL ROOT(MVIM,MV(IM+1),TI,BL,DTLR,MH(J),DTDMH(J))
      GO TO 20
      END
      SUBROUTINE ROOT(A,B,Y,FUNCT,TOLERY,X,DFX)
C
C  ROOT FINDS A ROOT FOR (FUNCT MINUS Y) IN THE INTERVAL (A,B)
C
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)
      IERR = 0
    5 IF (IERR.EQ.1) WRITE(NWRIT,1010) A,B,Y,TOLERY
      X1 = A
      CALL FUNCT(X1,FX1,DFX,INF)
      FX1S = FX1
      DFXS = DFX
      IF (IERR.EQ.1) WRITE(NWRIT,1020) X1,FX1,DFX,INF
      X2 = B
   10 DO 30 I=1,20
      X = (X1+X2)/2.
      CALL FUNCT(X,FX,DFX,INF)
      IF (IERR.EQ.1) WRITE(NWRIT,1020) X,FX,DFX,INF
      IF ((FX1-Y)*(FX-Y).GT.0.) GO TO 20
      X2 = X
      GO TO 30
   20 X1 = X
      FX1 = FX
   30 CONTINUE
      IF (ABS(Y-FX).LT.TOLERY) RETURN
      IF (ABS(Y-FX1S).GT.1.2*TOLERY) GO TO 40
      X = A
      DFX = DFXS
      RETURN
   40 X = B
      CALL FUNCT(X,FX,DFX,INF)
      IF (ABS(Y-FX).LE.1.2*TOLERY) RETURN
      IF (IERR.EQ.1) RETURN
      WRITE(NWRIT,1000)
      IERR = 1
      GO TO 5
C
C  FORMAT STATEMENTS
C
1000  FORMAT(72H1ROOT HAS FAILED TO LOCATE A ROOT IN THE INTERVAL (A,B)
     1IN 20 ITERATIONS)
1010  FORMAT(22H ROOT ARGUMENTS -- A =,G13.5,3X,3HB =,G13.5,3X,3HY =,
     1G13.5,3X,8HTOLERY =,G13.5/16X,1HX,17X,2HFX,15X,3HDFX,10X,3HINF)
1020  FORMAT(8X,G16.5,2G18.5,I6)
      END
      SUBROUTINE DENSTY(RHOW,RHO,VEL,TWLMR,CPTIP,EXPON,RHOIP,GAM,AR,TIP,
     1   JZ)
C
C  DENSTY CALCULATES DENSITY AND VELOCITY FROM THE WEIGHT FLOW PARAMETER
C  DENSITY TIMES VELOCITY
C
      COMMON NREAD,NWRIT,ITER,IEND,LER(2),NER(2)
      VEL = RHOW/RHO
      IF (VEL.NE.0.) GO TO 10
      RHO = RHOIP*(1.-TWLMR/CPTIP)**EXPON
   10 TTIP = 1.-(VEL**2+TWLMR)/CPTIP
      IF (TTIP.LT.0.) GO TO 30
      IF (LER(1).GT.5) GO TO 25
      TEMP = TTIP**(EXPON-1.)
      RHOT = RHOIP*TEMP*TTIP
      RHOWP = -VEL**2/GAM*RHOIP/AR*TEMP/TIP+RHOT
      IF (JZ.EQ.1.AND.RHOWP.LE.0.) GO TO 30
      IF (JZ.EQ.2.AND.RHOWP.GE.0.) GO TO 30
      VELNEW = VEL+(RHOW-RHOT*VEL)/RHOWP
      VELNEW = ABS(VELNEW)
      IF (ABS(VELNEW-VEL)/VELNEW.LT..0001) GO TO 20
      VEL = VELNEW
      GO TO 10
   20 VEL = VELNEW
      RHO = RHOW/VEL
      RETURN
   25 RHO = RHOIP*TTIP**EXPON
      RETURN
   30 TGROG = 2.*GAM*AR/(GAM+1.)
      VEL = SQRT(TGROG*TIP*(1.-TWLMR/CPTIP))
      RHO = RHOIP*(1.-(VEL**2+TWLMR)/CPTIP)**EXPON
      RWMORW = RHOW/RHO/VEL
      IF (RWMORW.LT.1.) GO TO 40
      NER(1) = NER(1)+1
      WRITE(NWRIT,1000) LER(1),NER(1),RWMORW
      IF (NER(1).EQ.50) STOP
      RETURN
   40 IF (JZ.EQ.1) VEL=0.
      IF (JZ.EQ.2) VEL=VEL*1.1
      GO TO 10
 1000 FORMAT(16HLDENSTY CALL NO.,I3/9H NER(1) =,I3/10H RHO*W IS ,F7.4,
     134H TIMES THE MAXIMUM VALUE FOR RHO*W)
      END
      FUNCTION IPF(IM,IT)
      COMMON /CALCON/ ACTWT,ACTOMG,ACTLAM,MBIM1,MBIP1,MBOM1,MBOP1,MMM1,
     1   HM1,HT,DTLR,DMLR,PITCH,CP,EXPON,TWW,CPTIP,TGROG,TBI,TBO,TWL,
     2   WI,WMI,WCRI,ITMIN,ITMAX,NIP,IMS1,IMS2,IMS(2),BV(2),MLE(2),
     3   THLE(2),RMI(2),RMO(2),BESP(50),MV(100),RM(100),BE(100),
     4   BEF(100),DBDM(100),DBFDM(100),SAL(100),PLOSIM(100),AAA(100),
     5   BBB(100),IV(101),ITV(100,2),TV(100,2),DTDMV(100,2),
     6   BETAV(100,2),MH(100,2),DTDMH(100,2),BETAH(100,2),RMH(100,2),
     7   BEH(100,2),PLOSMH(100,2)
      IPF = IV(IM)+IT-ITV(IM,1)
      RETURN
      END
      SUBROUTINE CONTIN(XEST,YCALC,IND,JZ,YGIV,XDEL)
C
C--CONTIN CALCULATES AN ESTIMATE OF THE RELATIVE FLOW VELOCITY
C--FOR USE IN THE VELOCITY GRADIENT EQUATION
C
      DIMENSION X(3),Y(3)
      NCALL = NCALL+1
      IF (IND.NE.1.AND.NCALL.GT.100) GO TO 160
      GO TO (10,30,40,50,60,110,150),IND
C--FIRST CALL
   10 NCALL = 1
      XORIG = XEST
      IF (YCALC.GT.YGIV.AND.JZ.EQ.1) GO TO 20
      IND = 2
      Y(1) = YCALC
      X(1) = 0.
      XEST = XEST+XDEL
      RETURN
   20 IND = 3
      Y(3) = YCALC
      X(3) = 0.
      XEST = XEST-XDEL
      RETURN
C--SECOND CALL
   30 IND = 4
      Y(2) = YCALC
      X(2) = XEST-XORIG
      XEST = XEST+XDEL
      RETURN
   40 IND = 5
      Y(2) = YCALC
      X(2) = XEST-XORIG
      XEST = XEST-XDEL
      RETURN
C -- THIRD OR LATER CALL - FIND SUBSONIC OR SUPERSONIC SOLUTION
   50 Y(3) = YCALC
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      X(3) = XEST-XORIG
      GO TO 70
   60 Y(1) = YCALC
      X(1) = XEST-XORIG
   70 IF (YGIV.LT.AMIN1(Y(1),Y(2),Y(3))) GO TO (120,130),JZ
   80 IND = 6
      CALL PABC(X,Y,APA,BPB,CPC)
      DISCR = BPB**2-4.*APA*(CPC-YGIV)
      IF (DISCR.LT.0.) GO TO 140
      IF (ABS(400.*APA*(CPC-YGIV)).LE.BPB**2) GO TO 90
      XEST ■ -BPB-SIGN(SQRT(DISCR),APA)
      IF (JZ.EQ.1.AND.APA.GT.0..AND.Y(3).GT.Y(1)) XEST = -BPB+
     1SQRT(DISCR)
      IF (JZ.EQ.2.AND.APA.LT.0.) XEST = -BPB-SQRT(DISCR)
      XEST = XEST/2./APA
      GO TO 100
   90 IF (JZ.EQ.2.AND.BPB.GT.0.) GO TO 130
      ACB2 ■ APA/BPB*(CPC-YGIV)/BPB
      IF (ABS(ACB2).LE.1.E-8) ACB2=0.
      XEST = -(CPC-YGIV)/BPB*(1.+ACB2+2.*ACB2**2)
  100 IF (XEST.GT.X(3)) GO TO 130
      IF (XEST.LT.X(1)) GO TO 120
      XEST = XEST+XORIG
      RETURN
C--FOURTH OR LATER CALL - NOT CHOKED
  110 IF(XEST-XORIG.GT.X(3)) GO TO 130
      IF(XEST-XORIG.LT.X(1)) GO TO 120
      Y(2) = YCALC
      X(2) = XEST-XORIG
      GO TO 70
C--THIRD OR LATER CALL - SOLUTION EXISTS,
C--BUT RIGHT OR LEFT SHIFT REQUIRED
  120 IND = 5
C--LEFT SHIFT
      XEST = X(1)-XDEL+XORIG
      XOSHFT = XEST-XORIG
      XORIG = XEST
      Y(3) ■ Y(2)
      X(3) = X(2)-XOSHFT
      Y(2) = Y(1)
      X(2) = X(1)-XOSHFT
      RETURN
  130 IND = 4
C--RIGHT SHIFT
      XEST ■ X(3)+XDEL+XORIG
      XOSHFT = XEST-XORIG
      XORIG = XEST
      Y(1) ■ Y(2)
      X(1) = X(2)-XOSHFT
      Y(2) = Y(3)
      X(2) = X(3)-XOSHFT
      RETURN
C--THIRD OR LATER CALL - APPEARS TO BE CHOKED
  140 XEST ■ -BPB/2./APA
      IND = 7
      IF (XEST.LT.X(1)) GO TO 120
      IF(XEST.GT.X(3)) GO TO 130
      XEST = XEST+XORIG
      RETURN
C--FOURTH OR LATER CALL - PROBABLY CHOKED
  150 IF (YCALC.GE.YGIV) GO TO 110
      IND = 10
      RETURN
C--NO SOLUTION FOUND IN 100 ITERATIONS
  160 IND = 11
      RETURN
      END
      SUBROUTINE PABC(X,Y,A,B,C)
C
C--PABC CALCULATES COEFFICIENTS A,B,C OF THE PARABOLA
C--Y=A*X**2+B*X+C, PASSING THROUGH THE GIVEN X,Y POINTS
C
      DIMENSION X(3),Y(3)
      C1 = X(3)-X(1)
      C2 ■ (Y(2)-Y(1))/(X(2)-X(1))
      A = (C1*C2-Y(3)+Y(1))/C1/(X(2)-X(3))
      B = C2-(X(1)+X(2))*A
      C = Y(1)-X(1)*B-X(1)**2*A
      RETURN
      END
      SUBROUTINE SPLINE (X,Y,N,SLOPE,EM)
C
C--SPLINE CALCULATES FIRST AND SECOND DERIVATIVES AT SPLINE POINTS
C--END CONDITION - SECOND DERIVATIVES AT END POINTS ARE
C--SDR1 AND SDRN TIMES SECOND DERIVATIVES AT ADJACENT POINTS
C
      COMMON NREAD,NWRIT
      DIMENSION X(N),Y(N),SLOPE(N),EM(N)
      DIMENSION G(101),SB(101)
      IERR ■ 0
      SDR1 = .5
      SDRN = .5
      C ■ X(2)-X(1)
      IF (C.EQ.0.) GO TO 50
      SB(1) = -SDR1
      G(1) = 0.
      NO = N-1
      IF (NO.LE.0) GO TO 60
      IF (NO.EQ.1) GO TO 20
      DO 10 I=2,NO
      A = C
      C = X(I+1)-X(I)
      IF (A*C.EQ.0.) GO TO 50
      IF (A*C.LT.0.) IERR = 1
      W = 2.*(A+C)-A*SB(I-1)
      SB(I) = C/W
      F = (Y(I+1)-Y(I))/C-(Y(I)-Y(I-1))/A
   10 G(I) = (6.*F-A*G(I-1))/W
   20 EM(N) = SDRN*G(N-1)/(1.+SDRN*SB(N-1))
      DO 30 I=2,N
      K = N+1-I
   30 EM(K) = G(K)-SB(K)*EM(K+1)
      SLOPE(1) = (X(1)-X(2))/6.*(2.*EM(1)+EM(2))+(Y(2)-Y(1))/(X(2)-X(1))
      DO 40 I=2,N
   40 SLOPE(I) = (X(I)-X(I-1))/6.*(2.*EM(I)+EM(I-1))+(Y(I)-Y(I-1))/
     1(X(I)-X(I-1))
      IF (IERR.EQ.0) RETURN
   50 WRITE(NWRIT,1000)
      WRITE(NWPIT,1020) N,(X(I),Y(I),I=1,N)
      IF (IERR.EQ.0) STOP
      WRITE(NWRIT,1030)                                                 SPLINE42
      RETURN                                                            SPLINE43
   60 WRITE(NWRIT,1010)                                                 SPLINE44
      WRITE(NWRIT,1020) N,(X(I),Y(I),I=1,N)                             SPLINE45
      STOP                                                              SPLINE46
 1000 FORMAT (1H1,10X,44HSPLINE ERROR -- ONE OF THREE POSSIBLE CAUSES/  SPLINE47
     117X,51H1.  ADJACENT X POINTS ARE DUPLICATES OF EACH OTHER./       SPLINE48
     217X,38H2.  SOME X POINTS ARE OUT OF SEQUENCE./                    SPLINE49
     317X,32H3.  SOME X POINTS ARE UNDEFINED.)                          SPLINE50
 1010 FORMAT (1H1,10X,62HSPLINE ERROR -- NUMBER OF SPLINE POINTS GIVEN ISPLINE51
     1S LESS THAN TWO)                                                  SPLINE52
 1020 FORMAT (//17X,18HNUMBER OF POINTS =,I4//17X,8HX  ARRAY,6X,8HY  ARRSPLINE53
     1AY/(17X,2G13.5))                                                  SPLINE54
 1030 FORMAT (1H1)                                                      SPLINE55
      END                                                               SPLINE56
      SUBROUTINE SPLINT (X,Y,N,Z,MAX,YINT,DYDX,D2YDX2)                  SPLINT 2
C                                                                       SPLINT 3
C--SPLINT CALCULATES INTERPOLATED POINTS AND DERIVATIVES                SPLINT 4
C--FOR A SPLINE CURVE                                                   SPLINT 5
C--END CONDITION - SECOND DERIVATIVES AT END POINTS ARE                 SPLINT 6
C--SDR1 AND SDRN TIMES SECOND DERIVATIVES AT ADJACENT POINTS            SPLINT 7
C                                                                       SPLINT 8
      COMMON NREAD,NWRIT                                                SPLINT 9
      DIMENSION X(N),Y(N),Z(MAX),YINT(MAX),DYDX(MAX),D2YDX2(MAX)        SPLINT10
      DIMENSION G(101),SB(101),EM(101)                                  SPLINT11
      IERR = 0                                                          SPLINT12
      SDR1 = .5                                                         SPLINT13
      SDRN = .5                                                         SPLINT14
      TOLER= ABS(X(N)-X(1))/FLOAT(N)*1.E-5                              SPLINT15
      C = X(2)-X(1)                                                     SPLINT16
      IF (C.EQ.0.) GO TO 130                                            SPLINT17
      SB(1) = -SDR1                                                     SPLINT18
      G(1) = 0.                                                         SPLINT19
      NO ■ N-1                                                          SPLINT20
      IF (NO.LE.0) GO TO 140                                            SPLINT21
      IF (NO.EQ.1) GO TO 20                                             SPLINT22
      DO 10 I=2,NO                                                      SPLINT23
      A = C                                                             SPLINT24
      C ■ X(I+1)-X(I)                                                   SPLINT25
      IF (A*C.EQ.0.) GO TO 130                                          SPLINT26
      IF (A*C.LT.0.) IERR = 1                                           SPLINT27
      W = 2.*(A+C)-A*SB(I-1)                                            SPLINT28
      SB(I) = C/W                                                       SPLINT29
      F ■ (Y(I+1)-Y(I))/C-(Y(I)-Y(I-1))/A                               SPLINT30
   10 G(I) ■ (6.*F-A*G(I-1))/W                                          SPLINT31
   20 EM(N) = SDRN*G(N-1)/(1.+SDRN*SB(N-1))                             SPLINT32
      DO 30 I=2,N                                                       SPLINT33
      K = N+1-I                                                         SPLINT34
   30 EM(K) = G(K)-SB(K)*EM(K+1)                                        SPLINT35
      IF (MAX.LE.0) RETURN                                              SPLINT36
C                                                                       SPLINT37
      ENTRY SPLENT                                                      SPLINT38
      DO 120 I=1,MAX                                                    SPLINT39
      K=2                                                               SPLINT40
      IF (ABS(Z(I)-X(1)).LT.TOLER) GO TO 40                             SPLINT41
      IF (Z(I).GT.2.0*X(1)-X(2)) GO TO 50                               SPLINT42
      GO TO 80                                                          SPLINT43
   40 YINT(I) = Y(1)                                                    SPLINT44
      SK = X(K)-X(K-1)                                                  SPLINT45
      GO TO 110                                                         SPLINT46
   50 IF (ABS(Z(I)-X(K)).LT.TOLER) GO TO 60                             SPLINT47
      IF (Z(I).GT.X(K)) GO TO 70                                        SPLINT48
      GO TO 100                                                         SPLINT49
   60 YINT(I) = Y(K)                                                    SPLINT50
      SK = X(K)-X(K-1)                                                  SPLINT51
      GO TO 110                                                         SPLINT52
   70 IF (K.GE.N) GO TO 90                                              SPLINT53
      K = K+1                                                           SPLINT54
      GO TO 50                                                          SPLINT55
   80 S2 = X(2)-X(1)                                                    SPLINT56
      Y0 = EM(1)*S2**2+2.*Y(1)-Y(2)                                     SPLINT57
      DYDX(I) = (Y(2)-Y(1))/S2-7.*EM(1)/6.*S2                           SPLINT58
      YINT(I) = Y0+DYDX(I)*(Z(I)-X(1)+S2)                               SPLINT59
      D2YDX2(I) = 0.                                                    SPLINT60
      GO TO 120                                                         SPLINT61
   90 IF (Z(I).LT.2.*X(N)-X(N-1)) GO TO 100                             SPLINT62
      SN = X(N)-X(N-1)                                                  SPLINT63
      YNP1 = EM(N)*SN**2+2.*Y(N)-Y(N-1)                                 SPLINT64
      DYDX(I) = (Y(N)-Y(N-1))/SN+7.*EM(N)/6.*SN                         SPLINT65
      YINT(I) = YNP1+DYDX(I)*(Z(I)-X(N)-SN)                             SPLINT66
      D2YDX2(I) = 0.                                                    SPLINT67
      GO TO 120                                                         SPLINT68
  100 SK = X(K)-X(K-1)                                                  SPLINT69
      YINT(I) = EM(K-1)*(X(K)-Z(I))**3/6./SK  +EM(K)*(Z(I)-X(K-1))**3/6.SPLINT70
     1  /SK+(Y(K)/SK  -EM(K)*SK  /6.)*(Z(I)-X(K-1))+(Y(K-1)/SK  -EM(K-1)SPLINT71
     2  *SK/6.)*(X(K)-Z(I))                                             SPLINT72
  110 DYDX(I)=-EM(K-1)*(X(K)-Z(I))**2/2.0/SK  +EM(K)*(X(K-1)-Z(I))**2/2.SPLINT73
     1   /SK+(Y(K)-Y(K-1))/SK  -(EM(K)-EM(K-1))*SK/6.                   SPLINT74
      D2YDX2(I) = EM(K)-(X(K)-Z(I))/SK*(EM(K)-EM(K-1))                  SPLINT75
  120 CONTINUE                                                          SPLINT76
      IF (IERR.EQ.0) RETURN                                             SPLINT77
  130 WRITE(NWRIT,1000)                                                 SPLINT78
      WRITE(NWRIT,1020) N,(X(I),Y(I),I=1,N)                             SPLINT79
      IF (IERR.EQ.0) STOP                                               SPLINT80
      WRITE(NWRIT,1030)                                                 SPLINT81
      RETURN                                                            SPLINT82
  140 WRITE(NWRIT,1010)                                                 SPLINT83
      WRITE(NWRIT,1020) N,(X(I),Y(I),I=1,N)                             SPLINT84
      STOP                                                              SPLINT85
 1000 FORMAT (1H1,10X,44HSPLINT ERROR -- ONE OF THREE POSSIBLE CAUSES/  SPLINT86
     117X,51H1.  ADJACENT X POINTS ARE DUPLICATES OF EACH OTHER./       SPLINT87
     217X,38H2.  SOME X POINTS ARE OUT OF SEQUENCE./                    SPLINT88
     317X,32H3.  SOME X POINTS ARE UNDEFINED.)                          SPLINT89
 1010 FORMAT (1H1,10X,62HSPLINT ERROR -- NUMBER OF SPLINE POINTS GIVEN ISPLINT90
     1S LESS THAN TWO)                                                  SPLINT91
 1020 FORMAT (//17X,18HNUMBER OF POINTS =,I4//17X,8HX  ARRAY,6X,8HY  ARRSPLINT92
     1AY/(17X,2G13.5))                                                  SPLINT93
 1030 FORMAT (1H1)                                                      SPLINT94
      END                                                               SPLINT95
      SUBROUTINE SPLISL(X,Y,N,Y1P,YNP,SLOPE,EM)                         SPLISL 2
C                                                                       SPLISL 3
C--SPLISL CALCULATES FIPST AND SECOND DERIVATIVES AT SPLINE POINTS      SPLISL 4
C--END CONDITION - FIRST DERIVATIVES SPECIFIED AT END POINTS            SPLISL 5
C                                                                       SPLISL 6
      COMMON NREAD,NWRIT                                                SPLISL 7
      DIMENSION X(N),Y(N),SLOPE(N),EM(N)                                SPLISL 8
      DIMENSION G(101),SB(101)                                          SPLISL 9
      IERR = 0                                                          SPLISL10
      C = X(2)-X(1)                                                     SPLISL11
      IF (C.EQ.0.) GO TO 50                                             SPLISL12
      SB(1) = .5                                                        SPLISL13
      F = (Y(2)-Y(1))/C-Y1P                                             SPLISL14
      G(1) = 3.*F/C                                                     SPLISL15
      NO = N-1                                                          SPLISL16
      IF (NO.LE.0) GO TO 60                                             SPLISL17
      IF (NO.EQ.1) GO TO 20                                             SPLISL18
      DO 10 I=2,NO                                                      SPLISL19
      A = C                                                             SPLISL20
      C = X(I+1)-X(I)                                                   SPLISL21
      IF (A*C.EQ.0.) GO TO 50                                           SPLISL22
      IF (A*C.LT.0.) IERR = 1                                           SPLISL23
      W = 2.*(A+C)-A*SB(I-1)                                            SPLISL24
      SB(I) = C/W                                                       SPLISL25
      F = (Y(I+1)-Y(I))/C-(Y(I)-Y(I-1))/A                               SPLISL26
   10 G(I) = (6.*F-A*G(I-1))/W                                          SPLISL27
   20 W = C*(2.-SB(N-1))                                                SPLISL28
      F = YNP-(Y(N)-Y(N-1))/C                                           SPLISL29
      EM(N) = (6.*F-C*G(N-1))/W                                         SPLISL30
      DO 30 I=2,N                                                       SPLISL31
      K = N+1-I                                                         SPLISL32
   30 EM(K) = G(K)-SB(K)*EM(K+1)                                        SPLISL33
      SLOPE(1) = Y1P                                                    SPLISL34
      DO 40 I=2,NO                                                      SPLISL35
   40 SLOPE(I) ■ (X(I)-X(I-1))/6.*(2.*EM(I)+EM(I-1))+(Y(I)-Y(I-1))/     SPLISL36
     1(X(I)-X(I-1))                                                     SPLISL37
      SLOPE(N) = YNP                                                    SPLISL38
      IF (IERR.EQ.0) RETURN                                             SPLISL39
   50 WRITE(NWRIT,1000)                                                 SPLISL40
      WRITE(NWRIT,1020) N,(X(I),Y(I),I=1,N)                             SPLISL41
      IF (IERR.EQ.0) STOP                                               SPLISL42
      WRITE(NWRIT,1030)                                                 SPLISL43
      RETURN                                                            SPLISL44
   60 WRITE(NWRIT,1010)                                                 SPLISL45
      WRITE(NWRIT,1020) N,(X(I),Y(I),I=1,N)                             SPLISL46
      STOP                                                              SPLISL47
 1000 FORMAT (1H1,10X,44HSPLISL ERROR -- ONE OF THREE POSSIBLE CAUSES/  SPLISL48
     117X,51H1.  ADJACENT X POINTS ARE DUPLICATES OF EACH OTHER./       SPLISL49
     217X,38H2.  SOME X POINTS ARE OUT OF SEQUENCE./                    SPLISL50
     317X,32H3.  SOME X POINTS ARE UNDEFINED.)                          SPLISL51
 1010 FORMAT (1H1,10X,62HSPLISL ERROR -- NUMBER OF SPLINE POINTS GIVEN ISPLISL52
     1S LESS THAN TWO)                                                  SPLISL53
 1020 FORMAT (//17X,18HNUMBER OF POINTS =,I4//17X,8HX  ARRAY,6X,8HY  ARRSPLISL54
     1AY/(17X,2G13.5))                                                  SPLISL55
 1030 FORMAT (1H1)                                                      SPLISL56
      END                                                               SPLISL57
      SUBROUTINE SPLIPR(DX,Y,N,SLOPE,EM)                                SPLIPR 2
C                                                                       SPLIPR 3
C--SPLIPR CALULATES FIRST AND SECOND DERIVATIVES AT EQUALLY SPACED      SPLIPR 4
C--SPLINE POINTS, USING SOR                                             SPLIPR 5
C--END CONDITIONS - FIRST AND SECOND DERIVATIVES ARE PERIODIC, AND      SPLIPR 6
C--Y INCREASES BY ONE IN THIS PERIOD                                    SPLIPR 7
C                                                                       SPLIPR 8
      COMMON NREAD,NWRIT                                                SPLIPR 9
      DIMENSION Y(N),SLOPE(N),EM(N)                                     SPLIPR10
      DIMENSION F(101)                                                  SPLIPR11
      IF(N.LT.2) GO TO 50                                               SPLIPR12
      NO = N-1                                                          SPLIPR13
      DYP = 1.+Y(1)-Y(N)                                                SPLIPR14
      CONST = 3./2./DX**2                                               SPLIPR15
      DO 10 I=1,NO                                                      SPLIPR16
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      EM(I) = 0.                                                        SPLIPR17
      DYM = DYP                                                         SPLIPR18
      DYP = Y(I+1)-Y(I)                                                 SPLIPR19
   10 F(I) = CONST*(DYP-DYM)                                            SPLIPR20
      EM(N) = 0.                                                        SPLIPR21
      DYM = DYP                                                         SPLIPR22
      DYP ■ 1.+Y(1)-Y(N)                                                SPLIPR23
      F(N) = CONST*(DYP-DYM)                                            SPLIPR24
      ORF = 2./(1.+SQRT(.75))                                           SPLIPR25
      DO 30 K=1,10                                                      SPLIPR26
      EM(1) = EM(1)-ORF*((EM(N)+EM(2))/4.+EM(1)-F(1))                   SPLIPR27
      IF(NO.EQ.1) GO TO 30                                              SPLIPR28
      DO 20 I=2,NO                                                      SPLIPR29
   20 EM(I) = EM(I)-ORF*((EM(I-1)+EM(I+1))/4.+EM(I)-F(I))               SPLIPR30
   30 EM(N) = EM(N)-ORF*((EM(N-1)+EM(1))/4.+EM(N)-F(N))                 SPLIPR31
      SLOPE(1) = -DX/6.*(2.*EM(1)+EM(2))+(Y(2)-Y(1))/DX                 SPLIPR32
      DO 40 I=2,N                                                       SPLIPR33
   40 SLOPE(I) = DX/6.*(2.*EM(I)-EM(I-1))+(Y(I)-Y(I-1))/DX              SPLIPR34
      RETURN                                                            SPLIPR35
   50 WRITE(NWRIT,1000)                                                 SPLIPR36
      STOP                                                              SPLIPR37
 1000 FORMAT (1H1,10X,62HSPLIPR ERROR -- NUMBER OF SPLINE POINTS GIVEN ISPLIPR38
     1S LESS THAN TWO)                                                  SPLIPR39
      END                                                               SPLIPR40
      SUBROUTINE INTGRL(X,Y,N,SUM)                                      INTGRL 2
C                                                                       INTGRL 3
C--INTGRL CALCULATES THE INTEGRAL OF A SPLINE CURVE PASSING THROUGH     INTGRL 4
C--A GIVEN SET OF POINTS                                                INTGRL 5
C--END CONDITION - SECOND DERIVATIVES AT END POINTS ARE                 INTGRL 6
C--SDR1 AND SDRN TIMES SECOND DERIVATIVES AT ADJACENT POINTS            INTGRL 7
C                                                                       INTGRL 8
      COMMON NREAD,NWRIT                                                INTGRL 9
      DIMENSION X(N),Y(N),SUM(N)                                        INTGRL10
      DIMENSION G(101),SB(101),EM(101)                                  INTGRL11
      IERR = 0                                                          INTGRL12
      SDR1 = .5                                                         INTGRL13
      SDRN = .5                                                         INTGRL14
      C ■ X(2)-X(1)                                                     INTGRL15
      IF (C.EQ.0.) GO TO 50                                             INTGRL16
      SB(1) = -SDR1                                                     INTGRL17
      G(1) ■ 0.                                                         INTGRL18
      NO ■ N-1                                                          INTGRL19
      IF (NO.LE.0) GO TO 60                                             INTGRL20
      IF (NO.EQ.1) GO TO 20                                             INTGRL21
      DO 10 I=2,NO                                                      INTGRL22
      A = C                                                             INTGRL23
      C = X(I+1)-X(I)                                                   INTGRL24
      IF (A*C.EQ.0.) GO TO 50                                           INTGRL25
      IF (A*C.LT.0.) IERR ■ 1                                           INTGRL26
      W = 2.*(A+C)-A*SB(I-1)                                            INTGRL27
      SB(I) = C/W                                                       INTGRL28
      F = (Y(I+1)-Y(I))/C-(Y(I)-Y(I-1))/A                               INTGRL29
   10 G(I) = (6.*F-A*G(I-1))/W                                          INTGRL30
   20 EM(N) = SDRN*G(N-1)/(1.+SDRN*SB(N-1))                             INTGRL31
      DO 30 I=2,N                                                       INTGRL32
      K = N+1-I                                                         INTGRL33
   30 EM(K) = G(K)-SB(K)*EM(K+1)                                        INTGRL34
      SUM(1) = 0.                                                       INTGRL35
      DO 40 I=2,N                                                       INTGRL36
   40 SUM(I) = SUM(I-1)+(X(I)-X(I-1))*(Y(I)+Y(I-1))/2.-(X(I)-X(I-1))**3 INTGRL37
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     1*(EM(I)+EM(I-1))/24.                                              INTGRL38
      IF (IERR.EQ.0) RETURN                                             INTGRL39
   50 WRITE(NWRIT,1000)                                                 INTGRL40
      WRITE(NWRIT,1020) N,(X(I),Y(I),I=1,N)                             INTGRL41
      IF (IERR.EQ.0) STOP                                               INTGRL42
      WRITE(NWRIT,1030)                                                 INTGRL43
      RETURN                                                            INTGPL44
   60 WRITE(NWRIT,1010)                                                 INTGRL45
      WRITE(NWRIT,1020) N,(X(I),Y(I),I=1,N)                             INTGRL46
      STOP                                                              INTGRL47
 1000 FORMAT (1H1,10X,44HINTGRL ERROR -- ONE OF THREE POSSIBLE CAUSES/  INTGRL48
     117X,51H1.  ADJACENT X POINTS ARE DUPLICATES OF EACH OTHER./       INTGRL49
     217X,38H2.  SOME X POINTS ARE OUT OF SEQUENCE./                    INTGRL50
     317X,32H3.  SOME X POINTS ARE UNDEFINED.)                          INTGRL51
 1010 FORMAT (1H1,10X,62HINTGRL ERROR -- NUMBER OF SPLINE POINTS GIVEN IINTGRL52
     1S LESS THAN TWO)                                                  INTGRL53
 1020 FORMAT (//17X,18HNUMBER OF POINTS =,I4//17X,8HX  ARRAY,6X,8HY  ARRINTGRL54
     1AY/(17X,2G13.5))                                                  INTGRL55
 1030 FORMAT (1H1)                                                      INTGRL56
      END                                                               INTGRL57
      SUBROUTINE PLOTMY(X,Y,K,P)                                        PLOTMY 2
C--PLOTMY PLOTS MULTIPLE CURVES                                         PLOTMY 3
      COMMON NREAD,NWRIT                                                PLOTMY 4
      LOGICAL FORY,STUG,TONLY                                           PLOTMY 5
      DIMENSION YLABEL(11),A(104),KPCSTD(6),XLAB(8),YLAB(6),FKFD(6)     PLOTMY 6
      DIMENSION X(1),Y(1),P(1),K(1)                                     PLOTMY 7
      LEVEL 2,  X,Y                                                     PLOTMY 8
      COMMON /JOLO/ F,DX,TLINX,N,LABOUT,KFD,FORY,STUG,TONLY             PLOTMY 9
      EQUIVALENCE (KPC,TPC)                                             PLOTMY10
      DATA BLANK,XGRID,YGRID,RMARK /1H ,1H-,1H1,1H=/                    PLOTMY11
      DATA KPCSTD /1H*,1H+,1HO,1HX,1H=,1HO  /                           PLOTMY12
      DATA XLAB/4H (1H,4H  ,5,4HX, F,4H10.0,4H,104,4HA1,F,4H10.0,4H)   /PLOTMY13
      DATA YLAB/4H (1H,4H  , ,4H8X, ,4H 11F,4H10.0,4H)   /              PLOTMY14
      DATA FKFD/4H10.1,4H10.2,4H10.3,4H10.4,4H10.5,4H10.6/              PLOTMY15
C                                                                       PLOTMY16
  100 WRITE(NWRIT,1000)                                                 PLOTMY17
      KODE = K(1)                                                       PLOTMY18
      KN = K(2)                                                         PLOTMY19
      NPTS = K(3)                                                       PLOTMY20
      LABOUT ■ 1                                                        PLOTMY21
      KTL = 1                                                           PLOTMY22
      FKFD0 = XLAB(4)                                                   PLOTMY23
      IF(P(1).GT.2.) GO TO 110                                          PLOTMY24
C--P(1) = 1. (DUPX)                                                     PLOTMY25
      KTL = KN                                                          PLOTMY26
      GO TO 130                                                         PLOTMY27
  110 IF(P(1).GT.4.) GO TO 140                                          PLOTMY28
C--P(1) = 3. (DUPY)                                                     PLOTMY29
      KTIMES = KN-1                                                     PLOTMY30
      DO 120 I=1,KTIMES                                                 PLOTMY31
      MM = I*NPTS                                                       PLOTMY32
      K(2*I+3) = NPTS                                                   PLOTMY33
      DO 120 II=1,NPTS                                                  PLOTMY34
      L = MM+II                                                         PLOTMY35
  120 Y(L) = Y(II)                                                      PLOTMY36
C--P(1) = 1. OR 3. (DUPX OR DUPY)                                       PLOTMY37
  130 NPTST = KN*NPTS                                                   PLOTMY38
      TLINX = 55*(1+NPTS/35)                                            PLOTMY39
      GO TO 160                                                         PLOTMY40
C--P(1) = 5. (NO DUP)                                                   PLOTMY41
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  140 NPTST = 0                                                         PLOTMY42
      DO 150 I=1,KN                                                     PLOTMY43
  150 NPTST = NPTST+K(2*I+1)                                            PLOTMY44
      TLINX = 55*(1+NPTST/(35*KN))                                      PLOTMY45
  160 IF(MOD(KODE,2).NE.0) GO TO 180                                    PLOTMY46
C--OPTION 1 NOT CHOSEN                                                  PLOTMY47
      DO 170 I=1,KN                                                     PLOTMY48
  170 K(2*I+2) = KPCSTD(I)                                              PLOTMY49
  180 NX = 10                                                           PLOTMY50
C--OPTION 2                                                             PLOTMY51
      IF(MOD(KODE/2,2).NE.0) NX ■ P(3)                                  PLOTMY52
      IF (NX.EQ.0) NX = 1000                                            PLOTMY53
      NY = 10                                                           PLOTMY54
C--OPTION 4                                                             PLOTMY55
      IF(MOD(KODE/4,2).NE.0) NY = P(4)                                  PLOTMY56
      IF(NY.EQ.0) NY = 100                                              PLOTMY57
C--OPTION 8 NOT AVAILABLE                                               PLOTMY58
      IF(MOD(KODE/8,2).NE.0) WRITE(NWRIT,1080)                          PLOTMY59
C--ALL OPTIONS                                                          PLOTMY60
      FORY = .TRUE.                                                     PLOTMY61
      STUG = .FALSE.                                                    PLOTMY62
      TONLY = .FALSE.                                                   PLOTMY63
      IF(MOD(KODE/32,2).EQ.0) GO TO 190                                 PLOTMY64
C--OPTION 32                                                            PLOTMY65
      STUG = .TRUE.                                                     PLOTMY66
      KSY = P(9)                                                        PLOTMY67
      PWR10Y = 10.** (KSY-6)                                            PLOTMY68
      FY = P(10)*PWR10Y                                                 PLOTMY69
      F = FY                                                            PLOTMY70
C--SPECIAL CASE OF OPTION 32                                            PLOTMY71
      IF(P(5).GE.2.) GO TO 190                                          PLOTMY72
      TONLY = .TRUE.                                                    PLOTMY73
      DY =  P(11)*PWR10Y                                                PLOTMY74
      DX =  DY                                                          PLOTMY75
C--ALL OPTIONS                                                          PLOTMY76
  190 N = NPTST                                                         PLOTMY77
      CALL PISTUG(Y)                                                    PLOTMY78
      IF(DX.EQ.0.) GO TO 510                                            PLOTMY79
      FY = F                                                            PLOTMY80
      DY ■ DX                                                           PLOTMY81
C--MODIFY Y LABEL FORMAT IF NECESSARY                                   PLOTMY82
      IF(KFD.GT.0.AND.KFD.LE.6) YLAB(5) = FKFD(KFD)                     PLOTMY83
C--SET LOGICAL VARIABLES                                                PLOTMY84
      FORY = .FALSE.                                                    PLOTMY85
      STUG = .FALSE.                                                    PLOTMY86
      TONLY = .FALSE.                                                   PLOTMY87
C--OPTION 16                                                            PLOTMY88
      IF(MOD(KODE/16,2).EQ.0) GO TO 200                                 PLOTMY89
      STUG = .TRUE.                                                     PLOTMY90
      KSX = P(6)                                                        PLOTMY91
      PWR10X = 10.**(KSX-6)                                             PLOTMY92
      FX ■ P(7)*PWR10X                                                  PLOTMY93
      F = FX                                                            PLOTMY94
C--SPECIAL CASE OF OPTION 16                                            PLOTMY95
      IF(MOD(IFIX(P(5)),2).EQ.1) GO TO 200                              PLOTMY96
      TONLY = .TRUE.                                                    PLOTMY97
      DX ■ P(8)*FWR10X                                                  PLOTMY98
  200 IF(P(1).LT.2.)N = NPTS                                            PLOTMY99
C--ALL OPTIONS                                                          PLOTM100
      ILIM = N                                                          PLOTM101
      CALL PISTUG(X)
      IF(DX.EQ.0.) GO TO 510
      FX = F
C--MODIFY X LABEL FORMAT IF NECESSARY
      IF(KFD.GT.0.AND.KFD.LE.6) XLAB(4) = FKFD(KFD)
      IF(KFD.GT.0.AND.KFD.LE.6) XLAB(7) = FKFD(KFD)
C--COMPUTE AND TEST Y LABELS
  210 TDY = DY*10.
      DO 220 I=1,11
      TEMP = FY+FLOAT(I-1)*TDY
      ATEMP = ABS(TEMP)
      IF (ATEMP.LT.1.E-7) TEMP = 0.
      IF (ATEMP.GE.1.E+7) LABOUT = 2
  220 YLABEL(I) = TEMP
      KSYLAB = 1
C--WRITE Y LABELS
  230 WRITE(NWRIT,YLAB) YLABEL
      IF(KSYLAB.EQ.2) GO TO 510
C--INITIALIZE VARIABLES FOR MAIN PLOT
      KSYLAB = 2
      LCTR = 0
      NCTR = 1
      KOUT = 1
      KQUIT = 1
      XMIN = FX-DX/2.
      XMAX = FX+DX/2.
C--FILL THE A ARRAY FOR CURRENT LINE OF PLOT
C----FILL THE A ARRAY WITH BLANKS OR X-GRID MARKS, AS APPROPRIATE
  240 AFILL = BLANK
      IF(MOD(LCTR,NX).EQ.0) AFILL = XGRID
C--FILL IN LINE AND INSERT Y GRID MARKS
  260 DO 270 I=2,104
  270 A(I) = AFILL
      DO 280  I=2,104,NY
  280 A(I) = YGRID
      A(1) = BLANK
      IF(KOUT.EQ.2) GO TO 410
C--FIND INDEX OF NEXT X ON THE CURRENT LINE
      IGON = 1
  290 CONTINUE
      IF(IGON.GT.ILIM) GO TO 420
      DO 300 I=IGON,ILIM
      IF(X(I).LE.XMIN.OR.X(I).GT.XMAX) GO TO 300
      IMIN = I
      GO TO 310
  300 CONTINUE
C--IF NO MORE POINTS ON THE CURRENT LINE, WRITE IT OUT
      GO TO 420
C--PLACE PLOTTING CHARACTER IN PROPER POSITION (KYL) IN THE A ARRAY
  310 DO 390 IM=1,KTL
      LL = IMIN+(IM-1)*NPTS
      KY = (Y(LL)-FY)/DY+.5
      IF(P(1).LT.2.) GO TO 340
C--DUPY OR NODUP
      IK = 0
      KLAST = 2*KN+1
      DO 320 IL=3,KLAST,2
      IK ■ IK+K(IL)
      IF(IK.GE.IMIN) GO TO 330
  320 CONTINUE
      LABOUT = 5
      GO TO 510
  330 KPC ■ K(IL+1)
      GO TO 350
C--DUPX
  340 KPC = K(2*IM+2)
C--DEFINE KYL
  350 KYL = KY+2
C--PLOT OUT RANGE Y AS ■
      IF(KY.LT.0) GO TO 360
      IF(KY.GT.101) GO TO 370
      GO TO 390
  360 KYL = 1
      GO TO 380
  370 KYL ■ 104
  380 TPC = RMARK
  390 A(KYL) = TPC
C--ARE ALL POINTS DONE_
      IF(NCTR.GE.ILIM) GO TO 400
      NCTR = NCTR+1
      IGON = IMIN+1
      GO TO 290
C--ALL POINTS PLOTTED FOR ENTIRE PLOT
  400 KOUT = 2
  410 IF(MOD(LCTR,10).GT.5) NX = 10
      IF(MOD(LCTR,NX).EQ.0) KQUIT = 2
C
C--WRITE CURRENT LINE OF PLOT
  420 IF(MOD(LCTR,10).EQ.0) GO TO 430
C--WRITE LINE WITHOUT XLABEL
      WRITE(NWRIT,1020) A
      GO TO 440
  430 XLABEL = FX+FLOAT(LCTR)*DX
      TEMP ■ ABS(XLABEL)
      IF(TEMP.GE.1.E+7) LABOUT = 2
      IF(TEMP.LT.1.E-7) XLABEL ■ 0.
C--WRITE LINE WITH XLABEL
      WRITE(NWRIT,XLAB) XLABEL,A,XLABEL
C--INCREMENT LINE COUNTER
  440 LCTR = LCTR+1
      XMIN = XMAX
      XMAX = DX*(FLOAT(LCTR)+.5)+FX
C--DO NEXT LINE
      GO TO (240,230),KQUIT
C
C--PLOT COMPLETED - WRITE FINAL LINE OR ERROR MESSAGE
  510 GO TO (560,520,540,540,550),LABOUT
  520 WRITE(NWRIT,1040)
      GO TO 570
  540 WRITE(NWRIT,1050) (X(I),Y(I),I=1,2),(K(J),J=1,3),P(1)
      GO TO 570
  550 WRITE(NWRIT,1060)
  560 WRITE(NWRIT,1000)
C--RESTORE INITIAL FORMATS BEFORE RETURN
  570 CONTINUE
      YLAB(5) = FKFD0
      XLAB(4) = FKFD0
      XLAB(7) = FKFD0
      RETURN
C--FORMAT STATEMENTS
```

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 1000 FORMAT(1H  )                                                      PLOTM222
 1020 FORMAT(1H  ,15X,104A1)                                            PLOTM223
 1040 FORMAT(1H  ,3X,10HBAD LABELS)                                     PLOTM224
 1050 FORMAT(1H  ,5H N.G.,4G20.8,3I7,F8.2)                              PLOTM225
 1060 FORMAT(1H  ,16HERROR IN K ARRAY)                                  PLOTM226
 1080 FORMAT(1H  ,98X,28HOPTION 8 NO LONGER AVAILABLE)                  PLOTM227
      END                                                               PLOTM228
       SUBROUTINE PISTUG(ARRAY)                                         PISTUG 2
C--PISTUG CALCULATES DX, KFD, AND FX OR FY                              PISTUG 3
      LOGICAL FORY,STUG,TONLY                                           PISTUG 4
       DIMENSION ARRAY(1)                                               PISTUG 5
      LEVEL 2,  ARRAY                                                   PISTUG 6
      COMMON /JOLO/ F,DX,TLINX,N,LABOUT,KFD,FORY,STUG,TONLY             PISTUG 7
      KHAR(XMAX) = INT(ALOG10(XMAX)+40.)-40                             PISTUG 8
C--FIND X1, THE FIRST POINT TO BE PLOTTED                               PISTUG 9
   10 X1 = ARRAY(1)                                                     PISTUG10
      IF(STUG) GO TO 110                                                PISTUG11
      00 100 J=2,N                                                      PISTUG12
  100 X1 = AMIN1(X1,ARRAY(J))                                           PISTUG13
  110 IF(STUG) X1 = F                                                   PISTUG14
C--FIND XN, THE LAST POINT TO BE PLOTTED                                PISTUG15
      DIFMAX = 0.                                                       PISTUG16
      DO 120 J=1,N                                                      PISTUG17
      DIF = ABS(X1-ARRAY(J))                                            PISTUG18
      IF(DIF.LE.DIFMAX) GO TO 120                                       PISTUG19
      DIFMAX = DIF                                                      PISTUG20
      IHOLD = J                                                         PISTUG21
  120 CONTINUE                                                          PISTUG22
      IF(DIFMAX.EQ.0.) GO TO 300                                        PISTUG23
      XN = ARRAY(IHOLD)                                                 PISTUG24
      IF(TONLY) GO TO 150                                               PISTUG25
C--CALCULATE DX                                                         PISTUG26
      TLIN = 101.                                                       PISTUG27
      IF(.NOT.FORY) TLIN ◘ TLINX                                        PISTUG28
      C5 ◘ (XN-X1)/TLIN                                                 PISTUG29
      K7 = KHAR(ABS(C5))                                                PISTUG30
      C9 = ABS(C5)/10.**K7                                              PISTUG31
      D = 2.                                                            PISTUG32
      IF(C9.GT.2.) D ◘ 2.5                                              PISTUG33
      IF(C9.GT.2.5) D = 5.                                              PISTUG34
      IF(C9.GT.5.) D ◘ 10.                                              PISTUG35
      DX ◘ SIGN(D*10.**K7,C5)                                           PISTUG36
C--CALCULATE KFD                                                        PISTUG37
  150 K7 = KHAR(ABS(DX))                                                PISTUG38
      IF(FLOAT(K7)+1.5.GT.5.6) LABOUT = 2                               PISTUG39
      KFD = MAX0(0,MIN0(6,-K7))                                         PISTUG40
      IF(STUG) GO TO 200                                                PISTUG41
C--CALCULATE F (FX OR FY)                                               PISTUG42
      KC12 ◘ INT(ABS(X1/DX))                                            PISTUG43
      KC15 = KC12-MOD(KC12,10)                                          PISTUG44
      IF(DX*X1.LT.0.) KC15 = KC15+10                                    PISTUG45
      IF(X1.LT.0.) KC15 = -KC15                                         PISTUG46
      F = ABS(DX)*FLOAT(KC15)                                           PISTUG47
      IF(.NOT.FORY) GO TO 200                                           PISTUG48
C--CALCULATE F DIFFERENTLY, IF NECESSARY, TO KEEP ALL POINTS ON PLOT    PISTUG49
      TEMP = F+100.*DX                                                  PISTUG50
      IF(TEMP.GE.SIGN(XN,DX)) GO TO 200                                 PISTUG51
      IF(DX*X1.LT.0.) KC12 = KC12+1                                     PISTUG52
      IF(X1.LT.0.) KC12 = -KC12                                         PISTUG53
      F = ABS(DX)*FLOAT(KC12)                                           PISTUG54
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C--RETURN                                                               PISTUG55
  200 RETURN                                                            PISTUG56
C--ERROR RETURN                                                         PISTUG57
  300 DX = 0.                                                           PISTUG58
      LABOUT = 3                                                        PISTUG59
      GO TO 200                                                         PISTUG60
      END                                                               PISTUG61
      SUBROUTINE BLADE(IPLOTB)                                          BLADE  2
C ***                 THE CENTRAL CONTROL ROUTINE                       BLADE  3
      REAL KIC, KICR, KIP, KIS, KM, KOC, KOCR, KOP, KOS, KTC, KTP, KTS  BLADE  4
      COMMON /SCALR/                                                    BLADE  5
     1 BLADES, CALP, CCC, CEPE, CKTC, CKTS, C1, C2, DRCE, DRCLEP, DRCLESBLADE  6
     2, DPCMST, DRCMT, DRCOI, DRCS, DRCT, DRCTEP, DRCTES, DRCTI, DRCTMP,BLADE  7
     3 DRCTMS, DRCTPI, DRCTSI, DSME, DSMT, DSOT, DSP, DSP1, DSP2, DSSE, BLADE  8
     4 DSS1, DSS2, DST, DSTI, EMT, IR, IW, KIC, KIP, KIS, KM, KOC, KOP, BLADE  9
     5 KOS, KTC, KTP, KTS, PI, RCI, RCMS, RCO, RCT, RCTP, RCTS, REE,    BLADE 10
     6 RELEP, PELES, REM, REMS, REMT, REOI, RES, RET, RETEP, RETES, RETIBLADE 11
     7, RETMP, RETMS, RETP, RETS, R1C, SGAM, SALP, SKTC, SKTS, TEPE,    BLADE 12
     8 THMAX, TKTN                                                      BLADE 13
      COMMON /INPUTB/                                                   BLADE 14
     1 ALP, KICR, KOCR, NB, P, R, SOLID, T, THLE, THTE, TMX, ZM         BLADE 15
      COMMON /INPUTT/RDUM1(17),IDUM1(16),XCHORD(2),XSTGR(2),XRI(2),     BLADE 16
     1 XRO(2),XBETI(2),XBETO(2),IDUM2(2),RDUM2(270),XMSP(50,2),         BLADE 17
     2 XTHSP(50,2)                                                      BLADE 18
      COMMON/BLANK/                                                     BLADE 19
     1 THSP1(13), THSP2(13), ZMSP1(13), ZMSP2(13), BETI1, BETI2, BETO1, BLADE 20
     2 BETO2, CHORD, RI, RO, STGR                                       BLADE 21
      COMMON/INPUTA/ XXMSP(50,2),XXTHSP(50,2)                           BLADE 22
      DIMENSION FSB(13)                                                 BLADE 23
      DATA FSB/.0,.05,.12,.2,.3,.4,.5,.6,.7,.8,.88,.95,1.0/             BLADE 24
      IR = 5                                                            BLADE 25
      IW = 6                                                            BLADE 26
      PI = 3.1415927                                                    BLADE 27
      RADIAN = 57.29578                                                 BLADE 28
      IF(IPLOTB.NE.0)                                                   BLADE 29
     *WRITE (IW,2000)  NB, R, ALP, SOLID, KICR, KOCR, T, ZM, P, TMX,    BLADE 30
     X THLE, THTE                                                       BLADE 31
C *** INPUT OPTIONS ARE IP ◘ 1 OR 3 FOR PUNCH AND IP.GT.1 FOR PLOT      BLADE 32
      THMAX ◘ TMX/2.0                                                   BLADE 33
      KIC = KICR/RADIAN                                                 BLADE 34
      KOC = KOCR/RADIAN                                                 BLADE 35
      TALP = TAN(ALP/RADIAN)                                            BLADE 36
      SALP = TALP/SQRT(1.0 + TALP**2)                                   BLADE 37
      CALP = SQRT(1.0 - SALP**2)                                        BLADE 38
      BLADES ◘ NB                                                       BLADE 39
      GBL = (KIC + KOC)/2.0                                             BLADE 40
      SGAM = SIN(GBL)                                                   BLADE 41
      CGAM = SQRT(1.0 - SGAM**2)                                        BLADE 42
      CCC = 1.0 - THLE - THTE                                           BLADE 43
      C1 = T - THLE                                                     BLADE 44
      C2 = 1.0 - T - THTE                                               BLADE 45
      THD = THLE - THTE                                                 BLADE 46
      TEPE = THD/CCC                                                    BLADE 47
      CEPE = 1.0/SQRT(1.0 + TEPE**2)                                    BLADE 48
      SEPE ◘ TEPE*CEPE                                                  BLADE 49
      CALL CONIC(CHD)                                                   BLADE 50
C ***       BLADE ELEMENT SUCTION SURFACE Z AND THETA ARRAYS REFERENCED BLADE 51
C *** TO THE LOWEST Z POINT OF THE LEADING EDGE CIRCLE.                 BLADE 52
      ZTRS = (DRCTSI + THLE)*CHD                                        BLADE 53
      RTC = R1C + (DRCTSI + THLE)*SALP                                  BLADE 54
      TTRS = RETS/RTC                                                   BLADE 55
      FST = DSS1/(DSS1 + DSS2)                                          BLADE 56
      DO 50 K=1,13                                                      BLADE 57
      FS = FSB(K) - FST                                                 BLADE 58
      IF (FS.GT.0.0)  GO TO 20                                          BLADE 59
      DSS = DSS1*FS/FST                                                 BLADE 60
      DK = (KTS - KIS)*DSS/DSS1                                         BLADE 61
      GO TO 30                                                          BLADE 62
   20 DSS = DSS2*FS/(1.0 - FST)                                         BLADE 63
      DK = (KOS - KTS)*DSS/DSS2                                         BLADE 64
   30 CALL EPSLON(KTS,DK,RCTS,DSS,DRCTS,RES)                            BLADE 65
      ZMSP1(K) = ZTRS + DRCTS*CHD                                       BLADE 66
   50 THSP1(K) = TTRS + RES/(RTC + DRCTS*SALP)                          BLADE 67
C ***      BLADE ELEMENT PRESSURE SURFACE Z AND THETA ARRAYS REFERENCED BLADE 68
C *** TO THE LOWEST Z POINT OF THE LEADING EDGE CIRCLE.                 BLADE 69
      ZTRP = (DRCTPI + THLE)*CHD                                        BLADE 70
      RTC = R1C + (DRCTPI + THLE)*SALP                                  BLADE 71
      TTRP = RETP/RTC                                                   BLADE 72
      FST = DSP1/DSP                                                    BLADE 73
      DO 100 K=1,13                                                     BLADE 74
      FS = FSB(K) - FST                                                 BLADE 75
      IF (FS.GT.0.0)  GO TO 70                                          BLADE 76
      DSS = DSP1*FS/FST                                                 BLADE 77
      DK = (KTP - KIP)*DSS/DSP1                                         BLADE 78
      GO TO 80                                                          BLADE 79
   70 DSS = DSP2*FS/(1.0 - FST)                                         BLADE 80
      DK = (KOP - KTP)*DSS/DSP2                                         BLADE 81
   80 CALL EPSLON(KTP,DK,RCTP,DSS,DRCTS,RES)                            BLADE 82
      ZMSP2(K) = ZTRP + DRCTS*CHD                                       BLADE 83
  100 THSP2(K) = TTRP + RES/(RTC + DRCTS*SALP)                          BLADE 84
      CHORD = (DRCOI + THLE + THTE)*CHD                                 BLADE 85
      RI = THLE*CHD                                                     BLADE 86
      RO = THTE*CHD                                                     BLADE 87
      BETI1 = KIS*RADIAN                                                BLADE 88
      BETO1 = KOS*RADIAN                                                BLADE 89
      BETI2 = KIP*RADIAN                                                BLADE 90
      BETO2 = KOP*RADIAN                                                BLADE 91
      GBL=RADIAN*ASIN(SGAM)                                             BLADE 92
      IF(IPLOTB.NE.0)                                                   BLADE 93
     *WRITE (IW,2100) CHD, GBL                                          BLADE 94
      RTE = R1C + DRCOI*SALP                                            BLADE 95
      RM = R1C + (DRCTI + DRCMT)*SALP                                   BLADE 96
      REOI = REOI/RTE                                                   BLADE 97
      STGR = REOI                                                       BLADE 98
      RETI = RETI/(R1C + DRCTI*SALP)                                    BLADE 99
      REMT = RETI + REMT/RM                                             BLADE100
      RELES = RELES/(R1C + DRCLES*SALP)                                 BLADE101
      RETES = REOI + RETES/(RTE + DRCTES*SALP)                          BLADE102
      RELEP = RELEP/(R1C + DRCLEP*SALP)                                 BLADE103
      RETEP = REOI + RETEP/(RTE + DRCTEP*SALP)                          BLADE104
      REMS = REMT + REMS/(R1C + (DRCTSI - DRCTMS)*SALP)                 BLADE105
      REM = REMT + REM/(R1C + (DRCTPI - DRCTMP)*SALP)                   BLADE106
      RETMS = REMS + RETMS/(R1C + DRCTSI*SALP)                          BLADE107
      RETMP = REM + RETMP/(R1C + DRCTPI*SALP)                           BLADE108
      DRCMT = (DRCTI + DRCMT)*CHD                                       BLADE109
      DRCTMS = (DRCTSI - DRCTMS)*CHD                                    BLADE110
      DRCTMP = (DRCTPI - DRCTMP)*CHD                                    BLADE111
      DRCTSI = DRCTSI*CHD                                               BLADE112
      DRCTPI = DRCTPI*CHD                                               BLADE113
      DRCTI = DRCTI*CHD                                                 BLADE114
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      DRCTES = (DRCTES + DRCOI)*CHD                                     BLADE115
      DRCTEP = (DRCTEP + DRCOI)*CHD                                     BLADE116
      DRCOI = DRCOI*CHD                                                 BLADE117
      DRCLES = DRCLES*CHD                                               BLADE118
      DRCLEP = DRCLEP*CHD                                               BLADE119
      REF = 0.0                                                         BLADE120
      KTC = KTC*RADIAN                                                  BLADE121
      KTS = KTS*RADIAN                                                  BLADE122
      KTP = KTP*RADIAN                                                  BLADE123
      KM = KM*RADIAN                                                    BLADE124
      DSTI = DSTI*CHD                                                   BLADE125
      DSOT = DSOT*CHD                                                   BLADE126
      DSS1 = DSS1*CHD                                                   BLADE127
      DSS2 = DSS2*CHD                                                   BLADE128
      DSP1 = DSP1*CHD                                                   BLADE129
      DSP2 = DSP2*CHD                                                   BLADE130
      IF(IPLOTB.EQ.0) GO TO 110                                         BLADE131
      WRITE (IW,2120)  DRCLES, DRCTES, DRCTSI, DRCTMS, RELES, RETES,    BLADE132
     X RETMS, REMS, BETI1, BETO1, KTS, KM, DSS1, DSS2                   BLADE133
      WRITE (IW,2110)  REF, DRCOI, DRCTI, DRCMT, REF, REOI, RETI, REMT, BLADE134
     X KICR, KOCR, KTC, KM, DSTI, DSOT                                  BLADE135
      WRITE (IW,2130)  DRCLEP, DRCTEP, DRCTPI, DRCTMP, RELEP, RETEP,    BLADE136
     X RETMP, REM, BETI2, BETO2, KTP, KM, DSP1, DSP2                    BLADE137
  110 CONTINUE                                                          BLADE138
      RSALP = RADIAN*SALP                                               BLADE139
      RELES = RSALP*RELES                                               BLADE140
      RETES = RSALP*RETES                                               BLADE141
      RETMS = RSALP*RETMS                                               BLADE142
      REMS = RSALP*REMS                                                 BLADE143
      REOI = RSALP*REOI                                                 BLADE144
      RETI = RSALP*RETI                                                 BLADE145
      REMT = RSALP*REMT                                                 BLADE146
      RELEP = RSALP*RELEP                                               BLADE147
      RETEP = RSALP*RETEP                                               BLADE148
      RETMP = RSALP*RETMP                                               BLADE149
      REM = RSALP*REM                                                   BLADE150
      BETI1 = BETI1 + RELES                                             BLADE151
      BETO1 = BETO1 + RETES                                             BLADE152
      KTS = KTS + RETMS                                                 BLADE153
      BMS = KM + REMS                                                   BLADE154
C     KOCR = KOCR + REOI                                                BLADE155
      KTC = KTC + RETI                                                  BLADE156
      KM = KM + REMT                                                    BLADE157
      BETI2 = BETI2 + RELEP                                             BLADE158
      BETO2 = BETO2 + RETEP                                             BLADE159
      KTP = KTP + RETMP                                                 BLADE160
      BMP = KM + REM                                                    BLADE161
      IF(IPLOTB.EQ.0) GO TO 125                                         BLADE162
      WRITE (IW,2135)                                                   BLADE163
      WRITE (IW,2136)  RELES, RETES, RETMS, REMS, BETI1, BETO1, KTS, BMSBLADE164
      WRITE (IW,2137)  REF, REOI, RETI, REMT, KICR, KOCR, KTC, KM       BLADE165
      WRITE (IW,2138)  RELEP, RETEP, RETMP, REM, BETI2, BETO2, KTP, BMP BLADE166
      WRITE (IW,2140)  CHORD, STGR, RI, RO, BETI1, BETO1, RI, RO, BETI2,BLADE167
     X BETO2                                                            BLADE168
      DO 120 K=1,13                                                     BLADE169
  120 WRITE (IW,2150)  ZMSP1(K), THSP1(K), ZMSP2(K), THSP2(K)           BLADE170
      WRITE (IW,2160)                                                   BLADE171
  125 CONTINUE                                                          BLADE172
C *** ASSIGN VALUES TO BE PASSED TO TSONIC AND OPTIMIZATION PROGRAM     BLADE173
      XCHORD(1)=CHORD                                                   BLADE174
      XSTGR(1)=STGR                                                     BLADE175
      XRI(1)=RI                                                         BLADE176
      XRO(1)=RO                                                         BLADE177
      XBETI(1)=BETI1                                                    BLADE178
      XBETO(1)=BETO1                                                    BLADE179
      DO 130 K=1,13                                                     BLADE180
      XMSP(K,1)=ZMSP1(K)                                                BLADE181
      XXMSP(K,1)=ZMSP1(K)                                               BLADE182
      XXTHSP(K,1)=THSP1(K)                                              BLADE183
  130 XTHSP(K,1)=THSP1(K)                                               BLADE184
      XRI(2)=RI                                                         BLADE185
      XRO(2)=RO                                                         BLADE186
      XBETI(2)=BETI2                                                    BLADE187
      XBETO(2)=BETO2                                                    BLADE188
      DO 140 K=1,13                                                     BLADE189
      XMSP(K,2)=ZMSP2(K)                                                BLADE190
      XXMSP(K,2)=ZMSP2(K)                                               BLADE191
      XXTHSP(K,2)=THSP2(K)                                              BLADE192
  140 XTHSP(K,2)=THSP2(K)                                               BLADE193
      IF (IPLOTB.EQ.1) CALL EPLOT                                       BLADE194
      RETURN                                                            BLADE195
 2000 FORMAT (1H1 // 46X,39H*** INPUT FOR BLADE ELEMENT PROGRAM ***   //BLADE196
     1/ 49X,5HINLET,4X,6HOUTLET,4X,6HTRANS.,4X,7HMAX.TH.,3X,6HIN/OUT,5X,BLADE197
     2 4HMAX.,6X,4HL.E.,6X,4HT.E. / 10X,3HNO.,6X,5HINLET,5X,4HCONE,4X,  BLADE198
     3 8HSOLIDITY,4X,5HBLADE,5X,5HBLADE,5X,4HLOC.,6X,4HLOC.,5X,7HTURNINGBLADE199
     4,3X,6HTHICK.,5X,4HRAD.,6X,4HRAD. / 8X,6HBLADES,4X,6HRADIUS,5X,    BLAQE200
     5 5HANGLE,15X,5HANGLE,5X,5HANGLE,4X,6H/CHORD,4X,6H/CHORD,5X,4HRATE,BLADE201
     6 5X,6H/CHORD,4X,6H/CHORD,4X,6H/CHORD / 20X,3H(L),6X,5H(DEG),15X,  BLADE202
     7 5H(DEG),5X,5H(DEG) // 9X,I3,3X,3F10.5,F9.3,F10.4,6F10.5)         BLADE203
 2100 FORMAT (//////// 45X,41H*** OUTPUT FROM BLADE ELEMENT PROGRAM *** BLADE204
     1 /// 69X,7HELEMENT / 69X,7HSETTING / 58X,5HCHORD,7X,5HANGLE / 59X,BLADE205
     2 3H(L),8X,5H(DEG) // 52X,F12.5,F12.4 /// 10X,32H* MERID. LOC. FROMBLADE206
     3 L.E. CENT. **,2X,32H** THETA LOC. FROM L.E. CENT. **,2X,9(1H*),  BLADE207
     4 14H BLADE ANGLES ,9(1H*),3X,15HSEGMENT LENGTHS / 10X,8(4H****),  BLADE208
     5 2X,8(4H****),2X,33H(WITH RESPECT TO LOCAL CONIC RAY),2X,5(3H***) BLADE209
     6 // 8X,3(4X,5HINLET,2X,6HOUTLET,2X,6HTRANS.,2X,7HMAX.TH.),4X,     BLADE210
     7 5HFIRST,2X,6HSECOND / 8X,4(5X,3H(L)),3X,4(3X,5H(RAD)),2X,4(3X,   BLADE211
     8 5H(DEG)),1X,2(5X,3H(L)) / )                                      BLADE212
 2110 FORMAT (3X,5HCENT.,1X,4F8.5,2X,4F8.5,2X,4F8.3,3X,2F8.5 / )        BLADE213
 2120 FORMAT (3X,5HSUCT.,1X,4F8.5,2X,4F8.5,2X,4F8.3,3X,2F8.5 / )        BLADE214
 2130 FORMAT (3X,5HPRES.,1X,4F8.5,2X,4F8.5,2X,4F8.3,3X,2F8.5 / )        BLADE215
 2135 FORMAT ( // 44X,32H**** CONIC ANGLE COORD. - C ****,2X,9(1H*),    BLADE216
     1 14H BLADE ANGLES ,9(1H*) / 1H+,69X,1H- /  44X,32H** (FROM LEADINGBLADE217
     2 EDGE CENT.) ***,2X,32H(WITH RESPECT TO L.E. CENT. RAY)// 42X,    BLADE218
     3 2(4X,5HINLET,2X,6HOUTLET,2X,6HTRANS.,2X,7HMAX.TH.) / 43X,        BLADE219
     4 4(3X,5H(DEG)),2X,4(3X,5H(DEG)) / )                               BLADE220
 2136 FORMAT (37X,5HSUCT.,1X,4F8.3,2X,4F8.3 / )                         BLADE221
 2137 FORMAT (37X,5HCENT.,1X,4F8.3,2X,4F8.3 / )                         BLADE222
 2138 FORMAT (37X,5HPRES.,1X,4F8.3,2X,4F8.3 / )                         BLADE223
 2140 FORMAT (1H1 ///// 41X,51H*** OUTPUT THAT CAN BE PUNCHED FOR TSONICBLADE224
     1 INPUT *** /////51X,10(3H***)/51X,1H*,28X,1H*/ 51X,1H*,6X,5HCHORD,BLADE225
     2 6X,4HSTGR,7X,1H* / 51X,1H*,7X,3H(L),7X,5H(RAD),6X,1H* / 51X,1H*, BLADE226
     3 28X,1H* / 51X,1H*,2X,F10.5,F11.6,5X,1H* / 51X,1H*,28X,1H* / 15X, BLADE227
     4 103(1H*) / 15X,1H*,2(50X,1H*) / 15X,1H*14X,23H*** SUCTION SURFACEBLADE228
     5 ***,13X,1H*,13X,24H*** PRESSURE SURFACE ***,13X,1H* / 15X,1H*,2( BLADE229
     6 50X,1H*) / 15X,1H*,8X,34(1H*),8X,1H*,8X,34(1H*),8X,1H* / 15X,1H*,BLADE230
     7 2(50X,1H*) / 15X,2(1H*,8X,2HRI,9X,2HRO,8X,4HBETI,7X,4HBETO,6X),  BLADE23
     8 1H* / 15X,2(1H*,7X,3H(L),8X,3H(L),7X,5H(DEG),6X,5H(DEG),6X),1H* /BLADE23
     9 15X,1H*,2(50X,1H*) / 15X,1H*,2(1X,2F11.5,2F11.4,5X,1H*) / 15X,1H*BLADE23
     .,2(50X,1H*) / 15X,1H*,2(50X,1H*) / 15X,1H*,2(15X,4HZMSP,12X,4HTHSPBLADE23
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     1,15X,1H*) / 15X,1H*,2(16X,3H(L),12X,5H(RAD),14X,1H*) / 15X,1H*,   BLADE235
     2 2(50X,1H*) )                                                     BLADE236
 2150 FORMAT (15X,1H*,2(9X,F11.5,6X,F11.6,13X,1H*) )                    BLADE237
 2160 FORMAT (15X,1H*,2(50X,1H*)/ 15X,103(1H*) )                        BLADE239
      END                                                               BLADE239
      SUBROUTINE CONIC(CHORD)                                           CONIC  2
C ***     THIS IS THE MAIN BLADE ELEMENT LAYOUT ROUTINE.  BLADE ELEMENTSCONIC  3
C *** ARE LAID OUT ON A CONE SUCH THAT THE CIRCULAR ARC CHARACTERISTIC  CONIC  4
C *** OF CONSTANT RATE OF ANGLE CHANGE WITH PATH DISTANCE IS MAINTAINED.CONIC  5
      REAL KIC, KIP, KIS, KM, KOC, KOP, KOS, KTC, KTP, KTS              CONIC  6
      COMMON /SCALR/                                                    CONIC  7
     1 BLADES, CALP, CCC, CEPE, CKTC, CKTS, C1, C2, DRCE, DRCLEP, DRCLESCONIC  8
     2, DRCMST, DRCMT, DRCOI, DRCS, DRCT, DRCTEP, DRCTES, DRCTI, DRCTMP,CONIC  9
     3 DRCTMS, DRCTPI, DRCTSI, DSME, DSMT, DSOT, DSP, DSP1, DSP2, DSSE, CONIC 10
     4 DSS1, DSS2, DST, DSTI, EMT, IR, IW, KIC, KIP, KIS, KM, KOC, KOP, CONIC 11
     5 KOS, KTC, KTP, KTS, PI, RCI, RCMS, RCO, RCT, RCTP, RCTS, REE,    CONIC 12
     6 RELEP, RELES, REM, REMS, REMT, REOI, RES, RET, RETEP, RETES, RETICONIC 13
     7, RETMP, RETMS, RETP, RETS, R1C, SGAM, SALP, SKTC, SKTS, TEPE,    CONIC 14
     8 THMAX, TKTN                                                      CONIC 15
      COMMON /INPUTB/                                                   CONIC 16
     1 ALP, KICR, KOCR, NB, P, R, SOLID, T, THLE, THTE, TMX, ZM         CONIC 17
C ***      ESTABLISH BLADE ELEMENT CENTERLINE TO SATISFY CAMBER, CHORD  CONIC 18
C *** AND TRANSITION POINT REQUIREMENTS.                                CONIC 19
      PI2 = PI/2.0                                                      CONIC 20
      CGAM= SQRT(1.0 - SGAM**2)                                         CONIC 21
      ICONV = 0                                                         CONIC 22
      DKAPPA = KIC - KOC                                                CONIC 23
      ICL = 1                                                           CONIC 24
      DK2 = DKAPPA/(1.0 + P*C1/C2)                                      CONIC 25
   10 CHORD = 2.0*PI*R*SOLID/(BLADES - PI*SOLID*CGAM*SALP)              CONIC 26
      R1C = R/CHORD                                                     CONIC 27
      CCHORD = CALP*CHORD                                               CONIC 28
      IF (ICL.GT.1)  GO TO 15                                           CONIC 29
      EPS= CCC*SGAM*SALP/(R1C + (THLE + CCC*CGAM)*SALP)                 CONIC 30
      DPHI = DKAPPA - EPS                                               CONIC 31
      DPHI4 = DPHI/4.0                                                  CONIC 32
      DPHIHS = DPHI*DPHI4                                               CONIC 33
      DSOI = CCC/(1.0 - DPHIHS/6.0*(1.0 - DPHIHS/20.0))                 CONIC 34
      DSTI= C1/CCC*DSOI                                                 CONIC 35
      DSOT= DSOI - DSTI                                                 CONIC 36
   15 IF (ABS(SALP/R1C).LT.1.0E-08)  GO TO 20                           CONIC 37
      RCI= R1C/SALP + THLE                                              CONIC 38
      GO TO 30                                                          CONIC 39
   20 RCI= 1.0E+08                                                      CONIC 40
   30 DK1 = DKAPPA - DK2                                                CONIC 41
      CALL EPSLON(KIC,-DK1,RCI,DSTI, DRCTI, RETI)                       CONIC 42
      KTC = KIC - DK1                                                   CONIC 43
      RCT= RCI + DRCTI                                                  CONIC 44
   35 CALL EPSLON(KTC,-DK2,RCT,DSOT,DRCOT,REOT)                         CONIC 45
      RCO= RCT + DRCOT                                                  CONIC 46
      REOI= RCO/RCT*RETI + REOT                                         CONIC 47
      DRCOI= DRCTI + DRCOT                                              CONIC 48
      CALL TANKAP(RCI,DRCOI,REOI,TANCCO)                                CONIC 49
      TGBL= (TANCCO + TEPE)/(1.0 - TANCCO*TEPE)                         CONIC 50
      CALL RPOINT(PCI,DRCTI,RETI,TGBL,DRCTP)                            CONIC 51
      SECGBL= SQRT(1.0 + TGBL**2)                                       CONIC 52
      DC1= DRCTP*SECGBL - C1                                            CONIC 53
      DC2 = DRCOI*SQRT(1.0 + TANCCO**2)*CEPE - CCC                      CONIC 54
      IF (ICL.GT.1.AND.ABS(TGBL - TGBLL).LT.1.0E-04)  GO TO 37          CONIC 55
      ICL = 2                                                           CONIC 56
      TGBLL = TGBL
      CGAM = 1.0/SQRT(1.0 + TGBL**2)
      GO TO 38
   37 ICONV = 1
   38 IF (ABS(DC1).LT.1.0E-04)  GO TO 40
      DS1= DSTI*DC1/(C1 + DC1)
      DSTI= DSTI - DS1
      DSOT= DSOT - DSOI*DC2/(CCC + DC2) + DS1
      DSOI = DSTI + DSOT
      DK2 = DKAPPA/(1.0 + P*DSTI/DSOT)
      IF (ICONV.LT.1)  GO TO 10
      GO TO 30
   40 IF (ABS(DC2).LT.1.0E-05)  GO TO 50
      DSOT= DSOT - DSOI*DC2/(CCC + DC2)
      DSOI = DSTI + DSOT
      IF (ICONV.LT.1)  GO TO 10
      GO TO 35
C ***      CONIC COORDINATES OF THE MAXIMUM THICKNESS POINT
   50 SGAM=TGBL*CGAM
      ZMT = ZM - T
      IF (ABS(ZMT).GT.1.0E-07)  GO TO 120
      DRCMT= 0.0
      REMT= 0.0
      DK= 0.0
      DSMT = 0.0
      DSME= DSTI
      DRCTMS = 0.0
      RETMS = 0.0
      DRCTMP = 0.0
      RETMP = 0.0
      GO TO 150
  120 HKTC= KTC/2.0
      SHKTC= HKTC*SRS(HKTC)
      SHKTCQ= SHKTC**2
      SKTC= 2.0*SHKTC*SQRT(1.0 - SHKTCQ)
      IF (ABS(SKTC).LT.1.0E-07) SKTC = 1.0E-07
      CKTC= 1.0 - 2.0*SHKTCQ
      TKTN= -CKTC/SKTC
      IF (ZMT.GT.0.0)  GO TO 130
      DSMT= DSTI*ZMT/C1
      DKDS= DK1/DSTI
      DSME= DSTI
      GO TO 140
  130 DSMT= DSOT*ZMT/C2
      DKDS = DK2/DSOT
      DSME= -DSOT
  140 DK= -DSMT*DKDS
      CALL EPSLON(KTC,DK,RCT,DSMT,DRCMT,REMT)
      CALL RPOINT(RCT,DRCMT,REMT,TGBL,DRCMP)
      ZMTCAL= DRCMP*SECGBL
      IF (ABS(ZMTCAL - ZMT).LT.1.5E-05)  GO TO 150
      DSMT = DSMT*ZMT/ZMTCAL
      GO TO 140
  150 RCM= RCT + DRCMT
      KM= KTC  + DK
      HKM= KM/2.0
      SHKM= HKM*SRS(HKM)
      SHKMQ= SHKM**2
      CHKM= SQRT(1.0 - SHKMQ)
      SKM= 2.0*SHKM*CHKM
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      CKM= 1.0 - 2.0*SHKMQ
      DSME= DSME + DSMT
C ***      DEFINITION OF SUCTION SURFACE MAX. THICKNESS POINT
      CALL EPSLON(KM+PI2,0.0,RCM,THMAX,DRCM,REM)
      REMS = REM
      RCMS= RCM + DRCM
      IF (ZMT.GT.1.0E-07)  GO TO 180
      REMI = (1.0 + DRCMT/RCT)*RETI + REMT
C ***      DEFINITION OF SUCTION SURFACE CURVE FOR MAXIMUM THICKNESS
C *** POINT ON OR AHEAD OF THE TRANSITION POINT
      DK= 2.0*(THMAX - THLE)/DSME
      KIS ■ KIC + DK
      KIP = KIC - DK
      DRCIM= -DRCTI - DRCMT - DRCM
      EMSI= REMI/RCM + REM/RCMS
      CALL SURF(KIS,KM,SKM,CKM,RCI,DRCIM,THLE,EMSI,DSSE)
      DRCLES = DRCE
      RELES = REE
      IF (ABS(ZMT).LT.1.0E-07)  GO TO 160
      DRCMST= DRCMT + DRCM
      EMT= REM/RCMS + REMT/RCM
      CALL TRAN(KIS,THLE,THMAX,KTS,RCTS,RETS,DSS1)
      DRCTMS = DRCS
      RETMS ■ RES
      DHKT= (KTC - KTS)/2.0
      DK= 2.0*(DST - THTE - DSOT*DHKT)/(DSOT + (DST - THTE)*DHKT)
      DRCOTS= DRCOT - DRCT
      EMSO= RET/RCTS - REOT/RCO
      DRCTSI = DRCTI + DRCT
      GO TO 170
  160 RCTS= RCMS
      KTS= KM
      RETS = RCMS*EMSI
      DSS1 = -DSSE
      SKTS= SKM
      CKTS= CKM
      DK= 2.0*(THMAX - THTE)/DSOT
      DRCOTS= DRCOT - DRCM
      EMSO= REM/RCMS - REOT/RCO
      DRCTSI = DRCTI + DRCM
  170 KOS = KOC - DK
      KOP = KOC + DK
      CALL SURF(KOS,KTS,SKTS,CKTS,RCO,DRCOTS,THTE,EMSO,DSS2)
      DRCTES = DRCE
      RETES = REE
      GO TO 190
C ***      DEFINITION OF SUCTION SURFACE CURVE FOR MAXIMUM THICKNESS
C *** POINT BEHIND THE TRANSITION POINT
  180 DK= 2.0*(THMAX - THTE)/DSME
      KOS ■ KOC + DK
      KOP = KOC - DK
      DRCOM= DRCOT - DRCMT - DRCM
      EMSO= REMT/RCM - REOT/RCO + REM/RCMS
      CALL SURF(KOS,KM,SKM,CKM,RCO,DRCOM,THTE,EMSO,DSSE)
      DRCTES = DRCE
      RETES = REE
      DRCMST= DRCMT + DRCM
      EMT= REM/RCMS + REMT/RCM
      CALL TRAN(KOS,THTE,THMAX,KTS,RCTS,RETS,DSS2)
      DRCTMS = DPCS
      RETMS = RES                                                       CONIC177
      DHKT= (KTS- KTC)/2.0                                              CONIC178
      DK= 2.0*(DST - THLE - DSTI*DHKT)/(DSTI + (DST - THLE)*DHKT)       CONIC179
      KIS = KIC + DK                                                    CONIC180
      KIP = KIC - DK                                                    CONIC181
      DPCTSI = DRCTI + DRCT                                             CONIC182
      EMSI= RETI/RCT + RET/RCTS                                         CONIC183
      CALL SURF(KIS,KTS,SKTS,CKTS,RCI,-DRCTSI,THLE,EMSI,DSSE)           CONIC184
      DRCLES = DRCE                                                     CONIC185
      RELES = REE                                                       CONIC186
      DSS1 = -DSSE                                                      CONIC187
C ***       DEFINITION OF PRESSURE SURFACE MAXIMUM THICKNESS POINT      CONIC188
  190 CALL EPSLON(KM+PI2,0.0,RCM,-THMAX,DRCM,REM)                       CONIC189
      RCMS= RCM + DRCM                                                  CONIC190
      IF (ZMT.GT.1.0E-07)  GO TO 220                                    CONIC191
C ***       DEFINITION OF PRESSURE SURFACE CURVE FOR MAXIMUM THICKNESS  CONIC192
C *** POINT ON OR AHEAD OF THE TRANSTION POINT                          CONIC193
      DRCIM= -DRCTI - DRCMT - DRCM                                      CONIC194
      EMSI= REMI/RCM + REM/RCMS                                         CONIC195
      CALL SURF(KIP,KM,SKM,CKM,RCI,DRCIM,-THLE,EMSI,DSSE)               CONIC196
      DRCLEP = DRCE                                                     CONIC197
      RELEP = REE                                                       CONIC198
      IF (ABS(ZMT).LT.1.0E-07)  GO TO 200                               CONIC199
      DRCMST= DRCMT + DRCM                                              CONIC200
      EMT = REM/RCMS + REMT/RCM                                         CONIC201
      CALL TRAN(KIP,-THLE,-THMAX,KTP,RCTP,RETP,DSP1)                    CONIC202
      DRCTMP = DRCS                                                     CONIC203
      RETMP = RES                                                       CONIC204
      DRCOTS= DRCOT - DRCT                                              CONIC205
      EMSO = RET/RCTP - REOT/RCO                                        CONIC206
      DRCTPI = DRCTI + DRCT                                             CONIC207
      GO TO 210                                                         CONIC208
  200 RCTP = RCMS                                                       CONIC209
      KTP= KM                                                           CONIC210
      RETP= RCMS * EMSI                                                 CONIC211
      DSP1 = -DSSE                                                      CONIC212
      DRCOTS= DRCOT - DRCM                                              CONIC213
      EMSO = REM/RCMS - REOT/RCO                                        CONIC214
      DRCTPI = DRCTI + DRCM                                             CONIC215
  210 CALL SURF(KOP,KTP,SKTS,CKTS,RCO,DRCOTS,-THTE,EMSO,DSP2)           CONIC216
      DRCTEP = DRCE                                                     CONIC217
      RETEP = REE                                                       CONIC218
      GO TO 230                                                         CONIC219
C ***       DEFINITION OF PRESSURE SURFACE CURVE FOR THE MAXIMUM        CONIC220
C *** THICKNESS POINT BEHIND THE TRANSITION POINT                       CONIC221
  220 DRCOM= DRCOT - DRCMT - DRCM                                       CONIC222
      EMSO = REMT/RCM - REOT/RCO + REM/RCMS                             CONIC223
      CALL SURF(KOP,KM,SKM,CKM,RCO,DRCOM,-THTE,EMSO,DSSE)               CONIC224
      DRCTEP = DRCE                                                     CONIC225
      RETEP = REE                                                       CONIC226
      DRCMST= DRCMT + DRCM                                              CONIC227
      EMT = REM/RCMS + REMT/RCM                                         CONIC228
      CALL TRAN(KOP,-THTE,-THMAX,KTP,RCTP,RETP,DSP2)                    CONIC229
      DRCTMP = DPCS                                                     CONIC230
      RETMP = RES                                                       CONIC231
      DPCTPI = DPCTI + DRCT                                             CONIC232
      EMSI = RETI/RCT + RET/RCTP                                        CONIC233
      CALL SURF(KIP,KTP,SKTS,CKTS,RCI,-DRCTPI,-THLE,EMSI,DSSE)          CONIC234
      DRCLEP = DRCE                                                     CONIC235
      RELEP = REE                                                       CONIC236
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      DSP1 = -DSSE                                                      CONIC237
  230 DSS = DSS1 + DSS2                                                 CONIC238
      DSP = DSP1 + DSP2                                                 CONIC239
      DKE = KIS - KIC                                                   CONIC240
      IF (DKE.GT.0.0)  GO TO 240                                        CONIC241
      WRITE (IW,2000)                                                   CONIC242
  240 IF ((KOS - KOC).LE.0.0)  GO TO 250                                CONIC243
      WRITE (IW,2010)                                                   CONIC244
  250 RETURN                                                            CONIC245
 2000 FORMAT (//// 30X,73H** NOTE THAT THE ELEMENT THICKNESS IS DECREASICONIC246
     1NG FROM THE LEADING EDGE ** )                                     CONIC247
 2010 FORMAT (//// 23X,86H** NOTE THAT THE ELEMENT THICKNESS IS INCREASICONIC248
     2NG AS THE TRAILING EDGE IS APPROACHED **)                         CONIC249
      END                                                               CONIC250
      SUBROUTINE EPLOT                                                  EPLOT  2
      DIMENSION X(26),Y(26),STRING(132)                                 EPLOT  3
      COMMON/BLANK/                                                     EPLOT  4
     1 THSP1(13), THSP2(13), ZMSP1(13), ZMSP2(13), BETI1, BETI2, BETO1, EPLOT  5
     2 BETO2, CHORD, RI, RO, STGR                                       EPLOT  6
      EQUIVALENCE (X(1),ZMSP1(1)),(Y(1),THSP1(1))                       EPLOT  7
      DATA STRING/132*1H /, BLANK/1H /, PLUS/1H+/                       EPLOT  8
      WPITE(6,900)                                                      EPLOT  9
C *** FIND X RANGE                                                      EPLOT 10
      XR=0.0                                                            EPLOT 11
      DO 10 I=1,26                                                      EPLOT 12
   10 IF (X(I) .GT. XR) XR=X(I)                                         EPLOT 13
C *** ARPANGE POINTS IN ORDER OF DECREASING Y                           EPLOT 14
   20 IEX=0                                                             EPLOT 15
      DO 30 I=1,25                                                      EPLOT 16
      IF (Y(I) .GE. Y(I+1)) GO TO 30                                    EPLOT 17
      TEMP=X(I)                                                         EPLOT 18
      X(I)=X(I+1)                                                       EPLOT 19
      X(I+1)=TEMP                                                       EPLOT 20
      TEMP=Y(I)                                                         EPLOT 21
      Y(I)=Y(I+1)                                                       EPLOT 22
      Y(I+1)=TEMP                                                       EPLOT 23
      IEX=1                                                             EPLOT 24
   30 CONTINUE                                                          EPLOT 25
      IF (IEX .EQ. 1) GO TO 20                                          EPLOT 26
C *** FIND Y RANGE, X AND Y INCREMENTS                                  EPLOT 27
      YR=Y(1)-Y(26)                                                     EPLOT 28
C *** NOTE: 0.1IN/CHARACTER, 0.167IN/LINE, SO 79.2 = 0.6*132.0          EPLOT 29
      NY=0.5+79.2*YR/XR                                                 EPLOT 30
      DY=YR/(FLOAT(NY)-1.0)                                             EPLOT 31
      DX=XR/131.0                                                       EPLOT 32
C *** PLOT POINTS                                                       EPLOT 33
      IYO=0                                                             EPLOT 34
      DO 50 I=1,26                                                      EPLOT 35
      IY=1.5+(Y(1)-Y(I))/DY                                             EPLOT 36
      NFEED=IY-IYO                                                      EPLOT 37
      IYO=IY                                                            EPLOT 38
      IF (NFEED .EQ. 0) GO TO 45                                        EPLOT 39
      DO 40 IFEED=1,NFEED                                               EPLOT 40
   40 WRITE(6,1000)                                                     EPLOT 41
   45 IX=1.5+X(I)/DX                                                    EPLOT 42
      STRING(IX)=PLUS                                                   EPLOT 43
      WPITE(6,1010) STRING                                              EPLOT 44
      STRING(IX)=BLANK                                                  EPLOT 45
   50 CONTINUE                                                          EPLOT 46
      RETURN                                                            EPLOT 47
  900 FORMAT (1H1//40X,                                                   EPLOT 48
     154H*** PLOT OF BLADE SURFACE IN THETA - M COORDINATES ***/////)    EPLOT 49
 1000 FORMAT (1H )                                                        EPLOT 50
 1010 FORMAT (1H+,132A1)                                                  EPLOT 51
      END                                                                 EPLOT 52
      SUBROUTINE EPSLON(KO,DK,RO,DS,DR,RE)                                EPSLON 2
C ***      CALCULATION OF CONIC RADIAL AND CIRCUMFERENTIAL COMPONENTS OFEPSLON 3
C *** A BLADE ELEMENT SEGMENT WITH GIVEN PATH DISTANCE AND END ANGLES     EPSLON 4
      REAL KO                                                             EPSLON 5
    • IF (ABS(DS).LT.1.0E-08)  GO TO 70                                   EPSLON 6
      HDK= DK/2.0                                                         EPSLON 7
      IF (ABS(HDK).GT.0.78539816)  GO TO 2                                EPSLON 8
      SR= SRS(HDK)                                                        EPSLON 9
      SHDK= HDK*SR                                                        EPSLON10
      SHDKQ= SHDK**2                                                      EPSLON11
      CHDK= SQRT(1.0 - SHDKQ)                                             EPSLON12
      GO TO 6                                                             EPSLON13
    2 IF (HDK.LT.0.0)  GO TO 3                                            EPSLON14
      HDK = 1.5707963 - HDK                                               EPSLON15
      CHDK = HDK*SRS(HDK)                                                 EPSLON16
      SHDKQ = 1.0 - CHDK**2                                               EPSLON17
      SHDK = SQRT(SHDKQ)                                                  EPSLON18
      GO TO 4                                                             EPSLON19
    3 HDK = 1.5707963 + HDK                                               EPSLON20
      CHDK = HDK*SRS(HDK)                                                 EPSLON21
      SHDKQ = 1.0 - CHDK**2                                               EPSLON22
      SHDK = -SQRT(SHDKQ)                                                 EPSLON23
    4 SR = ABS(SHDK)/HDK                                                  EPSLON24
    6 HKO = KO/2.0                                                        EPSLON25
      IF (HKO.GT.0.78539816)  GO TO 7                                     EPSLON26
      SHKO= HKO*SRS(HKO)                                                  EPSLON27
      SHKOQ= SHKO**2                                                      EPSLON28
      CHKO= SQRT(1.0 - SHKOQ)                                             EPSLON29
      SKO= 2.0*SHKO*CHKO                                                  EPSLON30
      CKO= 1.0 - 2.0*SHKOQ                                                EPSLON31
      GO TO 8                                                             EPSLON32
    7 HKO = 0.78539816 - HKO                                              EPSLON33
      SHKO = HKO*SRS(HKO)                                                 EPSLON34
      SHKOQ = SHKO**2                                                     EPSLON35
      CHKO = SQRT(1.0 - SHKOQ)                                            EPSLON36
      SKO = 1.0 - 2.0*SHKOQ                                               EPSLON37
      CKO = 2.0*SHKO*CHKO                                                 EPSLON38
    8 SKA = SHDK*CKO + SKO*CHDK                                           EPSLON39
      CKA= CHDK*CKO - SKO*SHDK                                            EPSLON40
C ***      CONIC RADIAL COMPONENT OF THE PATH                             EPSLON41
      DR= DS*CKA*SR                                                       EPSLON42
      IF (ABS(DK).GT.0.00001) GO TO 10                                    EPSLON43
      DRR = DR/RO                                                         EPSLON44
      IF (ABS(DRR).LT.0.01)  GO TO 9                                      EPSLON45
C ***      CIRCUMFERENTIAL COMP. WHEN PATH ANGLE IS ESSENTIALLY CONSTANTEPSLON46
      RE = (RO + DR)*SKA/CKA*ALOG(1.0 + DRR)                              EPSLON47
      RETURN                                                              EPSLON48
    9 RE = (1.0 ● DRR)*DS*SR*SKA*(1.0 - DRR*(0.5 - DRR*(0.33333333 - DRREPSLON49
     X /4.0)))                                                            EPSLON50
      RETURN                                                              EPSLON51
   10 RS= RO/DS                                                           EPSLON52
      IF (ABS(RS).GT.10000.0) GO TO 60                                    EPSLON53
      IF (RS**2/ABS(DK).GT.1.7E+09) GO TO 60                              EPSLON54
C ***      CONIC CIRCUMFERENTIAL COMPONENT OF PATH BY GENERAL EQUATION  EPSLON55
      RCK= RS*DK - SKO                                                    EPSLON56
      QDKS= HDK**2/4.0                                                    EPSLON57
      SES = 0.66666667*RCK*QDKS*(1.0 - 0.6*QDKS*(1.0 - 0.15873016*QDKS* EPSLON58
     X (1.0 - 0.077777778*QDKS*(1.0 - 0.046753247*QDKS*(1.0 - .031339031EPSLON59
     X *QDKS)))))                                                         EPSLON60
      DRR= DR/RO                                                          EPSLON61
      IF (ABS(DRR).GT.0.21)  GO TO 20                                     EPSLON62
      RRM = 0.5*DRR*(1.0 - 0.25*DRR*(1.0 - 0.5*DRR*(1.0 - 0.625*DRR*(1.0EPSLON63
     X - 0.7*DRR*(1.0 - 0.75*DRR*(1.0 - 0.78571429*DRR*(1.0 - 0.8125*DRREPSLON64
     X *(1.0 - 0.83333333*DRR))))))))                                     EPSLON65
      RRQ = RRM  + 1.0                                                    EPSLON66
      GO TO 30                                                            EPSLON67
   20 RRQ= SQRT(1.0 + DRR)                                                EPSLON68
      RRM= RRQ - 1.0                                                      EPSLON69
   30 RM= RRQ*RS                                                          EPSLON70
      D = RCK*CHDK + SKA + DK*RM                                          EPSLON71
      XS= SHDKQ*(1.0 -RCK**2)/D**2                                        EPSLON72
      XSN= 35.0*ABS(XS)                                                   EPSLON73
      NXS= XSN                                                            EPSLON74
      N= 5 + NXS                                                          EPSLON75
      SXS= 0.0                                                            EPSLON76
      XPS= 1.0                                                            EPSLON77
      DKN= 1.0                                                            EPSLON78
      DO 40  KN=1,N                                                       EPSLON79
      IF (ABS(XPS).LT.1.0E-12.AND.KN.NE.1) GO TO 50                       EPSLON80
      XPS= XPS*XS                                                         EPSLON81
      DKN= DKN + 2.0                                                      EPSLON82
   40 SXS= SXS + XPS/DKN                                                  EPSLON83
   50 RE= (RO + DR)*(DK*(SKO + SKA + DK*RS*RRM - SES) - 4.0*RCK*SHDK*   EPSLON84
     X SXS)/D                                                             EPSLON85
      RETURN                                                              EPSLON86
C ***      CONIC CIRCUMFERENTIAL COMPONENT WHEN PATH DISTANCE IS A VERY EPSLON87
C *** SMALL FRACTION OF THE DISTANCE TO THE CONE VERTEX.                  EPSLON88
   60 DRR= DR/RO                                                          EPSLON89
      RE = (1.0 + DRR)/(1.0 ● 0.5*DRR*(1.0 - 0.25*DRR*(1.0 - 0.5*DRR*   EPSLON90
     X (1.0 - 0.625*DRR))))*DS*SKA*SR                                     EPSLON91
      RETURN                                                              EPSLON92
   70 DR = 0.0                                                            EPSLON93
      RE ■ 0.0                                                            EPSLON94
      RETURN                                                              EPSLON95
      END                                                                 EPSLON96
      SUBROUTINE RPOINT(RO,DR,RE,TK,DRP)                                  RPOINT 2
C ***      THIS SUBROUTINE CALCULATES THE CONIC RADIAL COORDINATE AT THERPOINT 3
C *** INTERSECTION OF PERPENDICULAR CONSTANT ANGLE LINES FROM TWO KNOWN RPOINT 4
C *** POINTS ON A CONE.  THE LINE THROUGH THE REFERENCE POINT HAS THE   RPOINT 5
C *** INPUT SLOPE TK.                                                     RPOINT 6
      R = DR/RO                                                           RPOINT 7
      CK = SQRT(1.0/(1.0 + TK**2))                                        RPOINT 8
      SK = TK*CK                                                          RPOINT 9
      IF (ABS(R).LT.0.01) GO TO 20                                        RPOINT10
      DRP = RO*(EXP((RE*SK/(RO + DR) + ALOG(1.0 + R)*CK)*CK) - 1.0)      RPOINT11
      RETURN                                                              RPOINT12
   20 C = (RE*SK/(RO + DR) + R*(1.0 - 0.5*R*(1.0 - 0.66666667*R*(1.0 -  RPOINT13
     X 0.75*R)))*CK)*CK                                                   RPOINT14
      DRP = C                                                             RPOINT15
   30 CS = DRP*(1.0 - 0.5*DRP*(1.0 - 0.66666667*DRP*(1.0 - 0.75*DRP)))  RPOINT16
      IF (ABS((CS - C)/C).LT.1.0E-06) GO TO 40                            RPOINT17
      DRP = DRP*C/CS                                                      RPOINT18
      GO TO 30                                                            RPOINT19
   40 DRP = DRP*RO                                                        RPOINT20
      RETURN                                                              RPOINT21
      END
      FUNCTION SRS(ANG)
C ***      SERIES FOR (SIN(ANG))/ANG WHEN THE MAGNITUDE OF ANG IS LESS
C *** THAN PI/4
      IF (ABS(ANG).LT.1.0E-05) GO TO 10
      AQ = ANG**2
      SRS = 1.0 - AQ/6.0*(1.0 - AQ/20.0*(1.0 - AQ/42.0*(1.0 - AQ/72.0)))
      RETURN
   10 SRS = 1.0
      RETURN
      END
      SUBROUTINE SURF(KE,KMM,SKM,CKM,RO,DRC,TE,EMS,DSS)
C ***       THIS SUBROUTINE CALCULATES THE BLADE ELEMENT SURFACE CURVE
C *** END POINT COORDINATES.  THE SURFACE CURVE IS NORMAL TO THE END
C *** POINT THICKNESS PATH AND TANGENT TO A SURFACE REFERENCE POINT
C *** WHICH IS EITHER THE TRANSITION OR MAXIMUM THICKNESS POINT.
      REAL KE, KE1, KIC, KIP, KIS, KM, KMM, KOC, KOP, KOS, KTC, KTP, KTS
      COMMON /SCALR/
     1 BLADES, CALP, CCC, CEPE, CKTC, CKTS, C1, C2, DRCE, DRCLEP, DRCLES
     2, DRCMST, DRCMT, DRCOI, DRCS, DRCT, DRCTEP, DRCTES, DRCTI, DRCTMP,
     3 DRCTMS, DRCTPI, DRCTSI, DSME, DSMT, DSOT, DSP, DSP1, DSP2, DSSE,
     4 DSS1, DSS2, DST, DSTI, EMT, IR, IW, KIC, KIP, KIS, KM, KOC, KOP,
     5 KOS, KTC, KTP, KTS, PI, RCI, RCMS, RCO, RCT, RCTP, RCTS, REE,
     6 RELEP, RELES, REM, REMS, REMT, REOI, RES, RET, RETEP, RETES, RETI
     7, RETMP, RETMS, RETP, RETS, R1C, SGAM, SALP, SKTC, SKTS, TEPE,
     8 THMAX, TKTN
      RMS = RO - DRC
      IT = 1
   10 CALL EPSLON(KE + 1.5707963,0.0,RO,TE,DRCE,REE)
      DRCS = DRC + DRCE
      DK = KE - KMM
      HDK = DK/2.0
      SR = SRS(HDK)
      SHDK = HDK*SR
      CHDK = SQRT(1.0 - SHDK**2)
      DSS = DRCS/(SR*(CHDK*CKM - SHDK*SKM))
      CALL EPSLON(KMM,DK,RMS,DSS,DRCS,RES)
      DRE = (RO + DRCE)*EMS + RES - REE
      IF (ABS(DRE).LT.1.0E-05) RETURN
      IF (IT.EQ.2) GO TO 20
      KE1 = KE
      DRE1 = DRE
      KE = KE - 2.0*DRE*(CKM*(1.0 -2.0*SHDK**2) -2.0*SKM*SHDK*CHDK)/DSS
      IT = 2
      GO TO 10
   20 KE = KE + (KE1 - KE)*DRE/(DRE - DRE1)
      GO TO 10
      END
      SUBROUTINE TANKAP(RO,DR,RE,TK)
C ***       CALCULATION OF THE SLOPE OF THE CONSTANT ANGLE PATH BETWEEN
C *** TWO POINTS IN CONIC RADIUS AND EPSILON COORDINATES
      R = DR/RO
      IF (ABS(R).LT.0.1) GO TO 20
      TK = RE/((RO + DR)*ALOG(1.0 + R))
      RETURN
   20 SUM = 1.0
      IF (ABS(R).GT.1.0E-08) GO TO 25
      IF (ABS(DR/RE).GT.1.0E-08) GO TO 35
      TK = 1.0E+08
      RETURN
   25 PROD = 1.0
      DN = 8.0/(-ALOG10(ABS(R)))
      NT = DN
      DO 30 I=1,NT
      N = I + 1
      DN = N
      PROD = -PROD*R
   30 SUM = SUM + PROD/DN
   35 TK = RE/((RO + DR)*R*SUM)
      RETURN
      END
      SUBROUTINE TRAN(KE,TE,TM,KT,RT,RE,DS)
C ***       THIS SUBROUTINE CALCULATES THE BLADE ELEMENT SURFACE CURVE
C *** TRANSITION POINT COORDINATES FROM THE INTERSECTION OF THE
C *** ESTABLISHED SURFACE CURVE OVER THE MAXIMUM THICKNESS POINT WITH A
C *** PATH PERPENDICULAR TO THE CENTERLINE AT THE TRANSITION POINT.
      REAL KE,KIC,KIP,KIS,KM,KOC,KOP,KOS,KT,KTC,KTP,KTS
      COMMON /SCALR/
     1 BLADES, CALP, CCC, CEPE, CKTC, CKTS, C1, C2, DRCE, DRCLEP, DRCLES
     2, DRCMST, DRCMT, DRCOI, DRCS, DRCT, DRCTEP, DRCTES, DRCTI, DRCTMP,
     3 DRCTMS, DRCTPI, DRCTSI, DSME, DSMT, DSOT, DSP, DSP1, DSP2, DSSE,
     4 DSS1, DSS2, DST, DSTI, EMT, IR, IW, KIC, KIP, KIS, KM, KOC, KOP,
     5 KOS, KTC, KTP, KTS, PI, RCI, RCMS, RCO, RCT, RCTP, RCTS, REE,
     6 RELEP, RELES, REM, REMS, REMT, REOI, RES, RET, RETEP, RETES, RETI
     7, RETMP, RETMS, RETP, RETS, R1C, SGAM, SALP, SKTC, SKTS, TEPE,
     8 THMAX, TKTN
      DST = TM - (TM - TE)*(DSMT/DSME)**2
      DSS = DST*(KM - KTC) - DSMT
      CS = (KE - KM)/DSSE
   10 DK = CS*DSS
      CALL EPSLON(KM,DK,RCMS,DSS,DRCS,RES)
      DRCT = DRCMST + DRCS
      RT = RCMS + DRCS
      RET = RES + RT*EMT
      CALL TANKAP(RCT,DRCT,RET,TK)
      TKD = (TK - TKTN)/(1.0 + TK*TKTN)
      IF (ABS(DST*TKD).LT.1.0E-05) GO TO 20
      DST = RET/(CKTC - SKTC*TKD)
      DSS = DSS + DST*TKD*SQRT(1.0 + TKD**2)/(1.0 -(DK +KM -KTC)**2/2.0)
      GO TO 10
   20 KT = KM + DK
      RE = RT*RETI/RCT + RET
      DS = DSS - DSSE
      IF (DSSE.GT.0.0) DS = -DS
      HKTS = KT/2.0
      SHKTS = HKTS*SRS(HKTS)
      SHKTSQ = SHKTS**2
      CHKTS = SQRT(1.0 - SHKTSQ)
      SKTS = 2.0*SHKTS*CHKTS
      CKTS = 1.0 - 2.0*SHKTSQ
      RETURN
      END
//
```

```
      FUNCTION YPC(DR,RE,EP)                                            YPC    2
C ***       Y PLOT COORDINATE FROM R AND EPSILON COORDINATES            YPC    3
      YPC = DR - RE*EP/2.0*(1.0 - EP**2/12.0*(1.0 - EP**2/30.0))        YPC    4
      RETURN                                                            YPC    5
      END                                                               YPC    6
      SUBROUTINE COPES(IFLAG)                                           COPES  2
C     ******************************************************************COPES  3
C             COPES - CONTROL PROGRAM FOR ENGINEERING SYNTHESIS.        COPES  4
C     ******************************************************************COPES  5
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCOPES  6
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCOPES  7
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                               COPES  8
      COMMON /COPES1/ TITLE(20)                                         COPES  9
      COMMON /COPES2/ RA(5000),IA(1000)                                 COPES 10
      COMMON /COPES3/ SGNOPT,NCALC,IOBJ,NSV,NSOBJ,NCONA,N2VX,M2VX,N2VY,MCOPES 11
     12VY,N2VAR,IPSENS,IP2VAR,IPDBG,NACMX1,NDVTOT,LOCR(25),LOCI(25),ISCRCOPES 12
     21,ISCR2,NXAPRX,NPS,NPFS,NPA,NF,INOM,IPAPRX,KMIN,KMAX,XFACT1,XFACT2COPES 13
     3,NAN2,NAN3,NPMAX,NPTOT,JNOM,MAXTRM                                COPES 14
      COMMON /GLOBCM/ ARRAY(1500)                                       COPES 15
C     BY G. N. VANDERPLAATS                         OCT., 1974.         COPES 16
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPES 17
C     NCALC OPTIONS:                                                    COPES 18
C         0. READ ALL INPUT AND STOP.                                   COPES 19
C         1. SINGLE PASS ANALYSIS.                                      COPES 20
C         2. OPTIMIZATION.                                              COPES 21
C         3. SENSITIVITY - Z = F(X).                                    COPES 22
C         4. TWO VARIABLE FUNCTION SPACE - Z = F(X,Y).                  COPES 23
C         5. OPTIMUM SENSITIVITY.                                       COPES 24
C         6. ANALYSIS/OPTIMIZATION USING APPROXIMATION TECHNIQUES.      COPES 25
C                                                                       COPES 26
C                                                                       COPES 27
C  NEAR,INC REVISION,           JULY, 1982                              COPES 28
C     -  COPES CHANGED TO A SUBROUTINE CONTROLLED BY TSOPT DRIVER       COPES 29
C     -  CONTROL PARAMETER IFLAG ADDED                                  COPES 30
C         IFLAG = 1,  EXECUTE COPES FROM BEGINNING, READING ALL INPUT   COPES 31
C         IFLAG = 2,  SKIP INPUT AND INITIALIZATION                     COPES 32
C                                                                       COPES 33
C                                                                       COPES 34
C     ------------------------------------------------------------------COPES 35
C     **********                     INPUT                     *********COPES 36
C     ------------------------------------------------------------------COPES 37
      NAN2=0                                                            COPES 38
      NAN3=0                                                            COPES 39
      IF(IFLAG.EQ.2) GO TO 15                                           COPES 40
C     DIMENSIONS OF ARRAYS ARRAY, RA AND IA.                            COPES 41
      NARRAY=1500                                                       COPES 42
      NDRA=5000                                                         COPES 43
      NDIA=1000                                                         COPES 44
C     READ GENERAL SYNTHESIS CONTROL INPUT.                             COPES 45
C     SCRATCH TAPE NUMBERS.                                             COPES 46
      ISCR1=20                                                          COPES 47
      ISCR2=40                                                          COPES 48
      CALL COPE01 (RA,IA,NDRA,NDIA)                                     COPES 49
      IF (NCALC.LT.0.OR.NCALC.GT.6) GO TO 340                           COPES 50
C     CHECK TO INSURE STORAGE REQUIREMENTS DO NOT EXCEED                COPES 51
C     DIMENSIONED SIZES OF ARRAYS RA AND IA.                            COPES 52
      NDRA1=LOCR(25)                                                    COPES 53
      NDIA1=LOCI(25)                                                    COPES 54
      IF (NDRA1.LE.NDRA.AND.NDIA1.LE.NDIA) GO TO 10                     COPES 55
      WRITE (6,360) NDRA,NDRA1,NDIA,NDIA1                               COPES 56
      GO TO 340                                                         COPES 57
   10 CONTINUE                                                          COPES 58
C     READ USER INPUT.                                                  COPES 59
      ICALC=1                                                           COPES 60
      CALL ANALIZ (ICALC)                                               COPES 61
      IF (NCALC.LT.1.OR.NCALC.GT.6) GO TO 340                           COPES 62
C     ------------------------------------------------------------------COPES 63
C     **********                   EXECUTION                  **********COPES 64
C     ------------------------------------------------------------------COPES 65
   15 CONTINUE                                                          COPES 66
      ICALC=2                                                           COPES 67
      JCALC=3                                                           COPES 68
      IF (NCALC.NE.2.AND.NCALC.LT.5) GO TO 60                           COPES 69
C     ------------------------------------------------------------------COPES 70
C     IF ABS(X(I)).GT.0 OVER-RIDE USER INPUT OF DECISION VARIABLES FOR  COPES 71
C     OPTIMIZATION.                                                     COPES 72
C     ------------------------------------------------------------------COPES 73
      DO 40 I=1,NDV                                                     COPES 74
      XX=ABS(RA(I))                                                     COPES 75
C     OVER-RIDE ANALIZ INPUT.                                           COPES 76
      N5=LOCR(5)                                                        COPES 77
      M2=LOCI(2)                                                        COPES 78
      DO 20 J=1,NDVTOT                                                  COPES 79
      NN1=IA(M2)                                                        COPES 80
      M2=M2+1                                                           COPES 81
      IF (NN1.NE.I) GO TO 20                                            COPES 82
      NN1=IA(J)                                                         COPES 83
      IF (XX.LT.1.0E-10) GO TO 30                                       COPES 84
      ARRAY(NN1)=RA(I)*RA(N5)                                           COPES 85
   20 N5=N5+1                                                           COPES 86
      GO TO 40                                                          COPES 87
   30 RA(I)=ARRAY(NN1)/RA(N5)                                           COPES 88
   40 CONTINUE                                                          COPES 89
C     TRANSFER DESIGN VARIABLES TO ARRAY.                               COPES 90
      M2=LOCI(2)                                                        COPES 91
      N5=LOCR(5)                                                        COPES 92
      DO 50 I=1,NDVTOT                                                  COPES 93
      N=IA(M2)                                                          COPES 94
      M=IA(I)                                                           COPES 95
      ARRAY(M)=RA(N)*RA(N5)                                             COPES 96
      N5=N5+1                                                           COPES 97
   50 M2=M2+1                                                           COPES 98
   60 CONTINUE                                                          COPES 99
      IF (NCALC.NE.3.AND.NCALC.NE.5) GO TO 80                           COPES100
C     ------------------------------------------------------------------COPES101
C     TRANSFER NOMINAL VALUES OF SENSITIVITY VARIABLES TO ARRAY.        COPES102
C     ------------------------------------------------------------------COPES103
      M16=LOCI(16)                                                      COPES104
      M17=LOCI(17)                                                      COPES105
      N15=LOCR(15)                                                      COPES106
      DO 70 I=1,NSV                                                     COPES107
      NN=IA(M16)                                                        COPES108
      M16=M16+1                                                         COPES109
      ARRAY(NN)=RA(N15)                                                 COPES110
      N15=N15+IA(M17)                                                   COPES111
   70 M17=M17+1                                                         COPES112
   80 CONTINUE                                                          COPES113
      IF (NCALC.LT.6) GO TO 290                                         COPES114
C     ------------------------------------------------------------------COPES115
C                  INITIALIZATION FOR APPROXIMATE ANALYSIS/OPTIMIZATION COPES116
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C     ------------------------------------------------------------------
      IF (NPA.EQ.0) GO TO 130
C     ANALIZ INPUT DEFINES AN X-VECTOR.
      M5=LOCI(5)
      N23=LOCR(23)
      DO 120 I=1,NXAPRX
      J=IA(M5)
C     IS THIS A DESIGN VARIABLE.
      DO 90 K=1,NDVTOT
      KK=K
      IF (IA(K).EQ.J) GO TO 100
90    CONTINUE
C     NO.
      AMULT=1.
      GO TO 110
C     YES.
100   K=LOCR(5)+KK-1
      AMULT=RA(K)
110   RA(N23)=ARRAY(J)/AMULT
      M5=M5+1
120   N23=N23+1
130   CONTINUE
      IF (NPS.GT.0.OR.NPFS.GT.0) GO TO 190
C     ONLY ONE DESIGN VECTOR IS AVAILABLE.  CREATE A SECOND X-VECTOR
C     SO OPTIMIZATION CAN PROCEED.
      N23=LOCR(23)
      N24=N23+NXAPRX
      M5=LOCI(5)
      DO 180 I=1,NXAPRX
C     GLOBAL LOCATION.
      IG=IA(M5)
      M5=M5+1
C     PROPOSED X-VALUE.
      XX=1.1*RA(N23)
      IF (ABS(XX).LT.1.0E-10) XX=.1
C     IS THIS A DESIGN VARIABLE.
      N5=LOCR(5)
      DO 140 J=1,NDVTOT
      JJ=J
      AMJ=RA(N5)
      IF (IA(J).EQ.IG) GO TO 150
C     NO.
      N5=N5+1
140   CONTINUE
      GO TO 170
150   CONTINUE
C     YES.  WHICH DESIGN VARIABLE IS IT.
      ID=LOCI(2)+JJ-1
      ID=IA(ID)
C     INSURE XX IS WITHIN BOUNDS.
      N2=LOCR(2)+ID-1
      N3=LOCR(3)+ID-1
      BL=RA(N2)*ABS(AMJ)
      BU=RA(N3)*ABS(AMJ)
      IF (BL.LE.BU) GO TO 160
      SAV=BL
      BL=BU
      BU=SAV
160   IF (XX.LT.BL) XX=BL
      IF (XX.GT.BU) XX=BU
      DX=RA(N23)-XX
      IF (ABS(DX).LT.1.0E-6) XX=1.001*RA(N23)
      IF (ABS(XX).LT.1.0E-6) XX=.001
170   RA(N24)=XX
      N23=N23+1
180   N24=N24+1
190   CONTINUE
      REWIND ISCR2
      NPSA=NPS+NPA
      IF (NPSA.EQ.0) GO TO 250
      IF (NPS.EQ.0) GO TO 210
C     READ X-VECTORS.
      NXI=LOCR(23)+NPA*NXAPRX
      DO 200 J=1,NPS
      NXIJ=NXI+NXAPRX-1
      READ (ISCR2) (RA(I),I=NXI,NXIJ)
200   NXI=NXI+NXAPRX
210   CONTINUE
      IF (NPFS.LE.0) NPSA=NPTOT
      NXI=LOCR(23)
      NY=NXI+NXAPRX*NPTOT
      DO 240 J=1,NPSA
C     TRANSFER X-VALUES.
      M5=LOCI(5)
      I1=NXI
      DO 220 I=1,NXAPRX
      II=IA(M5)
      ARRAY(II)=RA(I1)
      M5=M5+1
220   I1=I1+1
C     ANALIZE.
      NAN2=NAN2+1
      CALL ANALIZ (ICALC)
C     PUT FUNCTION VALUES IN Y-ARRAY.
      M6=LOCI(6)
      I1=NY
      DO 230 I=1,NF
      II=IA(M6)
      RA(I1)=ARRAY(II)
      I1=I1+1
230   M6=M6+1
      NXI=NXI+NXAPRX
      NY=NY+NF
240   CONTINUE
250   CONTINUE
      IF (NPFS.LE.0) GO TO 270
      NXI=LOCR(23)+NPSA*NXAPRX
      NY=LOCR(23)+NXAPRX*NPTOT+NF*NPSA
C     READ X AND Y VECTORS.
      DO 260 J=1,NPFS
      NXIJ=NXI+NXAPRX-1
      NYJ=NY+NF-1
C     X-VECTOR.
      READ (ISCR2) (RA(I),I=NXI,NXIJ)
C     Y-VECTOR.
      READ (ISCR2) (RA(I),I=NY,NYJ)
      NXI=NXI+NXAPRX
260   NY=NY+NF
270   CONTINUE
C     PUT X-F PAIRS BACK ON ISCR2.
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      REWIND ISCR2                                                      COPES237
      NXI=LOCR(23)                                                      COPES238
      NY=NXI+NXAPRX*NPTOT                                               COPES239
      DO 280 I=1,NPTOT                                                  COPES240
      NXIJ=NXI+NXAPRX-1                                                 COPES241
      NYJ=NY+NF-1                                                       COPES242
C     X-VECTOR.                                                         COPES243
      WRITE (ISCR2) (RA(J),J=NXI,NXIJ)                                  COPES244
C     Y-VECTOR.                                                         COPES245
      WRITE (ISCR2) (RA(J),J=NY,NYJ)                                    COPES246
      NXI=NXIJ+1                                                        COPES247
280   NY=NYJ+1                                                          COPES248
290   CONTINUE                                                          COPES249
      GO TO (300,300,310,320,310,330),NCALC                             COPES250
C     ------------------------------------------------------------------COPES251
C                              ONE ANALYSIS                             COPES252
C     ------------------------------------------------------------------COPES253
300   NAN2=NAN2+1                                                       COPES254
      CALL ANALIZ (ICALC)                                               COPES255
      IF(NCALC.GT.1) GO TO 305                                          COPES256
      NAN3=NAN3+1                                                       COPES257
      CALL ANALIZ (JCALC)                                               COPES258
      IF (NCALC.EQ.1) GO TO 340                                         COPES259
C     ------------------------------------------------------------------COPES260
C                              OPTIMIZATION                             COPES261
C     ------------------------------------------------------------------COPES262
C     OPTIMIZATION.                                                     COPES263
  305 CONTINUE                                                          COPES264
      CALL COPE02 (ARRAY,RA,IA,NARRAY,NDRA,NDIA)                        COPES265
C     OUTPUT RESULTS.                                                   COPES266
      CALL COPE18 (IOBJ,NDVTOT,NCONA,RA,IA,LOCR,LOCI,ARRAY)             COPES267
      NAN3=NAN3+1                                                       COPES268
      CALL ANALIZ (JCALC)                                               COPES269
      GO TO 340                                                         COPES270
C     ------------------------------------------------------------------COPES271
C                          SENSITIVITY ANALYSIS                         COPES272
C     ------------------------------------------------------------------COPES273
310   CONTINUE                                                          COPES274
C     ARRAY STARTING LOCATIONS.                                         COPES275
C     SENS.                                                             COPES276
      N1=LOCR(15)                                                       COPES277
      NN8=LOCR(16)-N1                                                   COPES278
C     NSENSZ.                                                           COPES279
      N2=LOCI(15)                                                       COPES280
      NN9=NSOBJ                                                         COPES281
C     ISENS.                                                            COPES282
      N3=LOCI(16)                                                       COPES283
      NN10=NSV                                                          COPES284
C     NSENS.                                                            COPES285
      N4=LOCI(17)                                                       COPES286
C     TEMP.                                                             COPES287
      N5=LOCR(23)                                                       COPES288
      CALL COPE04 (ARRAY,NARRAY,RA(N1),IA(N2),IA(N3),IA(N4),RA(N5),NN8,NCOPES289
     1N9,NN10,RA,IA,NDRA,NDIA)                                          COPES290
      CALL COPE04 (ARRAY,NARRAY,RA(N1),IA(N2),IA(N3),IA(N4),RA(N5),NN8,NCOPES289
     1N9,NN10,RA,IA,NDRA,NDIA)                                          COPES290
C     OUTPUT RESULTS.                                                   COPES291
      CALL COPE05 (RA,IA,NDRA,NDIA,ISCR1)                               COPES292
      GO TO 340                                                         COPES293
320   CONTINUE                                                          COPES294
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C     ------------------------------------------------------------------COPES295
C                       TWO VARIABLE FUNCTION SPACE                     COPES296
C     ------------------------------------------------------------------COPES297
      CALL COPE06 (ARRAY,RA,IA,NARRAY,NDRA,NDIA)                        COPES298
C     OUTPUT RESULTS.                                                   COPES299
      CALL COPE07 (RA,IA,NDRA,NDIA,ISCR1)                               COPES300
      GO TO 340                                                         COPES301
330   CONTINUE                                                          COPES302
C     ------------------------------------------------------------------COPES303
C                 APPROXIMATE ANALYSIS/OPTIMIZATION.                    COPES304
C     ------------------------------------------------------------------COPES305
      CALL COPE09                                                       COPES306
C     OUTPUT RESULTS.                                                   COPES307
      CALL COPE14 (NXAPRX,NF,NPTOT,RA,IA,LOCR,LOCI,TITLE,INOM,NDV,IPAPRXCOPES308
     1,ISCR2,MAXTRM)                                                    COPES309
      IF (KMAX.LT.0) GO TO 340                                          COPES310
      CALL COPE18 (IOBJ,NDVTOT,NCONA,RA,IA,LOCR,LOCI,ARRAY)             COPES311
      NAN3=NAN3+1                                                       COPES312
      CALL ANALIZ (JCALC)                                               COPES313
340   CONTINUE                                                          COPES314
      WRITE (6,350) NAN2,NAN3                                           COPES315
      REWIND ISCR1                                                      COPES316
      REWIND ISCR2                                                      COPES317
      RETURN                                                            COPES318
C     ------------------------------------------------------------------COPES319
C                                 FORMATS                               COPES320
C     ------------------------------------------------------------------COPES321
350   FORMAT (1H1,4X,23HPROGRAM CALLS TO ANALIZ//8X,5HICALC,3X,5HCALLS/1COPES322
     10X,1H1,7X,1H1/10X,1H2,I8/10X,1H3,I8)                              COPES323
360   FORMAT (//5X,60HREQUIRED STORAGE FOR ARRAY RA OR IA EXCEEDS DIMENSCOPES324
     1IONED SIZE/5X,5HARRAY,2X,9HDIMENSION,2X,8HREQUIRED/7X,2HRA,I8,6X,ICOPES325
     25/7X,2HIA,I8,6X,I5//5X,22H* * PROGRAM TERMINATED)                 COPES326
      END                                                               COPES327
      SUBROUTINE COPE01 (RA,IA,NDRA,NDIA)                               COPES328
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCOPES329
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCOPES330
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                               COPES331
      COMMON /COPES1/ ATITLE(20)                                        COPES332
      COMMON /COPES3/ SGNOPT,NCALC,IOBJ,NSV,NSOBJ,NCONA,N2VX,M2VX,N2VY,MCOPES333
     12VY,N2VAR,IPSENS,IP2VAR,IPDBG,NACMX1,NDVTOT,LOCR(25),LOCI(25),ISCRCOPES334
     21,ISCR2,NXAPRX,NPS,NPFS,NPA,NF,INOM,IPAPRX,KMIN,KMAX,XFACT1,XFACT2COPES335
     3,NAN2,NAN3,NPMAX,NPTOT,JNOM,MAXTRM                                COPES336
      DIMENSION RA(NDRA), IA(NDIA), TITLE(20)                           COPES337
      DATA END1/1HE/,END2/1HN/,END3/1HD/                                COPES338
      DATA COM/1H$/,BLANK/1H /                                          COPES339
C     ******************************************************************COPES340
C     ROUTINE TO READ CONTROL INPUT FOR COPES.                          COPES341
C     ******************************************************************COPES342
C     BY G. N. VANDERPLAATS                           MAR., 1973.       COPES343
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPES344
C     ------------------------------------------------------------------COPES345
C     READ CARD IMAGES AND STORE ON UNIT ISCR2.  STORE ON UNIT ISCR1    COPES346
C     WITHOUT COMMENT CARDS                                             COPES347
C     ------------------------------------------------------------------COPES348
      REWIND ISCR1                                                      COPES349
      REWIND ISCR2                                                      COPES350
      NCARDS=0                                                          COPES351
      LOCI(25)=0                                                        COPES352
      NCOM=0                                                            COPES353
      ICARD=0                                                           COPES354
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10    READ (5,580) (RA(I),I=1,80)                                         COPES355
      ICARD=ICARD+1                                                       COPES356
      NCARDS=NCARDS+1                                                     COPES357
      WRITE (ISCR2,590) NCARDS,(RA(I),I=1,80)                             COPES358
      IF (RA(1).EQ.COM) GO TO 10                                          COPES359
      IF (RA(1).EQ.END1.AND.(RA(2).EQ.END2.AND.RA(3).EQ.END3)) GO TO 20 COPES360
      IF (NCOM.NE.0) GO TO 30                                             COPES361
C     TITLE OR END CARD.                                                  COPES362
20    WRITE (ISCR1,580) (RA(I),I=1,80)                                    COPES363
      IF (NCOM.GT.0) GO TO 70                                             COPES364
C     IT WAS THE TITLE CARD.                                              COPES365
      NCOM=1                                                              COPES366
      GO TO 10                                                            COPES367
30    CONTINUE                                                            COPES368
C     FORMAT DATA AS REQUIRED.                                            COPES369
      NA=1                                                                COPES370
      NB=81                                                               COPES371
      CALL COPE08 (RA(NA),RA(NB),IFORM,NFLD)                              COPES372
C     DETERMINE NUMBER OF CARDS OF DATA AND ADD BLANKS TO FILL.           COPES373
      NBC=(NFLD-1)/8+1                                                    COPES374
      NB=80*NBC+80                                                        COPES375
      NA=10*NFLD+81                                                       COPES376
      IF (NA.GE.NB) GO TO 50                                              COPES377
      DO 40 I=NA,NB                                                       COPES378
40    RA(I)=BLANK                                                         COPES379
50    CONTINUE                                                            COPES380
      WRITE (ISCR1,580) (RA(I),I=81,NB)                                   COPES381
      IF (IFORM.GT.0) GO TO 10                                            COPES382
C     DATA WAS NOT PREVIOUSLY FORMATTED.                                  COPES383
      N1=1                                                                COPES384
      DO 60 II=1,NBC                                                      COPES385
      N1=N1+80                                                            COPES386
      N2=N1+79                                                            COPES387
      WRITE (ISCR2,590) NCARDS,(RA(I),I=N1,N2)                            COPES388
60    ICARD=ICARD+1                                                       COPES389
      GO TO 10                                                            COPES390
70    CONTINUE                                                            COPES391
      REWIND ISCR1                                                        COPES392
      REWIND ISCR2                                                        COPES393
C     ------------------------------------------------------------------COPES394
C                     GENERAL SYNTHESIS INFORMATION                       COPES395
C     ------------------------------------------------------------------COPES396
C     TITLE.                                                              COPES397
C --- DATA BLOCK A.                                                       COPES398
      READ (ISCR1,1190) (ATITLE(I),I=1,20)                                COPES399
C     CONTROL PARAMETERS.                                                 COPES400
C --- DATA BLOCK B.                                                       COPES401
      READ (ISCR1,1200) NCALC,NDV,NSV,N2VAR,NXAPRX,IPNPUT,IPDBG           COPES402
      IF (NCALC.LT.0.OR.NCALC.GT.6) WRITE (6,1220) NCALC                  COPES403
      IF (NCALC.LT.0.OR.NCALC.GT.6) RETURN                                COPES404
      IF (IPNPUT.GT.1) GO TO 100                                          COPES405
      WRITE (6,970)                                                       COPES406
      WRITE (6,980)                                                       COPES407
      WRITE (6,990) (ATITLE(I),I=1,20)                                    COPES408
C     ------------------------------------------------------------------COPES409
C                             CARD IMAGE PRINT                            COPES410
C     ------------------------------------------------------------------COPES411
      IF (IPNPUT.GT.0) GO TO 90                                           COPES412
      WRITE (6,870)                                                       COPES413
      WRITE (6,880)                                                       COPES414
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      DO 80 I=1,ICARD                                                     COPES415
      READ (ISCR2,590) NCARDS,(RA(J),J=1,80)                              COPES416
80    WRITE (6,890) NCARDS,(RA(J),J=1,80)                                 COPES417
      REWIND ISCR2                                                        COPES418
90    CONTINUE                                                            COPES419
      WRITE (6,1000) (ATITLE(I),I=1,20)                                   COPES420
      WRITE (6,1010) NCALC,NDV,NSV,N2VAR,NXAPRX,IPNPUT,IPDBG              COPES421
      WRITE (6,910)                                                       COPES422
100   NACMX1=0                                                            COPES423
      NDVTOT=0                                                            COPES424
      NCONA=0                                                             COPES425
      NCON=0                                                              COPES426
      IF (NDV.LE.0) GO TO 270                                             COPES427
C     ------------------------------------------------------------------COPES428
C                        OPTIMIZATION INFORMATION                         COPES429
C     ------------------------------------------------------------------COPES430
C     OPTIMIZATION CONTROL VARIABLES. - CONMIN DEPENDENT.                 COPES431
C --- DATA BLOCK C.                                                       COPES432
      READ (ISCR1,1200) IPRINT,ITMAX,ICNDIR,NSCAL,ITRM,LINOBJ,NACMX1,NFDCOPES433
     1G                                                                   COPES434
C --- DATA BLOCK D.                                                       COPES435
      READ (ISCR1,1210) FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,THETA,PHI,DELFUN,COPES436
     1DABFUN,ALPHAX,ABOBJ1                                                COPES437
C --- DATA BLOCK E.                                                       COPES438
C     TOTAL NO. OF D. V., OBJECTIVE GLOBAL NUMBER, SIGN                   COPES439
C     ON OPTIMIZATION OBJECTIVE.                                          COPES440
      READ (ISCR1,920) NDVTOT,IOBJ,SGNOPT                                 COPES441
      IF (NDVTOT.LT.NDV) NDVTOT=NDV                                       COPES442
      IF (NCALC.EQ.6.AND.NACMX1.EQ.0) NACMX1=2*NDV+2                      COPES443
      IF (NACMX1.LE.0) NACMX1=NDV+2                                       COPES444
      IF (IPNPUT.GE.2) GO TO 110                                          COPES445
      IF (ABS(SGNOPT).LT.1.0E-10) SGNOPT=-1.                              COPES446
      WRITE (6,1070) IOBJ,SGNOPT                                          COPES447
      WRITE (6,760) IPRINT,ITMAX,ICNDIR,NSCAL,ITRM,LINOBJ,NACMX1,NFDG   COPES448
      WRITE (6,770) FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,THETA,PHI,DELFUN,DABFCOPES449
     1UN,ALPHAX,ABOBJ1                                                    COPES450
110   N2=NDV+3                                                            COPES451
      N3=N2+NDV+2                                                         COPES452
      N4=N3+NDV+2                                                         COPES453
C --- DATA BLOCK F.                                                       COPES454
C     DESIGN VARIABLE INFORMATION, LB, UB, INITIAL VALUE, SCAL.           COPES455
      IF (IPNPUT.LT.2) WRITE (6,1080)                                     COPES456
      N5=N4+NDV+2                                                         COPES457
      IF (N5.LE.NDRA) GO TO 120                                           COPES458
      WRITE (6,780)                                                       COPES459
      WRITE (6,790)                                                       COPES460
      LOCR(25)=N5                                                         COPES461
      GO TO 550                                                           COPES462
120   CONTINUE                                                            COPES463
      NSIDE=0                                                             COPES464
      DO 130 I=1,NDV                                                      COPES465
      READ (ISCR1,1060) RA(N2),RA(N3),RA(I),RA(N4),(TITLE(J),J=1,5)      COPES466
      IF (RA(N2).GT.-1.0E+15.OR.RA(N3).LT.1.0E+15) NSIDE=1               COPES467
      IF (RA(N2).LE.-1.0E+15) RA(N2)=-1.1E+15                             COPES468
      IF (RA(N3).GE.1.0E+15) RA(N3)=1.1E+15                               COPES469
      IF (IPNPUT.LT.2) WRITE (6,1090) I,RA(N2),RA(N3),RA(I),RA(N4),(TITLCOPES470
     1E(J),J=1,5)                                                         COPES471
      N2=N2+1                                                             COPES472
      N3=N3+1                                                             COPES473
      N4=N4+1                                                             COPES474
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130   CONTINUE                                                          COPES475
C --- DATA BLOCK G.                                                     COPES476
C     D. V. NO., GLOBAL LOCATION, MULTIPLYING FACTOR.                   COPES477
      IF (IPNPUT.LT.2) WRITE (6,930)                                    COPES478
      N5=4*NDV+9                                                        COPES479
      M2=NDVTOT+1                                                       COPES480
      N6=N5+NDVTOT                                                      COPES481
      M3=M2+NDVTOT                                                      COPES482
      IF (N6.LE.NDPA) GO TO 140                                         COPES483
      WRITE (6,780)                                                     COPES484
      WRITE (6,800)                                                     COPES485
      LOCR(25)=N5                                                       COPES486
      GO TO 550                                                         COPES487
140   CONTINUE                                                          COPES488
      IF (M3.LE.NDIA) GO TO 150                                         COPES489
      WRITE (6,810)                                                     COPES490
      WRITE (6,800)                                                     COPES491
      LOCI(25)=M3                                                       COPES492
      GO TO 550                                                         COPES493
150   CONTINUE                                                          COPES494
      DO 160 I=1,NDVTOT                                                 COPES495
      READ (ISCR1,920) IA(M2),IA(I),RA(N5)                              COPES496
      IF (ABS(RA(N5)).LT.1.0E-20) RA(N5)=1.0                            COPES497
      IF (IPNPUT.LT.2) WRITE (6,940) I,IA(M2),IA(I),RA(N5)              COPES498
      M2=M2+1                                                           COPES499
      N5=N5+1                                                           COPES500
160   CONTINUE                                                          COPES501
      NCON=0                                                            COPES502
C --- DATA BLOCK H.                                                     COPES503
C     NUMBER OF CONSTRAINT SETS.                                        COPES504
      READ (ISCR1,920) NCONS                                            COPES505
      IF (IPNPUT.LT.2) WRITE (6,1110)                                   COPES506
      IF (IPNPUT.LT.2) WRITE (6,1120) NCONS                             COPES507
      IF (NCONS.EQ.0) GO TO 270                                         COPES508
      IF (IPNPUT.LT.2) WRITE (6,1130)                                   COPES509
      N6=4*NDV+NDVTOT+9                                                 COPES510
      M3=2*NDVTOT+1                                                     COPES511
      M4=2*NDVTOT+NCONS                                                 COPES512
      M4A=M4+1                                                          COPES513
      L=1                                                               COPES514
C --- DATA BLOCK I.                                                     COPES515
      DO 240 I=1,NCONS                                                  COPES516
      NNN=N6+3                                                          COPES517
      IF (NNN.GT.NDRA) GO TO 250                                        COPES518
C     GLOBAL NO. 1, GLOBAL NO. 2, LINEAR CONSTRAINT ID.                 COPES519
      READ (ISCR1,1200) ICONI,JCONI,LCONI                               COPES520
C     LB, NORM, UB, NORM.                                               COPES521
      READ (ISCR1,1210) (RA(J),J=N6,NNN)                                COPES522
      IF (RA(N6).LE.-1.0E+15) RA(N6)=-1.1E+15                           COPES523
      IF (RA(N6+2).GE.1.0E+15) RA(N6+2)=1.1E+15                         COPES524
      IF (RA(N6+1).LT.1.0E-20) RA(N6+1)=ABS(RA(N6))                     COPES525
      IF (RA(N6+1).LT.1.0E-20) RA(N6+1)=0.1                             COPES526
      IF (RA(N6+3).LT.1.0E-20) RA(N6+3)=ABS(RA(N6+2))                   COPES527
      IF (RA(N6+3).LT.1.0E-20) RA(N6+3)=0.1                             COPES528
C     NUMBER OF VARIABLES IN THIS SET.                                  COPES529
      NVAR=JCONI-ICONI+1                                                COPES530
      IF (NVAR.LT.1) NVAR=1                                             COPES531
      NCONA=NCONA+NVAR                                                  COPES532
C     HOW MANY CONSTRAINTS?                                             COPES533
      J1=0                                                              COPES534
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      IF (RA(N6).GE.-1.0E+15) J1=1                                      COPES535
      IF (RA(N6+2).LT.1.0E+15) J1=J1+1                                  COPES536
      NCONI=J1*NVAR                                                     COPES537
      NCON=NCON+NCONI                                                   COPES538
      IF (J1.EQ.0) GO TO 180                                            COPES539
C     ADD LINEAP CONSTRAINT IDENTIFIERS TO ISC.                         COPES540
      DO 170 J=1,NCONI                                                  COPES541
      M4=M4+1                                                           COPES542
      MMM=M4                                                            COPES543
      IF (MMM.GT.NDIA) GO TO 260                                        COPES544
170   IA(M4)=LCONI                                                      COPES545
180   CONTINUE                                                          COPES546
C     ADD LB, UB AND SCAL TO BLU IF NVAR.GT.1.                          COPES547
      IF (NVAR.EQ.1) GO TO 200                                          COPES548
      NVAR1=NVAR-1                                                      COPES549
      DO 190 J=1,NVAR1                                                  COPES550
      NNN=N6+7                                                          COPES551
      IF (NNN.GT.NDRA) GO TO 250                                        COPES552
      RA(N6+4)=RA(N6)                                                   COPES553
      RA(N6+5)=RA(N6+1)                                                 COPES554
      RA(N6+6)=RA(N6+2)                                                 COPES555
      RA(N6+7)=RA(N6+3)                                                 COPES556
      N6=N6+4                                                           COPES557
190   CONTINUE                                                          COPES558
200   CONTINUE                                                          COPES559
C     ADD CONSTRAINED VARIABLE GLOBAL IDENTIFIERS TO ICON.              COPES560
      ICON1=ICONI                                                       COPES561
      MMM=M4+NVAR-1                                                     COPES562
      IF (MMM.GT.NDIA) GO TO 260                                        COPES563
      DO 230 J=1,NVAR                                                   COPES564
      IF (J.EQ.1) GO TO 220                                             COPES565
C     SHIFT ISC VECTOR.                                                 COPES566
      L1=M4+1                                                           COPES567
      L2=M4                                                             COPES568
      DO 210 K=M4A,M4                                                   COPES569
      IA(L1)=IA(L2)                                                     COPES570
      L1=L1-1                                                           COPES571
210   L2=L2-1                                                           COPES572
      M4=M4+1                                                           COPES573
      M4A=M4A+1                                                         COPES574
220   IA(M3)=ICON1                                                      COPES575
      ICON1=ICON1+1                                                     COPES576
230   M3=M3+1                                                           COPES577
      IF (IPNPUT.LT.2) WRITE (6,1100) L,ICONI,JCONI,LCONI,RA(N6),RA(N6+1COPES578
     1),RA(N6+2),RA(N6+3)                                               COPES579
      N6=N6+4                                                           COPES580
      L=NCON+1                                                          COPES581
240   CONTINUE                                                          COPES582
      IF (IPNPUT.LT.2) WRITE (6,900) NCONA                              COPES583
      GO TO 270                                                         COPES584
250   WRITE (6,780)                                                     COPES585
      WRITE (6,820)                                                     COPES586
      LOCR(25)=NNN                                                      COPES507
      GO TO 550                                                         COPES508
260   WRITE (6,810)                                                     COPES589
      WRITE (6,820)                                                     COPES590
      LOCI(25)=MMM                                                      COPES591
      GO TO 550                                                         COPES592
270   CONTINUE                                                          COPES593
C     STAPTING LOCATIONS FOR APPROXIMATION INFORMATION.                 COPES594
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      NAPR=4*NDV+NDVTOT+4*NCONA+9                                       COPES595
      NAPI=2*(NDV+NCONA)+2*NDVTOT+NCONA+1                               COPES596
      NF=0                                                              COPES597
      KMAX=0                                                            COPES598
      NPTOT=0                                                           COPES599
      MAXTRM=0                                                          COPES600
      IF (NXAPRX.LE.0) GO TO 450                                        COPES601
C     ------------------------------------------------------------------COPES602
C                     APPROXIMATE ANALYSIS/DESIGN                       COPES603
C     ------------------------------------------------------------------COPES604
C --- DATA BLOCK J.                                                     COPES605
C     CONTROL PARAMETERS.                                               COPES606
      READ (ISCR1,1200) NF,NPS,NPFS,NPA,INOM,ISCRX,ISCRXF,IPAPRX        COPES607
      IF (NPA.NE.0) NPA=1                                               COPES608
      IF (NPS.EQ.0.AND.NPFS.EQ.0) NPA=1                                 COPES609
      IF (ISCRX.EQ.0) ISCRX=5                                           COPES610
      IF (ISCRXF.EQ.0) ISCRXF=5                                         COPES611
      IF (IPNPUT.LT.2) WRITE (6,600) NF,NPS,NPFS,NPA,INOM,ISCRX,ISCRXF,ICOPES612
     1PAPRX                                                             COPES613
      NPSFS=NPS+NPFS                                                    COPES614
      IF (NPSFS.LT.2) NPA=1                                             COPES615
      NPTOT=NPS+NPFS+NPA                                                COPES616
      IF (NPTOT.LT.2) NPTOT=2                                           COPES617
      READ (ISCR1,1200) KMIN,KMAX,NPMAX,JNOM,INXLOC,INFLOC,MAXTRM       COPES618
      IF (INXLOC.EQ.0) NXAPRX=NDVTOT                                    COPES619
      M=NXAPRX+(NXAPRX*(NXAPRX+1))/2                                    COPES620
      IF (NPMAX.LE.0) NPMAX=2*M                                         COPES621
      IF (KMAX.EQ.0) KMAX=3*M-NPTOT+1                                   COPES622
      IF (KMIN.EQ.0) KMIN=2*NDV-NPTOT+1                                 COPES623
      IF (KMIN.LT.0) KMIN=0                                             COPES624
      IF (KMAX.GT.0.AND.KMAX.LT.KMIN) KMAX=KMIN                         COPES625
      IF (JNOM.EQ.0) JNOM=2*M                                           COPES626
      IF (MAXTRM.LT.1) MAXTRM=3                                         COPES627
      IF (IPNPUT.LT.2) WRITE (6,610) KMIN,KMAX,NPMAX,JNOM,INXLOC,INFLOC,COPES628
     1MAXTRM                                                            COPES629
C --- DATA BLOCK K, PART 1.                                             COPES630
C     DELX BOUNDS ON APPROXIMATE OPTIMIZATION.                          COPES631
      IF (NDV.LE.0) GO TO 290                                           COPES632
      N7=NAPR                                                           COPES633
      NN7=N7+NDV-1                                                      COPES634
      IF (NN7.LE.NDRA) GO TO 280                                        COPES635
      WRITE (6,780)                                                     COPES636
      WRITE (6,560)                                                     COPES637
280   CONTINUE                                                          COPES638
      READ (ISCR1,1210) (RA(I),I=N7,NN7)                                COPES639
      IF (IPNPUT.LT.2) WRITE (6,570)                                    COPES640
      IF (IPNPUT.LT.2) WRITE (6,1160) (RA(I),I=N7,NN7)                  COPES641
C --- DATA BLOCK K, PART 2.                                             COPES642
C     MULTIPLIERS ON DELX.                                              COPES643
      READ (ISCR1,1210) XFACT1,XFACT2                                   COPES644
      IF (XFACT1.LT.1.0E-10) XFACT1=1.5                                 COPES645
      IF (XFACT2.LT.1.0E-10) XFACT2=2.                                  COPES646
      IF (IPNPUT.LT.2) WRITE (6,620) XFACT1,XFACT2                      COPES647
290   CONTINUE                                                          COPES648
C --- DATA BLOCK L.                                                     COPES649
C     GLOBAL LOCATIONS OF X-VARIABLES.                                  COPES650
      M5=NAPI                                                           COPES651
      MM5=M5+NXAPRX-1                                                   COPES652
      IF (MM5.LE.NDIA) GO TO 300                                        COPES653
      WRITE (6,780)                                                     COPES654
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      WRITE (6,630)                                                     COPES655
      LOCI(25)=MM5                                                      COPES656
      GO TO 550                                                         COPES657
300   CONTINUE                                                          COPES658
      IF (INXLOC.EQ.0) GO TO 310                                        COPES659
      READ (ISCR1,1200) (IA(I),I=M5,MM5)                                COPES660
      GO TO 330                                                         COPES661
310   CONTINUE                                                          COPES662
C     X-LOCATIONS ARE DEFAULTED TO DESIGN VARIABLE LOCATIONS.           COPES663
      DO 320 I=1,NXAPRX                                                 COPES664
      IA(M5)=IA(I)                                                      COPES665
320   M5=M5+1                                                           COPES666
      M5=NAPI                                                           COPES667
330   CONTINUE                                                          COPES668
      IF (IPNPUT.LT.2) WRITE (6,640)                                    COPES669
      IF (IPNPUT.LT.2) WRITE (6,1180) (IA(I),I=M5,MM5)                  COPES670
C --- DATA BLOCK M.                                                     COPES671
C     GLOBAL LOCATIONS OF FUNCTIONS.                                    COPES672
      M6=NAPI+NXAPRX                                                    COPES673
      MM6=M6+NF-1                                                       COPES674
      IF (MM6.LE.NDIA) GO TO 340                                        COPES675
      WRITE (6,780)                                                     COPES676
      WRITE (6,650)                                                     COPES677
      LOCI(25)=MM6                                                      COPES678
      GO TO 550                                                         COPES679
340   CONTINUE                                                          COPES680
      IF (INFLOC.EQ.0) GO TO 350                                        COPES681
      READ (ISCR1,1200) (IA(I),I=M6,MM6)                                COPES682
      GO TO 380                                                         COPES683
350   CONTINUE                                                          COPES684
C     FUNCTION LOCATIONS ARE DEFAULTED TO OBJECTIVE AND CONSTRAINT      COPES685
C     LOCATIONS.                                                        COPES686
      NF1=1                                                             COPES687
      M3=2*NDVTOT+1                                                     COPES688
      IA(M6)=IOBJ                                                       COPES689
      IF (NCONA.EQ.0) GO TO 370                                         COPES690
      DO 360 I=1,NCONA                                                  COPES691
      IF (IA(M3).EQ.IOBJ) GO TO 360                                     COPES692
      NF1=NF1+1                                                         COPES693
      M6=M6+1                                                           COPES694
      IA(M6)=IA(M3)                                                     COPES695
360   M3=M3+1                                                           COPES696
370   NF=NF1                                                            COPES697
380   M6=NAPI+NXAPRX                                                    COPES698
      MM6=M6+NF-1                                                       COPES699
      IF (IPNPUT.LT.2) WRITE (6,660)                                    COPES700
      IF (IPNPUT.LT.2) WRITE (6,1180) (IA(I),I=M6,MM6)                  COPES701
C --- DATA BLOCK N.                                                     COPES702
C     READ INPUT X-VECTORS AND STORE ON UNIT ISCR2.                     COPES703
      REWIND ISCR2                                                      COPES704
      IF (NPS.EQ.0) GO TO 410                                           COPES705
      N7=NAPR+NDV                                                       COPES706
      NN7=N7+NXAPRX-1                                                   COPES707
      IF (NN7.LE.NDRA) GO TO 390                                        COPES708
      WRITE (6,780)                                                     COPES709
      WRITE (6,670)                                                     COPES710
      LOCR(25)=NN7                                                      COPES711
      GO TO 550                                                         COPES712
390   CONTINUE                                                          COPES713
      IF (IPNPUT.LT.2) WRITE (6,680) ISCRX                              COPES714
      DO 400 I=1,NPS                                                    COPES715
C     BINARY READ IF ISCRX.NE.5.                                        COPES716
      IF (ISCRX.NE.5) READ (ISCRX) (RA(J),J=N7,NN7)                     COPES717
C     FORMATTED READ IF ISCRX.EQ.5.                                     COPES718
      IF (ISCRX.EQ.5) READ (ISCP1,1210) (RA(J),J=N7,NN7)                COPES719
      WRITE (ISCR2) (RA(J),J=N7,NN7)                                    COPES720
      IF (IPNPUT.LT.2) WRITE (6,710) I,I                                COPES721
      IF (IPNPUT.LT.2) WRITE (6,1160) (RA(J),J=N7,NN7)                  COPES722
400   CONTINUE                                                          COPES723
410   CONTINUE                                                          COPES724
C --- DATA BLOCK O.                                                     COPES725
C     READ INPUT X-F PAIRS AND STORE ON UNIT ISCR2.                     COPES726
      IF (NPFS.EQ.0) GO TO 440                                          COPES727
      N7=NAPR+NDV                                                       COPES728
      NN7=N7+NXAPRX-1                                                   COPES729
      NN8=N7+NF-1                                                       COPES730
      IF (NN7.GT.NN8) NN8=NN7                                           COPES731
      IF (NN8.LE.NDRA) GO TO 420                                        COPES732
      WRITE (6,780)                                                     COPES733
      WRITE (6,690)                                                     COPES734
      LOCR(25)=NN8                                                      COPES735
      GO TO 550                                                         COPES736
420   CONTINUE                                                          COPES737
      NN8=N7+NF-1                                                       COPES738
      IF (IPNPUT.LT.2) WRITE (6,700) ISCRXF                             COPES739
      DO 430 I=1,NPFS                                                   COPES740
C     X-VECTOR.                                                         COPES741
C     BINARY READ IF ISCRXF.NE.5.                                       COPES742
      IF (ISCRXF.NE.5) READ (ISCRXF) (RA(J),J=N7,NN7)                   COPES743
C     FORMATTED READ IF ISCRXF.EQ.5.                                    COPES744
      IF (ISCRXF.EQ.5) READ (ISCR1,1210) (RA(J),J=N7,NN7)               COPES745
      II=I+NPS                                                          COPES746
      IF (IPNPUT.LT.2) WRITE (6,710) I,II                               COPES747
      IF (IPNPUT.LT.2) WRITE (6,720)                                    COPES748
      IF (IPNPUT.LT.2) WRITE (6,1160) (RA(J),J=N7,NN7)                  COPES749
      WRITE (ISCR2) (RA(J),J=N7,NN7)                                    COPES750
C     FUNCTION VALUES.                                                  COPES751
C     BINARY READ IF ISCRXF.NE.5.                                       COPES752
      IF (ISCRXF.NE.5) READ (ISCRXF) (RA(J),J=N7,NN8)                   COPES753
C     FORMATTED READ IF ISCRXF.EQ.5.                                    COPES754
      IF (ISCRXF.EQ.5) READ (ISCR1,1210) (RA(J),J=N7,NN8)               COPES755
      IF (IPNPUT.LE.2) WRITE (6,730)                                    COPES756
      IF (IPNPUT.LT.2) WRITE (6,1160) (RA(J),J=N7,NN8)                  COPES757
      WRITE (ISCR2) (RA(J),J=N7,NN8)                                    COPES758
430   CONTINUE                                                          COPES759
440   CONTINUE                                                          COPES760
450   CONTINUE                                                          COPES761
      NSOBJ=0                                                           COPES762
      NSVTOT=0                                                          COPES763
C     STARTING LOCATIONS FOR SENSITIVITY INFORMATION.                   COPES764
      NSVR=NAPR+NDV                                                     COPES765
      NSVI=NAPI+NXAPRX+NF                                               COPES766
      IF (NSV.LE.0) GO TO 500                                           COPES767
C     ------------------------------------------------------------------COPES768
C                           SENSITIVITY INFORMATION                     COPES769
C     ------------------------------------------------------------------COPES770
      IF (IPNPUT.LT.2) WRITE (6,1020)                                   COPES771
C --- DATA BLOCK P, PART 1.                                             COPES772
C     NSOBJ, IPSENS                                                     COPES773
      READ (ISCR1,1200) NSOBJ,IPSENS                                    COPES774
C --- DATA BLOCK P, PART 2.                                             COPES775
C     NSENSZ.                                                           COPES776
      M15=NSVI                                                          COPES777
      MM15=M15+NSOBJ-1                                                  COPES778
      IF (MM15.LE.NDIA) GO TO 460                                       COPES779
      WRITE (6,810)                                                     COPES780
      WRITE (6,830)                                                     COPES781
      LOCI(25)=MM15                                                     COPES782
      GO TO 550                                                         COPES783
460   CONTINUE                                                          COPES784
      READ (ISCR1,1200) (IA(I),I=M15,MM15)                              COPES785
      IF (IPNPUT.LT.2) WRITE (6,960) IPSENS,NSOBJ                       COPES786
      IF (IPNPUT.LT.2) WRITE (6,950) (IA(I),I=M15,MM15)                 COPES787
      IF (IPNPUT.LT.2) WRITE (6,1030)                                   COPES788
      N15=NSVR                                                          COPES789
      M16=NSVI+NSOBJ                                                    COPES790
      M17=M16+NSV                                                       COPES791
      DO 490 I=1,NSV                                                    COPES792
C --- DATA BLOCK Q, PART 1.                                             COPES793
C     ISENS, NSENS.                                                     COPES794
      READ (ISCR1,1200) IA(M16),NN1                                     COPES795
      NN15=N15+NN1-1                                                    COPES796
      IF (NN15.LE.NDRA) GO TO 470                                       COPES797
      WRITE (6,780)                                                     COPES798
      WRITE (6,840)                                                     COPES799
      LOCR(25)=NN15                                                     COPES800
      GO TO 550                                                         COPES801
470   CONTINUE                                                          COPES802
C --- DATA BLOCK Q, PART 2.                                             COPES803
C     SENS.                                                             COPES804
      READ (ISCR1,1210) (RA(J),J=N15,NN15)                              COPES805
      IF (IPNPUT.GE.2) GO TO 480                                        COPES806
      JJ=N15+5                                                          COPES807
      IF (JJ.GT.NN15) JJ=NN15                                           COPES808
      WRITE (6,1040) I,IA(M16),(RA(J),J=N15,JJ)                         COPES809
      JJ=JJ+1                                                           COPES810
      IF (JJ.LE.NN15) WRITE (6,1050) (RA(J),J=JJ,NN15)                  COPES811
480   CONTINUE                                                          COPES812
      NSVTOT=NSVTOT+NN1                                                 COPES813
      IA(M17)=NN1                                                       COPES814
      N15=NN15+1                                                        COPES815
      M16=M16+1                                                         COPES816
      M17=M17+1                                                         COPES817
490   CONTINUE                                                          COPES818
500   CONTINUE                                                          COPES819
      M2VX=0                                                            COPES820
      M2VY=0                                                            COPES821
C     STARTING LOCATIONS FOR TWO-VARIABLE FUNCTION SPACE INFORMATION.   COPES822
      N2VR=NSVR+NSVTOT                                                  COPES823
      N2VI=NSVI+NSOBJ+2*NSV                                             COPES824
      IF (N2VAR.LE.0) GO TO 540                                         COPES825
C     ------------------------------------------------------------------COPES826
C                   TWO-VARIABLE FUNCTION SPACE INFORMATION             COPES827
C     ------------------------------------------------------------------COPES828
C --- DATA BLOCK R.                                                     COPES829
C     VARIABLE NUMBERS AND NUMBER OF VALUES OF X AND Y.                 COPES830
      READ (ISCR1,1200) N2VX,M2VX,N2VY,M2VY,IP2VAR                      COPES831
      N20=N2VR                                                          COPES832
      M20=N2VI                                                          COPES833
      MM20=M20+N2VAR-1                                                  COPES834
      IF (MM20.LE.NDIA) GO TO 510                                       COPES835
      WRITE (6,810)                                                     COPES836
      WRITE (6,850)                                                     COPES837
      LOCI(25)=MM20                                                     COPES838
      GO TO 550                                                         COPES839
510   CONTINUE                                                          COPES840
C --- DATA BLOCK S.                                                      COPES841
C     GLOBAL VARIABLE NUMBERS CORRESPONDING TO FUNCTIONS OF X AND Y.    COPES842
      READ (ISCR1,1200) (IA(I),I=M20,MM20)                              COPES843
      IF (IPNPUT.LT.2) WRITE (6,1170) IP2VAR                            COPES844
      IF (IPNPUT.LT.2) WRITE (6,1180) (IA(I),I=M20,MM20)                COPES845
C --- DATA BLOCK T.                                                      COPES846
C     VALUES OF X COMPONENTS.                                           COPES847
      NN20=N20+M2VX-1                                                   COPES848
      IF (NN20.LE.NDRA) GO TO 520                                       COPES849
      WRITE (6,780)                                                     COPES850
      WRITE (6,740)                                                     COPES851
      LOCP(25)=NN20                                                     COPES852
      GO TO 550                                                         COPES853
520   READ (ISCR1,1210) (RA(I),I=N20,NN20)                              COPES854
      IF (IPNPUT.LT.2) WRITE (6,1140) N2VX                              COPES855
      IF (IPNFUT.LT.2) WRITE (6,1160) (RA(I),I=N20,NN20)                COPES856
C --- DATA BLOCK U.                                                      COPES857
C     VALUES OF Y COMPONENTS.                                           COPES858
      N21=N20+M2VX                                                      COPES859
      NN21=N21+M2VY-1                                                   COPES860
      IF (NN21.LE.NDRA) GO TO 530                                       COPES861
      WRITE (6,780)                                                     COPES862
      WRITE (6,750)                                                     COPES863
      LOCR(25)=NN21                                                     COPES864
      GO TO 550                                                         COPES865
530   CONTINUE                                                          COPES866
      NN20=NN21                                                         COPES867
      READ (ISCR1,1210) (RA(I),I=N21,NN21)                              COPES868
      IF (IPNPUT.LT.2) WRITE (6,1150) N2VY                              COPES869
      IF (IPNFUT.LT.2) WRITE (6,1160) (RA(I),I=N21,NN21)                COPES870
540   CONTINUE                                                          COPES871
C     ------------------------------------------------------------------COPES872
C                     DYNAMIC STORAGE ALLOCATION                        COPES873
C     ------------------------------------------------------------------COPES874
      NDV2=NDV+2                                                        COPES875
C     REAL VARIABLES.                                                   COPES876
C     X.                                                                COPES877
      LOCR(1)=1                                                         COPES878
C     VLB.                                                              COPES879
      LOCR(2)=NDV+3                                                     COPES880
C     VUB.                                                              COPES881
      LOCR(3)=LOCR(2)+NDV2                                              COPES882
C     SCAL.                                                             COPES883
      LOCR(4)=LOCR(3)+NDV2                                              COPES884
C     AMULT.                                                            COPES885
      LOCR(5)=LOCR(4)+NDV2                                              COPES886
C     BLU.                                                              COPES887
      LOCR(6)=LOCR(5)+NDVTOT                                            COPES888
C     DELX.                                                             COPES889
      LOCR(7)=LOCR(6)+4*NCONA                                           COPES890
      LOCR(8)=LOCR(7)+NDV                                               COPES891
C     SENS.                                                             COPES892
      LOCR(15)=LOCR(8)                                                  COPES893
C     XM2V.                                                             COPES894
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      LOCR(20)=LOCR(15)+NSVTOT                                          COPES895
C     YM2V.                                                             COPES896
      LOCR(21)=LOCR(20)+M2VX                                            COPES897
      LOCR(22)=LOCR(21)+M2VY                                            COPES898
C     START OF EXECUTION STORAGE.                                       COPES899
      LOCR(23)=LOCR(22)                                                 COPES900
C     INTEGER VARIABLES.                                                COPES901
C     IDSGN.                                                            COPES902
      LOCI(1)=1                                                         COPES903
C     NDSGN.                                                            COPES904
      LOCI(2)=NDVTOT+1                                                  COPES905
C     ICON.                                                             COPES906
      LOCI(3)=LOCI(2)+NDVTOT                                            COPES907
C     ISC.                                                              COPES908
      LOCI(4)=LOCI(3)+NCONA                                             COPES909
C     LOCX.                                                             COPES910
      LOCI(5)=LOCI(4)+2*(NDV+NCONA)                                     COPES911
C     LOCF.                                                             COPES912
      LOCI(6)=LOCI(5)+NXAPRX                                            COPES913
      LOCI(7)=LOCI(6)+NF                                                COPES914
C     NSENSZ.                                                           COPES915
      LOCI(15)=LOCI(7)                                                  COPES916
C     ISENS.                                                            COPES917
      LOCI(16)=LOCI(15)+NSOBJ                                           COPES918
C     NSENS.                                                            COPES919
      LOCI(17)=LOCI(16)+NSV                                             COPES920
      LOCI(18)=LOCI(17)+NSV                                             COPES921
C     N2VZ.                                                             COPES922
      LOCI(20)=LOCI(18)                                                 COPES923
      LOCI(21)=LOCI(20)+N2VAR                                           COPES924
C     START OF EXECUTION STORAGE.                                       COPES925
      LOCI(23)=LOCI(21)                                                 COPES926
C     EXECUTION STORAGE REQUIREMENTS.                                   COPES927
      NRI=NDV                                                           COPES928
      IF (NACMX1.GT.NRI) NRI=NACMX1                                     COPES929
      NR2=3*NCON+12*NDV+NACMX1*(NDV2+NACMX1)+3*NRI+12                   COPES930
      NI2=NACMX1+2*NRI+2*NDV+NCON                                       COPES931
      NR3=NSV                                                           COPES932
      IF (NSOBJ.GT.NR3) NR3=NSOBJ                                       COPES933
      NR4=N2VAR                                                         COPES934
      NR5=NP2+NP3                                                       COPES935
      NI5=NI2                                                           COPES936
      M=NXAPRX+(NXAPRX*(NXAPRX+1))/2                                    COPES937
      IF (MAXTRM.LT.3) M=MAXTFM*NXAPRX                                  COPES938
      NR6=3*NXAFRX+6+NDV+2*NF+M*NF                                      COPES939
      NI6=NCONA+NXAPRX                                                  COPES940
      NRI=(KMAX+1-NPTOT)*(NXAPRX+NF+1)                                  COPES941
      IF (NRI.LT.NR2) NRI=NR2                                           COPES942
      IF (KMAX.LT.0) NRI=NPTOT*(NXAPRX+NF+1)                            COPES943
      NP7=NR6+NRI                                                       COPES944
      NI7=NI6+NI2                                                       COPES945
C     START OF TEMPORARY STORAGE.                                       COPES946
      LOCR(24)=LOCR(23)                                                 COPES947
      LOCI(24)=LOCI(23)                                                 COPES948
      IF (NCALC.EQ.2) LOCR(24)=LOCR(23)+NR2                             COPES949
      IF (NCALC.EQ.3) LOCR(24)=LOCR(23)+NR3                             COPES950
      IF (NCALC.EQ.4) LOCR(24)=LOCR(23)+NR4                             COPES951
      IF (NCALC.EQ.5) LOCR(24)=LOCP(23)+NR5                             COPES952
      IF (NCALC.EQ.6.AND.KMAX.LT.0) LOCR(24)=LOCR(23)+NR6               COPES953
      IF (NCALC.EQ.6.AND.KMAX.GT.0) LOCR(24)=LOCR(23)+NR7               COPES954
      IF (NCALC.EQ.2) LOCI(24)=LOCI(23)+NI2                             COPES955
      IF (NCALC.EQ.5) LOCI(24)=LOCI(23)+NI5                             COPES956
      IF (NCALC.EQ.6.AND.KMAX.LT.0) LOCI(24)=LOCI(23)+NI6               COPES957
      IF (NCALC.EQ.6.AND.KMAX.GT.0) LOCI(24)=LOCI(23)+NI7               COPES958
C     TOTAL STORAGE REQUIREMENTS.                                       COPES959
      LOCR(25)=LOCR(24)                                                 COPES960
      LOCI(25)=LOCI(24)                                                 COPES961
      IF (NCALC.EQ.5) LOCR(25)=LOCR(25)+4*NDV+8                         COPES962
      IF (NCALC.EQ.5) LOCI(25)=LOCI(25)+2*NDVTOT                        COPES963
      IF (IPNPUT.LT.2) WRITE (6,860) LOCR(23),LOCR(25),NDRA,LOCI(23),LOCCOPES964
     1I(25),NDIA                                                        COPES965
550   CONTINUE                                                          COPES966
      RETURN                                                            COPES967
C     ------------------------------------------------------------------COPES968
C                               FORMATS                                 COPES969
C     ------------------------------------------------------------------COPES970
560   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK K)                       COPES971
570   FORMAT (//5X,43HDELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION)      COPES972
580   FORMAT (80A1)                                                     COPES973
590   FORMAT (I5/80A1)                                                  COPES974
600   FORMAT (///5X,49H* • APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATIONCOPES975
     1//5X,38HNUMBER OF FUNCTIONS APPROXIMATED, NF =,I5/5X,38HNUMBER OF COPES976
     2INPUT X-VECTORS,       NPS =,I5/5X,38HNUMBER OF INPUT X-F PAIRS,  COPES977
     3    NPFS =,I5/5X,38HX-VECTOR FROM ANALIZ,            NPA =,I5/5X,3COPES978
     48HNOMINAL DESIGN,                  INOM =,I5/5X,38HREAD UNIT FOR X-COPES979
     5VECTORS,        ISCRX =,I5/5X,38HREAD UNIT FOR X-F PAIRS,      ISCRCOPES980
     6XF =,I5/5X,38HPRINT CONTROL,                   IPAPRX =,I5)       COPES981
610   FORMAT (/5X,38HMINIMUM APPROXIMATING CYCLES,   KMIN =,I5/5X,38HMAXCOPES982
     1IMUM APPROXIMATING CYCLES,   KMAX =,I5/5X,38HMAXIMUM DESIGNS USED COPES983
     2IN FIT,   NPMAX =,I5/5X,38HNOMINAL DESIGN PARAMETER,        JNOM =,COPES984
     3I5/5X,38HX-LOCATION INPUT PARAMETER,   INXLOC =,I5/5X,38HF-LOCATIOCOPES985
     4N INPUT PARAMETER,   INFLOC =,I5/5X,38HTAYLER SERIES I.D. CODE,   COPES986
     5   MAXTRM =,I5)                                                   COPES987
620   FORMAT (/5X,38HMULTIPLIER ON DELX,               XFACT1 =,E12.4/5X,38HCOPES988
     1MULTIPLIER ON DELX,               XFACT2 =,E12.4)                 COPES989
630   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK L)                       COPES990
640   FORMAT (//5X,31HGLOBAL LOCATIONS OF X-VARIABLES)                  COPES991
650   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK M)                       COPES992
660   FORMAT (//5X,29HGLOBAL LOCATIONS OF FUNCTIONS)                    COPES993
670   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK N)                       COPES994
680   FORMAT (//5X,25HX-VECTORS INPUT FROM UNIT,I5)                     COPES995
690   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK O)                       COPES996
700   FORMAT (////5X,25HX-F PAIRS INPUT FROM UNIT,I5)                   COPES997
710   FORMAT (//5X,6HNUMBER,I5,5X,6HDESIGN,I5)                          COPES998
720   FORMAT (/5X,8HX-VECTOR)                                           COPES999
730   FORMAT (/5X,15HFUNCTION VALUES)                                   COPE1000
740   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK T)                       COPE1001
750   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK U)                       COPE1002
760   FORMAT (/5X,58HCONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVECOPE1003
     1R-RIDE)//5X,6HIPRINT,2X,5HITMAX,3X,6HICNDIR,3X,5HNSCAL,3X,4HITRM,3COPE1004
     2X,6HLINOBJ,2X,6HNACMX1,3X,4HNFDG/8I8)                             COPE1005
770   FORMAT (/6X,4HFDCH,12X,5HFDCHM,11X,2HCT,14X,5HCTMIN/1X,4(2X,E14.5)COPE1006
     1//6X,3HCTL,13X,6HCTLMIN,10X,5HTHETA,11X,3HPHI/1X,4(2X,E14.5)//6X,6COPE1007
     2HDELFUN,10X,6HDABFUN,10X,6HALPHAX,10X,6HABOBJ1/1X,4(2X,E14.5))    COPE1008
780   FORMAT (//5X,54HREQUIRED STORAGE IN ARRAY RA EXCEEDS AVAILABLE STOCOPE1009
     1RAGE)                                                             COPE1010
790   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK F)                       COPE1011
800   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK G)                       COPE1012
810   FORMAT (//5X,54HREQUIRED STORAGE IN ARRAY IA EXCEEDS AVAILABLE STOCOPE1013
     1RAGE)                                                             COPE1014
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820   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK I)                       COPE1015
830   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK P)                       COPE1016
840   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK Q)                       COPE1017
850   FORMAT (/5X,27HUNABLE TO READ DATA BLOCK R)                       COPE1018
860   FORMAT (////5X,39H* • ESTIMATED DATA STORAGE REQUIREMENTS//15X,4HRCOPE1019
     1EAL,26X,7HINTEGER/5X,27HINPUT  EXECUTION  AVAILABLE,5X,27HINPUT  ECOPE1020
     2XECUTION  AVAILABLE/I9,2I10,2X,3I10)                              COPE1021
870   FORMAT (1H1,4X,27HCARD IMAGES OF CONTROL DATA///5X,4HCARD,20X,5HIMCOPE1022
     1AGE)                                                              COPE1023
880   FORMAT (1H0)                                                      COPE1024
890   FORMAT (I8,1H),2X,80A1)                                           COPE1025
900   FORMAT (/5X,40HTOTAL NUMBER OF CONSTRAINED PARAMETERS =,I5)       COPE1026
910   FORMAT (//5X,26HCALCULATION CONTROL, NCALC/5X,5HVALUE,3X,7HMEANINGCOPE1027
     1/7X,1H1,5X,15HSINGLE ANALYSIS/7X,1H2,5X,12HOPTIMIZATION/7X,1H3,5X,COPE1028
     211HSENSITIVITY/7X,1H4,5X,27HTWO-VARIABLE FUNCTION SPACE/7X,1H5,5X,COPE1029
     319HOPTIMUM SENSITIVITY/7X,1H6,5X,24HAPPROXIMATE OPTIMIZATION)     COPE1030
920   FORMAT (2I10,F10.2)                                               COPE1031
930   FORMAT (//5X,16HDESIGN VARIABLES/11X,5HD. V.,5X,6HGLOBAL,4X,11HMULCOPE1032
     1TIPLYING/5X,2HID,5X,3HNO.,5X,8HVAR. NO.,5X,6HFACTOR)              COPE1033
940   FORMAT (2I7,5X,I5,6X,E12.5)                                       COPE1034
950   FORMAT (5X,16I5)                                                  COPE1035
960   FOPMAT (/5X,34HPRINT CONTROL,                  IPSENS =,I5/5X,34HNUMBER COPE1036
     1OF SENSITIVITY OBJECTIVES =,I5//5X,53HGLOBAL NUMBERS ASSOCIATED WICOPE1037
     2TH SENSITIVITY OBJECTIVES)                                        COPE1038
970   FORMAT (1H1,//////,5X,47HCCCCCCC   0000000   PPPPPPP   EEEEEEE   SCOPE1039
     1SSSSSS/5X,47HC          O     O  P     P  E         S      /5X,47COPE1040
     2HC          O     O  P     P  E         S      /5X,47HC         OCOPE1041
     3     O   PPPPPPP   EEEE      SSSSSSS/5X,47HC         O     O  P COPE1042
     4        E                  S/5X,47HC         O     O  P          E   COPE1043
     5             S/5X,47HCCCCCCC   0000000   P          EEEEEEE   SSSSSSSCOPE1044
     6)                                                                 COPE1045
980   FORMAT (/////14X,29HC O N T R O L   P R O G R A M//26X,5HF O R//8XCOPE1046
     1,41HE N G I N E E R I N G   S Y N T H E S I S)                    COPE1047
990   FORMAT (/////24X,9HT I T L E//5X,20A4)                            COPE1048
1000  FORMAT (1H1,4X,6HTITLE:/5X,20A4)                                  COPE1049
1010  FORMAT (///5X,19HCONTROL PARAMETERS;/5X,42HCALCULATION CONTROL,   COPE1050
     1              NCALC =,I5/5X,42HNUMBER OF GLOBAL DESIGN VARIABLES,   COPE1051
     2NDV =,I5/5X,42HNUMBER OF SENSITIVITY VARIABLES,     NSV =,I5/5X,42COPE1052
     3HNUMBER OF FUNCTIONS IN TWO-SPACE,  N2VAR =,I5/5X,42HNUMBER OF APPCOPE1053
     4ROXIMATING VAR.     NXAPRX =,I5/5X,42HINPUT INFORMATION PRINT CODCOPE1054
     5E,     IPNPUT =,I5/5X,42HDEBUG PRINT CODE,                  IPDBG COPE1055
     6=,I5)                                                             COPE1056
1020  FORMAT (////5X,27H* * SENSITIVITY INFORMATION)                    COPE1057
1030  FORMAT (/14X,6HGLOBAL,4X,7HNOMINAL/5X,6HNUMBER,2X,8HVARIABLE,4X,5HCOPE1058
     1VALUE,6X,18HOFF-NOMINAL VALUES)                                   COPE1059
1040  FORMAT (5X,I4,I8,5X,E12.5,1X,5E11.4)                              COPE1060
1050  FORMAT (35X,5E11.4)                                               COPE1061
1060  FORMAT (4F10.2,10A4)                                              COPE1062
1070  FORMAT (////5X,28H* * OPTIMIZATION INFORMATION//5X,35HGLOBAL VARIACOPE1063
     1BLE NUMBER OF OBJECTIVE,10X,1H=,I5/5X,46HMULTIPLIER (NEGATIVE INDICOPE1064
     2CATES MINIMIZATION) =,E12.4)                                      COPE1065
1080  FORMAT (/5X,27HDESIGN VARIABLE INFORMATION/5X,50HNON-ZERO INITIAL COPE1066
     1VALUE WILL OVER-RIDE MODULE INPUT/5X,5HD. V.,5X,5HLOWER,10X,5HUPPECOPE1067
     2R,9X,7HINITIAL/5X,3HNO.,7X,5HBOUND,10X,5HBOUND,10X,5HVALUE,10X,5HSCOPE1068
     3CALE)                                                             COPE1069
1090  FORMAT (I8,4X,E12.5,3X,E12.5,3X,E12.5,3X,E12.5,5A4)               COPE1070
1100  FORMAT (I8,I7,2I8,5X,E12.5,3X,E12.5,3X,E12.5,3X,E12.5)            COPE1071
1110  FORMAT (//5X,22HCONSTRAINT INFORMATION)                           COPE1072
1120  FORMAT (/5X,9HTHERE ARE,I3,16H CONSTRAINT SETS)                   COPE1073
1130  FORMAT (11X,6HGLOBAL,2X,6HGLOBAL,2X,6HLINEAR,6X,5HLOWER,6X,13HNORMCOPE1074
     1ALIZATION,6X,5HUPPER,6X,13HNORMALIZATION/6X,2HID,3X,6HVAR. 1,2X,6HCOPE1075
     2VAR. 2,4X,2HID,8X,5HBOUND,9X,6HFACTOR,10X,5HBOUND,9X,6HFACTOR)    COPE1076
 1140 FORMAT (//5X,49HGLOBAL VARIABLE NUMBER CORRESPONDING TO X, N2VX =,COPE1077
     1I5//5X,20HVALUES OF X-VARIABLE)                                   COPE1078
 1150 FORMAT (//5X,49HGLOBAL VARIABLE NUMBER CORRESPONDING TO Y, N2VY =,COPE1079
     1I5//5X,20HVALUES OF Y-VARIABLE)                                   COPE1080
 1160 FORMAT (3X,5E12.4)                                                COPE1081
 1170 FORMAT (////5X,51H* * TWO-VARIABLE FUNCTION SPACE MAPPING INFORMATCOPE1082
     1ION//5X,23HPRINT CONTROL, IP2VAR =,I5//5X,52HGLOBAL VARIABLE NUMBECOPE1083
     2RS ASSOCIATED WITH F(X,Y), M2VZ)                                  COPE1084
 1180 FORMAT (5X,10I5)                                                  COPE1085
 1190 FORMAT (20A4)                                                     COPE1086
 1200 FORMAT (8I10)                                                     COPE1087
 1210 FORMAT (8F10.2)                                                   COPE1088
 1220 FORMAT (///5X,26H* * * INPUT ERROR, NCALC =,I2,2X,41HIS LT.0 OR GTCOPE1089
     1.6  PROGRAM TERMINATED * * *)                                     COPE1090
      END                                                               COPE1091
      SUBROUTINE COPE02 (ARRAY,RA,IA,NARRAY,NDRA,NDIA)                  COPE1092
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCOPE1093
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCOPE1094
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                               COPE1095
      COMMON /COPES3/ SGNOPT,NCALC,IOBJ,NSV,NSOBJ,NCONA,N2VX,M2VX,N2VY,MCOPE1096
     12VY,N2VAR,IPSENS,IP2VAR,IPDBG,NACMX1,NDVTOT,LOCR(25),LOCI(25),ISCRCOPE1097
     21,ISCR2,NXAPRX,NPS,NPFS,NPA,NF,INOM,IPAPRX,KMIN,KMAX,XFACT1,XFACT2COPE1098
     3,NAN2,NAN3,NPMAX,NPTOT,JNOM,MAXTRM                                COPE1099
      DIMENSION ARRAY(NARRAY), RA(NDRA), IA(NDIA)                       COPE1100
C     ******************************************************************COPE1101
C                     ROUTINE TO CONTROL OPTIMIZATION.                  COPE1102
C     ******************************************************************COPE1103
C     BY G. N. VANDERPLAATS                          MAR., 1973.        COPE1104
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE1105
C     ------------------------------------------------------------------COPE1106
C                         ARRAY DIMENSIONS                              COPE1107
C     ------------------------------------------------------------------COPE1108
      NN1=NDV+2                                                         COPE1109
      NN2=2*NDV+NCON                                                    COPE1110
      NN3=NACMX1                                                        COPE1111
      NN4=NN3                                                           COPE1112
      IF (NDV.GT.NN4) NN4=NDV                                           COPE1113
      NN5=2*NN4                                                         COPE1114
      NN6=NDVTOT                                                        COPE1115
      NN7=NCONA                                                         COPE1116
C     ------------------------------------------------------------------COPE1117
C                       ARRAY STARTING LOCATIONS                        COPE1118
C     ------------------------------------------------------------------COPE1119
C     X, VLB, VUB, DF, A, S, G1, G2, C, B, SCAL, ISC, IC, MS1           COPE1120
      NX=1                                                              COPE1121
      NVLB=LOCR(2)                                                      COPE1122
      NVUB=LOCR(3)                                                      COPE1123
      NNSCAL=LOCR(4)                                                    COPE1124
      NDF=LOCR(23)                                                      COPE1125
      NG=NDF+NN1                                                        COPE1126
      NA=NG+NN2                                                         COPE1127
      NS=NA+NN1*NN3                                                     COPE1128
      NG1=NS+NN1                                                        COPE1129
      NG2=NG1+NN2                                                       COPE1130
      NC=NG2+NN2                                                        COPE1131
      NB=NC+NN4                                                         COPE1132
      NISC=LOCI(4)                                                      COPE1133
      NIC=LOCI(23)                                                      COPE1134
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      NMS1=NIC+NN3                                                      COPE1135
C     AMULT, BLU, IDSGN, NSDGN, ICON                                    COPE1136
      NAMULT=LOCR(5)                                                    COPE1137
      NBLU=LOCR(6)                                                      COPE1138
      NIDSGN=1                                                          COPE1139
      NNDSGN=LOCI(2)                                                    COPE1140
      NICON=LOCI(3)                                                     COPE1141
C     ------------------------------------------------------------------COPE1142
C                           OPTIMIZATION                                COPE1143
C     ------------------------------------------------------------------COPE1144
      IGOTO=0                                                           COPE1145
C     CALL CONMIN (X,VLB,VUB,G,SCAL,DF,A,S,G1,G2,B,C,ISC,IC,MS1,N1,N2,N3COPE1146
C    *,N4,N5)                                                           COPE1147
   10 CONTINUE                                                          COPE1148
      CALL CONMIN (RA(NX),RA(NVLB),RA(NVUB),RA(NG),RA(NNSCAL),RA(NDF),RACOPE1149
     1(NA),RA(NS),RA(NG1),RA(NG2),RA(NB),RA(NC),IA(NISC),IA(NIC),IA(NMS1COPE1150
     2),NN1,NN2,NN3,NN4,NN5)                                            COPE1151
C     ANALIZE.                                                          COPE1152
      CALL COPE03 (ARRAY,NARRAY,RA(NX),RA(NG),RA(NAMULT),RA(NBLU),IA(NIDCOPE1153
     1SGN),IA(NNDSGN),IA(NICON),NN1,NN2,NN6,NN7,ITER,OBJ)               COPE1154
      IF (IGOTO.GT.0) GO TO 10                                          COPE1155
      RETURN                                                            COPE1156
      END                                                               COPE1157
      SUBROUTINE COPE03 (ARRAY,NARRAY,X,G,AMULT,BLU,IDSGN,NDSGN,ICON,NN1COPE1158
     1,NN2,NN6,NN7,ITER,OBJ)                                            COPE1159
      COMMON /COPES3/ SGNOPT,NCALC,IOBJ,NSV,NSOBJ,NCONA,N2VX,M2VX,N2VY,MCOPE1160
     12VY,N2VAR,IPSENS,IP2VAR,IPDBG,NACMX1,NDVTOT,LOCR(25),LOCI(25),ISCRCOPE1161
     21,ISCR2,NXAPRX,NPS,NPFS,NPA,NF,INOM,IPAPRX,KMIN,KMAX,XFACT1,XFACT2COPE1162
     3,NAN2,NAN3,NPMAX,NPTOT,JNOM,MAXTRM                                COPE1163
      DIMENSION ARRAY(NARRAY), X(NN1), G(NN2), AMULT(NN6), BLU(4,NN7)   COPE1164
      DIMENSION IDSGN(NN6), NDSGN(NN6), ICON(NN7)                       COPE1165
C     ******************************************************************COPE1166
C     BUFFER BETWEEN CONMIN AND COPES FUNCTION EVALUATION.              COPE1167
C     ******************************************************************COPE1168
C     BY G. N. VANDERPLAATS                          MAR., 1973.        COPE1169
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE1170
C     INITIAL ANALYSIS HAS BEEN DONE.  IF ITER = 0, GO EVALUATE         COPE1171
C     OBJECTIVE AND CONSTRAINTS.                                        COPE1172
      IF (ITER.EQ.0) ITER1=0                                            COPE1173
      IF (ITER.LT.1) GO TO 40                                           COPE1174
C     ------------------------------------------------------------------COPE1175
C                PRINT OUTPUT IF DEBUG CONTROL IS TURNED ON             COPE1176
C     ------------------------------------------------------------------COPE1177
C     DEBUG OUTPUT AS REQUIRED.                                         COPE1178
      IF (IPDBG.LT.1) GO TO 20                                          COPE1179
      IF (ITER.EQ.ITER1.OR.ITER.LE.1) GO TO 20                          COPE1180
      XSAV2=X(1)                                                        COPE1181
      X(1)=XSAV1                                                        COPE1182
      N5=LOCR(5)                                                        COPE1183
      M2=LOCI(2)                                                        COPE1184
      DO 10 I=1,NDVTOT                                                  COPE1185
      N=NDSGN(I)                                                        COPE1186
      M=IDSGN(I)                                                        COPE1187
      IF (N.GT.0) ARRAY(M)=X(N)*AMULT(I)                                COPE1188
   10 CONTINUE                                                          COPE1189
      ICALC=3                                                           COPE1190
      NAN3=NAN3+1                                                       COPE1191
      CALL ANALIZ (ICALC)                                               COPE1192
      WRITE (6,70)                                                      COPE1193
      ITER1=ITER                                                        COPE1194
      X(1)=XSAV2                                                        COPE1195
   20 CONTINUE                                                          COPE1196
C     ------------------------------------------------------------------COPE1197
C              TRANSFER DESIGN VARIABLES TO USER APRAY                  COPE1198
C     ------------------------------------------------------------------COPE1199
      N5=LOCR(5)                                                        COPE1200
      M2=LOCI(2)                                                        COPE1201
      DO 30 I=1,NDVTOT                                                  COPE1202
      N=NDSGN(I)                                                        COPE1203
      M=IDSGN(I)                                                        COPE1204
      IF (N.GT.0) ARRAY(M)=X(N)*AMULT(I)                                COPE1205
   30 CONTINUE                                                          COPE1206
C     ------------------------------------------------------------------COPE1207
C                                 ANALIZE                               COPE1208
C     ------------------------------------------------------------------COPE1209
      ICALC=2                                                           COPE1210
      NAN2=NAN2+1                                                       COPE1211
      CALL ANALIZ (ICALC)                                               COPE1212
C     SAVE X(1).                                                        COPE1213
      XSAV1=X(1)                                                        COPE1214
C     ------------------------------------------------------------------COPE1215
C                                OBJECTIVE                              COPE1216
C     ------------------------------------------------------------------COPE1217
   40 CONTINUE                                                          COPE1218
      OBJ=-SGNOPT*ARRAY(IOBJ)                                           COPE1219
      IF (NCONA.EQ.0) RETURN                                            COPE1220
C     ------------------------------------------------------------------COPE1221
C                            CONSTRAINT VALUES                          COPE1222
C     ------------------------------------------------------------------COPE1223
      J=1                                                               COPE1224
      N=0                                                               COPE1225
      DO 60 I=1,NCONA                                                   COPE1226
C     PARAMETER IDENTIFIER.                                             COPE1227
      NN=ICON(I)                                                        COPE1228
      CC=ARRAY(NN)                                                      COPE1229
C     LOWER BOUND.                                                      COPE1230
      BB=BLU(1,I)                                                       COPE1231
      IF (BB.LT.-1.0E+15) GO TO 50                                      COPE1232
C     NORMALIZATION FACTOR.                                             COPE1233
      C1=BLU(2,I)                                                       COPE1234
C     CONSTRAINT VALUE.                                                 COPE1235
      N=N+1                                                             COPE1236
      G(N)=(BB-CC)/C1                                                   COPE1237
C     UPPER BOUND.                                                      COPE1238
   50 BB=BLU(3,I)                                                       COPE1239
C     NORMALIZATION FACTOR.                                             COPE1240
      C1=BLU(4,I)                                                       COPE1241
      J=J+4                                                             COPE1242
      IF (BB.GT.1.0E+15) GO TO 60                                       COPE1243
C     CONSTRAINT VALUE.                                                 COPE1244
      N=N+1                                                             COPE1245
      G(N)=(CC-BB)/C1                                                   COPE1246
   60 CONTINUE                                                          COPE1247
      RETURN                                                            COPE1248
C                                                                       COPE1249
C     ------------------------------------------------------------------COPE1250
C                               FORMATS                                 COPE1251
C     ------------------------------------------------------------------COPE1252
   70 FORMAT (1H1)                                                      COPE1253
      END                                                               COPE1254
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      SUBROUTINE COPE04 (ARRAY,NARRAY,SENS,NSENSZ,ISENS,NSENS,TEMP,NN8,NCOPE1255
     1N9,NN10,RA,IA,NDRA,NDIA)                                          COPE1256
      COMMON /COPES1/ TITLE(20)                                         COPE1257
      COMMON /COPES3/ SGNOPT,NCALC,IOBJ,NSV,NSOBJ,NCONA,N2VX,M2VX,N2VY,MCOPE1258
     12VY,N2VAR,IPSENS,IP2VAR,IPDBG,NACMX1,NDVTOT,LOCR(25),LOCI(25),ISCRCOPE1259
     21,ISCR2,NXAPRX,NPS,NPFS,NPA,NF,INOM,IPAPRX,KMIN,KMAX,XFACT1,XFACT2COPE1260
     3,NAN2,NAN3,NPMAX,NPTOT,JNOM,MAXTRM                                COPE1261
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCOPE1262
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCOPE1263
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                               COPE1264
      DIMENSION ARRAY(NARRAY), SENS(NN8), NSENSZ(NN9), ISENS(NN10), NSENCOPE1265
     1S(NN10), TEMP(1), RA(NDRA), IA(NDIA)                              COPE1266
C     ******************************************************************COPE1267
C     ROUTINE TO PROVIDE SENSITIVITY INFORMATION WITH RESPECT TO        COPE1268
C     A PRESCRIBED SET OF DESIGN VARIABLES.                             COPE1269
C     ******************************************************************COPE1270
C     BY G. N. VANDERPLAATS                           MAR., 1973.       COPE1271
C     STORE OUTPUT ON UNIT ISCR1.                                       COPE1272
      REWIND ISCP1                                                      COPE1273
      IF (IPDBG.LT.1) IPRINT=0                                          COPE1274
C     ------------------------------------------------------------------COPE1275
C                   WRITE BASIC INFORMATION ON UNIT ISCR1               COPE1276
C     ------------------------------------------------------------------COPE1277
C     TITLE.                                                            COPE1278
      WRITE (ISCR1,330) (TITLE(I),I=1,20)                               COPE1279
C     NCALC, NSV, NSOBJ                                                 COPE1280
      WRITE (ISCR1,340) NCALC,NSV,NSOBJ                                 COPE1281
C     ISENS(I),I=1,NSV.                                                 COPE1282
      WRITE (ISCR1,340) (ISENS(I),I=1,NSV)                              COPE1283
C     NSENSZ(I),I=1,NSOBJ.                                              COPE1284
      WRITE (ISCR1,340) (NSENSZ(I),I=1,NSOBJ)                           COPE1285
      JCALC=3                                                           COPE1286
      ICALC=2                                                           COPE1287
      NDVSAV=NDV                                                        COPE1288
C     ------------------------------------------------------------------COPE1289
C     **********                     NOMINAL                  **********COPE1290
C     ------------------------------------------------------------------COPE1291
      IF (NCALC.EQ.5) GO TO 10                                          COPE1292
C     STANDARD SENSITIVITY.                                             COPE1293
      NAN2=NAN2+1                                                       COPE1294
      CALL ANALIZ (ICALC)                                               COPE1295
      IF (IPSENS.GT.0) NAN3=NAN3+1                                      COPE1296
      IF (IPSENS.GT.0) CALL ANALIZ (JCALC)                              COPE1297
      GO TO 130                                                         COPE1298
   10 CONTINUE                                                          COPE1299
C     OPTIMUM SENSITIVITY.                                              COPE1300
C     SAVE X, VLB, VUB AND SCAL IN TEMPORARY STORAGE.                   COPE1301
      N=4*NDV+8                                                         COPE1302
      L=LOCR(24)                                                        COPE1303
      DO 20 I=1,N                                                       COPE1304
      RA(L)=RA(I)                                                       COPE1305
   20 L=L+1                                                             COPE1306
C     SAVE IDSGN AND NDSGN IN TEMPORARY STORAGE.                        COPE1307
      N=2*NDVTOT                                                        COPE1308
      L=LOCI(24)                                                        COPE1309
      DO 30 I=1,N                                                       COPE1310
      IA(L)=IA(I)                                                       COPE1311
   30 L=L+1                                                             COPE1312
C     SHIFT DESIGN VARIABLE INFORMATION IF ANY SENSITIVITY VARIABLE IS  COPE1313
C     ALSO A DESIGN VARIABLE.                                           COPE1314
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      NDV2=NDV+2                                                        COPE1315
      DO 90 I=1,NSV                                                     COPE1316
C     GLOBAL SENSITIVITY VARIABLE LOCATION.                             COPE1317
      N=ISENS(I)                                                        COPE1318
C     IS THIS ALSO A DESIGN VARIABLE.                                   COPE1319
      M2=LOCI(2)                                                        COPE1320
      DO 40 J=1,NDVTOT                                                  COPE1321
      L=IA(J)                                                           COPE1322
      IF (L.EQ.N) GO TO 50                                              COPE1323
   40 M2=M2+1                                                           COPE1324
C     SENSITIVITY VARIABLE IS NOT A DESIGN VARIABLE.                    COPE1325
      GO TO 90                                                          COPE1326
   50 CONTINUE                                                          COPE1327
C     SENSITIVITY VARIABLE IS ALSO A DESIGN VARIABLE.                   COPE1328
      NDV=NDV-1                                                         COPE1329
      IDV=IA(M2)                                                        COPE1330
C     ELIMINATE THIS DESIGN VARIABLE AND REDUCE HIGHER NUMBER DESIGN    COPE1331
C     VARIABLES BY ONE.                                                 COPE1332
      M2=LOCI(2)                                                        COPE1333
      DO 70 J=1,NDVTOT                                                  COPE1334
      IF (IA(M2).NE.IDV) GO TO 60                                       COPE1335
      IA(M2)=0                                                          COPE1336
C     SET DESIGN VARIABLE VALUES TO SENSITIVITY VARIABLE VALUE.         COPE1337
      K=IA(J)                                                           COPE1338
      M5=LOCR(5)+J-1                                                    COPE1339
      ARRAY(K)=ARRAY(N)*RA(M5)                                          COPE1340
   60 CONTINUE                                                          COPE1341
      IF (IA(M2).GT.IDV) IA(M2)=IA(M2)-1                                COPE1342
   70 M2=M2+1                                                           COPE1343
      IF (IDV.EQ.NDV) GO TO 90                                          COPE1344
C     SHIFT X, VLB, VUB AND SCAL.                                       COPE1345
      DO 80 J=IDV,NDV                                                   COPE1346
C     X.                                                                COPE1347
      RA(J)=RA(J+1)                                                     COPE1348
C     VLB.                                                              COPE1349
      K=J+NDV2                                                          COPE1350
      RA(K)=RA(K+1)                                                     COPE1351
C     VUB.                                                              COPE1352
      K=K+NDV2                                                          COPE1353
      RA(K)=RA(K+1)                                                     COPE1354
C     SCAL.                                                             COPE1355
      K=K+NDV2                                                          COPE1356
   80 RA(K)=RA(K+1)                                                     COPE1357
   90 CONTINUE                                                          COPE1358
      NAN2=NAN2+1                                                       COPE1359
      CALL ANALIZ (ICALC)                                               COPE1360
      IF (NDV.LE.0) GO TO 100                                           COPE1361
      CALL COPE02 (ARRAY,RA,IA,NARRAY,NDRA,NDIA)                        COPE1362
  100 CONTINUE                                                          COPE1363
      IF (IPSENS.GT.0) NAN3=NAN3+1                                      COPE1364
      IF (IPSENS.GT.0) CALL ANALIZ (JCALC)                              COPE1365
C     PUT X, VLB, VUB AND SCAL BACK.                                    COPE1366
      L=LOCR(24)                                                        COPE1367
      N=4*NDVSAV+8                                                      COPE1368
      DO 110 I=1,N                                                      COPE1369
      RA(I)=RA(L)                                                       COPE1370
  110 L=L+1                                                             COPE1371
C     PUT IDSGN AND NDSGN BACK.                                         COPE1372
      N=2*NDVTOT                                                        COPE1373
      L=LOCI(24)                                                        COPE1374
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      DO 120 I=1,N                                                      COPE1375
      IA(I)=IA(L)                                                       COPE1376
  120 L=L+1                                                             COPE1377
  130 CONTINUE                                                          COPE1378
C     ------------------------------------------------------------------COPE1379
C                    W?ITE NOMINAL RESULTS ON UNIT ISCR1                COPE1380
C     ------------------------------------------------------------------COPE1381
C     SENS(I,1).                                                        COPE1382
      M=1                                                               COPE1383
      DO 140 I=1,NSV                                                    COPE1384
      TEMP(I)=SENS(M)                                                   COPE1385
  140 M=M+NSENS(I)                                                      COPE1386
      WRITE (ISCR1,350) (TEMP(I),I=1,NSV)                               COPE1387
C     SENSITIVITY OBJECTIVES, OBJZ.                                     COPE1388
      DO 150 I=1,NSOBJ                                                  COPE1389
      M=NSENSZ(I)                                                       COPE1390
  150 TEMP(I)=ARRAY(M)                                                  COPE1391
      WRITE (ISCR1,350) (TEMP(I),I=1,NSOBJ)                             COPE1392
C     ------------------------------------------------------------------COPE1393
C     **********                   SENSITIVITIES              **********COPE1394
C     ------------------------------------------------------------------COPE1395
      NSVAL1=0                                                          COPE1396
      DO 320 II=1,NSV                                                   COPE1397
C     GLOBAL LOCATION OF SENSITIVITY VARIABLE.                          COPE1398
      ISENSV=ISENS(II)                                                  COPE1399
C     NUMBER OF SENSITIVITY VARIABLES, NSENSV.                          COPE1400
      NSENSV=NSENS(II)                                                  COPE1401
C     WRITE ISENSV AND NSENSV-1 ON UNIT ISCR1.                          COPE1402
      NSENSI=NSENSV-1                                                   COPE1403
      WRITE (ISCR1,340) ISENSV,NSENSI                                   COPE1404
      IF (NSENSV.LE.1) GO TO 320                                        COPE1405
      ID1=0                                                             COPE1406
      IF (NCALC.NE.5) GO TO 210                                         COPE1407
C     IS THIS SENSITIVITY VARIABLE ALSO A DESIGN VARIABLE.              COPE1408
      NDV=NDVSAV                                                        COPE1409
      DO 160 I=1,NDVTOT                                                 COPE1410
      JJ=I                                                              COPE1411
      IF (IA(I).EQ.ISENSV) GO TO 170                                    COPE1412
  160 CONTINUE                                                          COPE1413
C     ISENSV IS NOT A DESIGN VARIABLE.                                  COPE1414
      GO TO 210                                                         COPE1415
  170 CONTINUE                                                          COPE1416
C     ISENSV IS A DESIGN VARIABLE.  MODIFY OPTIMIZATION INFORMATION.    COPE1417
      NDV2=NDV+2                                                        COPE1418
      NDV=NDV-1                                                         COPE1419
C     SAVE X, VLB, VUB AND SCAL FOR THIS DESIGN VARIABLE AND SHIFT      COPE1420
C     REMAINING VARIABLES.                                              COPE1421
C     SAVE.                                                             COPE1422
      M2=LOCI(2)+JJ-1                                                   COPE1423
      ID1=IA(M2)                                                        COPE1424
      SAVX=RA(ID1)                                                      COPE1425
      K=ID1+NDV2                                                        COPE1426
      SAVL=RA(K)                                                        COPE1427
      K=K+NDV2                                                          COPE1428
      SAVU=RA(K)                                                        COPE1429
      K=K+NDV2                                                          COPE1430
      SAVS=RA(K)                                                        COPE1431
C     SHIFT                                                             COPE1432
      IF (ID1.GT.NDV) GO TO 190                                         COPE1433
      DO 180 I=ID1,NDV                                                  COPE1434
      RA(I)=RA(I+1)                                                     COPE1435
      K=I+NDV2                                                          COPE1436
      RA(K)=RA(K+1)                                                     COPE1437
      K=K+NDV2                                                          COPE1438
      RA(K)=RA(K+1)                                                     COPE1439
      K=K+NDV2                                                          COPE1440
 180  RA(K)=RA(K+1)                                                     COPE1441
 190  CONTINUE                                                          COPE1442
C     MODIFY NDSGN.                                                     COPE1443
      M2=LOCI(2)                                                        COPE1444
      DO 200 I=1,NDVTOT                                                 COPE1445
      IF (IA(M2).EQ.ID1) IA(M2)=0                                       COPE1446
      IF (IA(M2).GT.ID1) IA(M2)=IA(M2)-1                                COPE1447
 200  M2=M2+1                                                           COPE1448
 210  CONTINUE                                                          COPE1449
C     ------------------------------------------------------------------COPE1450
C              VARY THE VALUE OF THE SENSITIVITY PARAMETER              COPE1451
C     ------------------------------------------------------------------COPE1452
      NSVAL1=NSVAL1+1                                                   COPE1453
      NSVALN=NSVAL1                                                     COPE1454
      DO 280 JJ=2,NSENSV                                                COPE1455
      NSVAL1=NSVAL1+1                                                   COPE1456
      ARRAY(ISENSV)=SENS(NSVAL1)                                        COPE1457
C     WRITE SENS(I,J) ON UNIT ISCR1.                                    COPE1458
      WRITE (ISCR1,350) SENS(NSVAL1)                                    COPE1459
C     ANALIZE.                                                          COPE1460
      IF (NCALC.EQ.5) GO TO 220                                         COPE1461
C     STANDARD SENSITIVITY.                                             COPE1462
      NAN2=NAN2+1                                                       COPE1463
      CALL ANALIZ (ICALC)                                               COPE1464
      IF (IPSENS.GT.0) NAN3=NAN3+1                                      COPE1465
      IF (IPSENS.GT.0) CALL ANALIZ (JCALC)                              COPE1466
      GO TO 260                                                         COPE1467
 220  CONTINUE                                                          COPE1468
C     OPTIMUM SENSITIVITY.                                              COPE1469
      IF (NDV.EQ.NDVSAV) GO TO 240                                      COPE1470
C     SET LINKED DESIGN VARIABLE VALUES TO PRESCRIBED VALUE.            COPE1471
      M2=LOCI(2)                                                        COPE1472
      DO 230 I=1,NDVTOT                                                 COPE1473
      IF (IA(M2).NE.0) GO TO 230                                        COPE1474
      L=IA(I)                                                           COPE1475
      M5=LOCR(5)+I-1                                                    COPE1476
      ARRAY(L)=ARRAY(ISENSV)*RA(M5)                                     COPE1477
 230  M2=M2+1                                                           COPE1478
 240  CONTINUE                                                          COPE1479
      NAN2=NAN2+1                                                       COPE1480
      CALL ANALIZ (ICALC)                                               COPE1481
      IF (NDV.LE.0) GO TO 250                                           COPE1482
      CALL COPE02 (ARRAY,RA,IA,NARRAY,NDRA,NDIA)                        COPE1483
 250  CONTINUE                                                          COPE1484
      IF (IPSENS.GT.0) NAN3=NAN3+1                                      COPE1485
      IF (IPSENS.GT.0) CALL ANALIZ (JCALC)                              COPE1486
 260  CONTINUE                                                          COPE1487
C     ------------------------------------------------------------------COPE1488
C               WRITE SENSITIVITY RESULTS ON UNIT ISCR1                 COPE1489
C     ------------------------------------------------------------------COPE1490
C     OBJZ.                                                             COPE1491
      DO 270 I=1,NSOBJ                                                  COPE1492
      M=NSENSZ(I)                                                       COPE1493
 270  TEMP(I)=ARRAY(M)                                                  COPE1494
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      WRITE (ISCR1,350) (TEMP(I),I=1,NSOBJ)                             COPE1495
 280  CONTINUE                                                          COPE1496
      ARRAY(ISENSV)=SENS(NSVALN)                                        COPE1497
      IF (NCALC.NE.5.OR.ID1.EQ.0) GO TO 320                             COPE1498
C     RESTORE X, VLB, VUB AND SCAL.                                     COPE1499
      NDV=NDVSAV                                                        COPE1500
      IF (ID1.EQ.NDV) GO TO 300                                         COPE1501
      L=NDV-1                                                           COPE1502
      L1=L                                                              COPE1503
      DO 290 I=ID1,L1                                                   COPE1504
      RA(L+1)=RA(L)                                                     COPE1505
      K=L+NDV2                                                          COPE1506
      RA(K+1)=RA(K)                                                     COPE1507
      K=K+NDV2                                                          COPE1508
      RA(K+1)=PA(K)                                                     COPE1509
      K=K+NDV2                                                          COPE1510
      RA(K+1)=RA(K)                                                     COPE1511
 290  L=L-1                                                             COPE1512
      RA(ID1)=SAVX                                                      COPE1513
      K=ID1+NDV2                                                        COPE1514
      RA(K)=SAVL                                                        COPE1515
      K=K+NDV2                                                          COPE1516
      RA(K)=SAVU                                                        COPE1517
      K=K+NDV2                                                          COPE1518
      RA(K)=SAVS                                                        COPE1519
 300  CONTINUE                                                          COPE1520
C     RESTORE NDSGN.                                                    COPE1521
      M2=LOCI(2)                                                        COPE1522
      DO 310 I=1,NDVTOT                                                 COPE1523
      IF (IA(M2).GE.ID1) IA(M2)=IA(M2)+1                                COPE1524
      IF (IA(M2).EQ.0) IA(M2)=ID1                                       COPE1525
 310  M2=M2+1                                                           COPE1526
 320  CONTINUE                                                          COPE1527
      RETURN                                                            COPE1528
C     ------------------------------------------------------------------COPE1529
C                                FORMATS                                COPE1530
C     ------------------------------------------------------------------COPE1531
 330  FORMAT (20A4)                                                     COPE1532
 340  FORMAT (16I5)                                                     COPE1533
 350  FORMAT (5E15.8)                                                   COPE1534
      END                                                               COPE1535
      SUBROUTINE COPE05 (RA,IA,NDRA,NDIA,ISCR1)                         COPE1536
      DIMENSION RA(NDRA), IA(NDIA)                                      COPE1537
C     ******************************************************************COPE1538
C     ROUTINE TO PRINT SENSITIVITY INFORMATION STORED ON UNIT ISCR1.    COPE1539
C     ******************************************************************COPE1540
C     BY G. N. VANDERPLAATS                           JULY, 1974.       COPE1541
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE1542
      REWIND ISCR1                                                      COPE1543
C     ------------------------------------------------------------------COPE1544
C                        GENERAL INFORMATION                            COPE1545
C     ------------------------------------------------------------------COPE1546
C     TITLE.                                                            COPE1547
      READ (ISCR1,70) (RA(I),I=1,20)                                    COPE1548
C     NCALC, NSV, NSOBJ                                                 COPE1549
      READ (ISCR1,80) NCALC,NSV,NSOBJ                                   COPE1550
      IF (NCALC.NE.3.AND.NCALC.NE.5) RETURN                             COPE1551
      IF (NCALC.EQ.3) WRITE (6,90)                                      COPE1552
      IF (NCALC.EQ.5) WRITE (6,50)                                      COPE1553
      WRITE (6,60) (RA(I),I=1,20)                                       COPE1554
      WRITE (6,100) NSV,NSOBJ                                           COPE1555
C     ISENS(I),I=1,NSV.                                                 COPE1556
      READ (ISCR1,80) (IA(I),I=1,NSV)                                   COPE1557
      WRITE (6,110)                                                     COPE1558
      WRITE (6,120) (IA(I),I=1,NSV)                                     COPE1559
C     NSENSZ(I),I=1,NSOBJ.                                              COPE1560
      READ (ISCR1,80) (IA(I),I=1,NSOBJ)                                 COPE1561
      WRITE (6,130)                                                     COPE1562
      WRITE (6,120) (IA(I),I=1,NSOBJ)                                   COPE1563
C     ----------------------------------------------------------------- COPE1564
C                              NOMINAL INFORMATION                      COPE1565
C     ----------------------------------------------------------------- COPE1566
C     SENS(I),I=1,NSV.                                                  COPE1567
      READ (ISCR1,140) (RA(I),I=1,NSV)                                  COPE1568
      WRITE (6,150)                                                     COPE1569
      WRITE (6,160) (RA(I),I=1,NSV)                                     COPE1570
C     OBJZ(I),I=1,NSOBJ.                                                COPE1571
      READ (ISCR1,140) (RA(I),I=1,NSOBJ)                                COPE1572
      WRITE (6,170)                                                     COPE1573
      WRITE (6,160) (RA(I),I=1,NSOBJ)                                   COPE1574
C     ------------------------------------------------------------------COPE1575
C     **********         SENSITIVITY INFORMATION              **********COPE1576
C     ------------------------------------------------------------------COPE1577
      WRITE (6,180)                                                     COPE1578
      DO 40 ISENS=1,NSV                                                 COPE1579
C     ISENSI, NSENSI                                                    COPE1580
      READ (ISCR1,80) ISENSI,NSENSI                                     COPE1581
      WRITE (6,190) ISENSI                                              COPE1582
      IF (NSENSI.EQ.0) WRITE (6,200)                                    COPE1583
      IF (NSENSI.EQ.0) GO TO 40                                         COPE1584
      DO 30 JJ=1,NSENSI                                                 COPE1585
C     SENS(I,J).                                                        COPE1586
      READ (ISCR1,140) SENSIJ                                           COPE1587
C     OBJZ(I),I=1,NSOBJ.                                                COPE1588
      READ (ISCR1,140) (RA(I),I=1,NSOBJ)                                COPE1589
      N=MIN0(4,NSOBJ)                                                   COPE1590
      WRITE (6,210) SENSIJ,(RA(I),I=1,N)                                COPE1591
      N=(NSOBJ-1)/4                                                     COPE1592
      IF (N.LT.1) GO TO 20                                              COPE1593
      L1=5                                                              COPE1594
      DO 10 I=1,N                                                       COPE1595
      L2=L1+3                                                           COPE1596
      L2=MIN0(L2,NSOBJ)                                                 COPE1597
      WRITE (6,220) (RA(J),J=L1,L2)                                     COPE1598
10    L1=L1+4                                                           COPE1599
20    CONTINUE                                                          COPE1600
30    CONTINUE                                                          COPE1601
40    CONTINUE                                                          COPE1602
      RETURN                                                            COPE1603
C     ------------------------------------------------------------------COPE1604
C                                    FORMATS                            COPE1605
C     ------------------------------------------------------------------COPE1606
50    FORMAT (1H1,4X,46HOPTIMUM SENSITIVITY ANALYSIS RESULTS (NCALC=5)) COPE1607
60    FORMAT (//5X,5HTITLE/5X,20A4)                                     COPE1608
70    FORMAT (20A4)                                                     COPE1609
80    FORMAT (16I5)                                                     COPE1610
90    FORMAT (1H1,4X,47HSTANDARD SENSITIVITY ANALYSIS RESULTS (NCALC=3))COPE1611
100   FORMAT (//5X,36HNUMBER OF SENSITIVITY VARIABLES, NSV,9X,1H=,I5/5X,COPE1612
     139HNUMBER OF SENSITIVITY OBJECTIVES, NSOBJ,6X,1H=,I5)             COPE1613
110   FORMAT (//5X,52HGLOBAL NUMBERS ASSOCIATED WITH SENSITIVITY VARIABLCOPE1614
     1ES)                                                               COPE1615
120   FORMAT (5X,10I5)                                                  COPE1616
130   FORMAT (//5X,53HGLOBAL NUMBERS ASSOCIATED WITH SENSITIVITY OBJECTICOPE1617
     1VES)                                                              COPE1618
140   FORMAT (5E15.8)                                                   COPE1619
150   FORMAT (////5X,26HNOMINAL DESIGN INFORMATION//5X,31HVALUES OF SENSCOPE1620
     1ITIVITY VARIABLES)                                                COPE1621
160   FORMAT (5X,5E13.5)                                                COPE1622
170   FORMAT (//5X,41HVALUES OF SENSITIVITY OBJECTIVE FUNCTIONS)        COPE1623
180   FORMAT (/////5X,28HSENSITIVITY ANALYSIS RESULTS)                  COPE1624
190   FORMAT (//5X,15HGLOBAL VARIABLE,I5//10X,1HX,20X,4HF(X))           COPE1625
200   FORMAT (/5X,35HTHE NOMINAL VALUE IS THE ONLY VALUE/5X,27HSPECIFIEDCOPE1626
     1 FOR THIS VARIABLE)                                               COPE1627
210   FORMAT (/3X,E12.4,3X,4E13.4)                                      COPE1628
220   FORMAT (18X,4E13.4)                                               COPE1629
      END                                                               COPE1630
      SUBROUTINE COPE06 (ARRAY,RA,IA,NARRAY,NDRA,NDIA)                  COPE1631
      COMMON /COPES1/ TITLE(20)                                         COPE1632
      COMMON /COPES3/ SGNOPT,NCALC,IOBJ,NSV,NSOBJ,NCONA,N2VX,M2VX,N2VY,MCOPE1633
     12VY,N2VAR,IPSENS,IP2VAR,IPDBG,NACMX1,NDVTOT,LOCR(25),LOCI(25),ISCRCOPE1634
     21,ISCR2,NXAPRX,NPS,NPFS,NPA,NF,INOM,IPAPRX,KMIN,KMAX,XFACT1,XFACT2COPE1635
     3,NAN2,NAN3,NFMAX,NPTOT,JNOM,MAXTRM                                COPE1636
      DIMENSION ARRAY(NARRAY), RA(NDRA), IA(NDIA)                       COPE1637
C     ******************************************************************COPE1638
C     ROUTINE TO CALCULATE FUNCTIONS OF TWO DESIGN VARIABLES FOR ALL    COPE1639
C     COMBINATIONS OF A SET OF PRESCRIBED VALUES OF THESE VARIABLES.    COPE1640
C     ******************************************************************COPE1641
C     WRITE OUTPUT INFORMATION ON SCRATCH UNIT ISCR1.                   COPE1642
C     BY G. N. VANDERPLAATS                           AUG., 1974.       COPE1643
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE1644
      REWIND ISCR1                                                      COPE1645
C     ------------------------------------------------------------------COPE1646
C                               UNIT ISCR1 WRITE                        COPE1647
C     ------------------------------------------------------------------COPE1648
      WRITE (ISCR1,40) (TITLE(I),I=1,20)                                COPE1649
      WRITE (ISCR1,50) NCALC,N2VAR,M2VX,N2VX,M2VY,N2VY                  COPE1650
C     N2VZ.                                                             COPE1651
      M20=LOCI(20)                                                      COPE1652
      M21=LOCI(21)-1                                                    COPE1653
      WRITE (ISCR1,50) (IA(I),I=M20,M21)                                COPE1654
C     ------------------------------------------------------------------COPE1655
C                           TWO-VARIABLE FUNCTION SPACE                 COPE1656
C     ------------------------------------------------------------------COPE1657
      ICALC=2                                                           COPE1658
      KCALC=3                                                           COPE1659
      ISIGN=1                                                           COPE1660
      N20=LOCR(20)                                                      COPE1661
      N21=LOCP(21)-1                                                    COPE1662
      DO 30 I=1,M2VX                                                    COPE1663
      ARRAY(N2VX)=RA(N20)                                               COPE1664
      DO 20 J=1,M2VY                                                    COPE1665
      N21=N21+ISIGN                                                     COPE1666
      ARRAY(N2VY)=RA(N21)                                               COPE1667
C     ANALIZE.                                                          COPE1668
      NAN2=NAN2+1                                                       COPE1669
      CALL ANALIZ (ICALC)                                               COPE1670
      IF (IP2VAR.GT.0) CALL ANALIZ (KCALC)                              COPE1671
      IF (IP2VAR.GT.0) NAN3=NAN3+1                                      COPE1672
C     ------------------------------------------------------------------COPE1673
C                                 UNIT ISCR1 WRITE                      COPE1674
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C     ------------------------------------------------------------------COPE1675
C     WRITE X, Y.                                                       COPE1676
      WRITE (ISCR1,60) RA(N20),RA(N21)                                  COPE1677
C     F(X,Y) VALUES.                                                    COPE1678
      N23=LOCR(23)                                                      COPE1679
      N24=N23                                                           COPE1680
      M20=LOCI(20)                                                      COPE1681
      DO 10 K=1,N2VAR                                                   COPE1682
      N=IA(M20)                                                         COPE1683
      RA(N24)=ARRAY(N)                                                  COPE1684
      N24=N24+1                                                         COPE1685
      M20=M20+1                                                         COPE1686
10    CONTINUE                                                          COPE1687
      N24=N23+N2VAR-1                                                   COPE1688
      WRITE (ISCR1,60) (RA(K),K=N23,N24)                                COPE1689
20    CONTINUE                                                          COPE1690
      N21=N21+ISIGN                                                     COPE1691
      N20=N20+1                                                         COPE1692
      ISIGN=-ISIGN                                                      COPE1693
30    CONTINUE                                                          COPE1694
      RETURN                                                            COPE1695
C     ------------------------------------------------------------------COPE1696
C                                FORMATS                                COPE1697
C     ------------------------------------------------------------------COPE1698
C                                                                       COPE1699
C                                                                       COPE1700
C                                                                       COPE1701
40    FORMAT (20A4)                                                     COPE1702
50    FORMAT (16I5)                                                     COPE1703
60    FORMAT (5E15.8)                                                   COPE1704
      END                                                               COPE1705
      SUBROUTINE COPE07 (RA,IA,NDRA,NDIA,ISCR1)                         COPE1706
      DIMENSION RA(NDRA), IA(NDIA)                                      COPE1707
C     ******************************************************************COPE1708
C     ROUTINE TO PRINT TWO VARIABLE FUNCTION SPACE INFORMATION STORED ONCOPE1709
C     UNIT ISCR1.                                                       COPE1710
C     ******************************************************************COPE1711
C     BY G. N. VANDERPLAATS                          AUG., 1974.        COPE1712
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE1713
      REWIND ISCR1                                                      COPE1714
C     ------------------------------------------------------------------COPE1715
C                        GENERAL INFORMATION                            COPE1716
C     ------------------------------------------------------------------COPE1717
C     TITLE.                                                            COPE1718
      READ (ISCR1,60) (RA(I),I=1,20)                                    COPE1719
      READ (ISCR1,70) NCALC,N2VAR,M2VX,N2VX,M2VY,N2VY                   COPE1720
      IF (NCALC.NE.4.AND.NCALC.NE.6) RETURN                             COPE1721
      WRITE (6,50)                                                      COPE1722
      WRITE (6,40) (RA(I),I=1,20)                                       COPE1723
C     N2VZ(I),I=1,N2VAR.                                                COPE1724
      READ (ISCR1,70) (IA(I),I=1,N2VAR)                                 COPE1725
C     N2VX, N2VY.                                                       COPE1726
      WRITE (6,120) N2VX,N2VY                                           COPE1727
C     N2VZ.                                                             COPE1728
      WRITE (6,130)                                                     COPE1729
      WRITE (6,80) (IA(I),I=1,N2VAR)                                    COPE1730
C     ------------------------------------------------------------------COPE1731
C               TWO-VARIABLE FUNCTION SPACE INFORMATION                 COPE1732
C     ------------------------------------------------------------------COPE1733
      DO 30 I=1,M2VX                                                    COPE1734
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      WRITE (6,140)                                                     COPE1735
      DO 30 J=1,M2VY                                                    COPE1736
C     X, Y.                                                             COPE1737
      READ (ISCR1,150) XX,YY                                            COPE1739
C     F(X,Y).                                                           COPE1739
      READ (ISCR1,150) (RA(K),K=1,N2VAR)                                COPE1740
      N=4                                                               COPE1741
      IF (N2VAR.LT.4) N=N2VAR                                           COPE1742
      IF (J.EQ.1) WRITE (6,100) XX,YY,(RA(K),K=1,N)                     COPE1743
      IF (J.GT.1) WRITE (6,90) YY,(RA(K),K=1,N)                         COPE1744
      IF (N.GE.N2VAR) GO TO 20                                          COPE1745
      N=5                                                               COPE1746
      M=(N2VAR-1)/4                                                     COPE1747
      DO 10 K=1,M                                                       COPE1748
      L=N+3                                                             COPE1749
      IF (L.GT.N2VAR) L=N2VAR                                           COPE1750
      WRITE (6,110) (RA(KK),KK=N,L)                                     COPE1751
10    N=L+1                                                             COPE1752
20    CONTINUE                                                          COPE1753
30    CONTINUE                                                          COPE1754
      RETURN                                                            COPE1755
C     ------------------------------------------------------------------COPE1756
C                                FORMATS                                COPE1757
C     ------------------------------------------------------------------COPE1758
40    FORMAT (//5X,5HTITLE/5X,20A4)                                     COPE1759
50    FORMAT (1H1,4X,35HTWO-VARIABLE FUNCTION SPACE RESULTS)            COPE1760
60    FORMAT (20A4)                                                     COPE1761
70    FORMAT (16I5)                                                     COPE1762
80    FORMAT (5X,10I5)                                                  COPE1763
90    FORMAT (/15X,E12.4,3X,4E13.4)                                     COPE1764
100   FORMAT (/3X,2E12.4,3X,4E13.4)                                     COPE1765
110   FORMAT (30X,4E13.4)                                               COPE1766
120   FORMAT (////5X,48HGLOBAL NUMBER ASSOCIATED WITH X-VARIABLE, N2VX =COPE1767
     1,I5//5X,48HGLOBAL NUMBER ASSOCIATED WITH Y-VARIABLE, N2VY =,I5)   COPE1768
130   FORMAT (//5X,37HGLOBAL NUMBERS ASSOCIATED WITH F(X,Y))            COPE1769
140   FORMAT (//10X,1HX,11X,1HY,20X,6HF(X,Y))                           COPE1770
150   FORMAT (5E15.8)                                                   COPE1771
      END                                                               COPE1772
      SUBROUTINE COPE08 (A,B,IFORM,NFLD)                                COPE1773
      DIMENSION A(1), B(1), C(10)                                       COPE1774
      DATA COMMA/1H,/,BLANK/1H /                                        COPE1775
C     ROUTINE TO CONVERT UNFORMATTED DATA TO FORMATTED DATA IN FIELDS   COPE1776
C     OF 10,EACH FIELD RIGHT JUSTIFIED.                                 COPE1777
C     BY G. N. VANDERPLAATS                             AUG., 1978.     COPE1778
C     NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE1779
C --- INPUT.                                                            COPE1780
C     A       - ARRAY OF DATA SEPERATED BY COMMAS.  MINIMUM DIMENSION OF COPE1781
C               IS A(80).                                               COPE1782
C --- OUTPUT.                                                           COPE1783
C     B       - ARRAY OD DATA IN FIELDS OF 10 AND RIGHT JUSTIFIED.      COPE1784
C               MINIMUM DIMENSION OF B IS 10*NFLD.                      COPE1785
C     IFORM   - 0 IF A WAS UNFORMATTED.                                 COPE1786
C               1 IF A WAS ALLREADY FORMATTED.                          COPE1787
C     NFLD    - NUMBER OF FIELDS OF DATA.                               COPE1788
C --- NOTE.                                                             COPE1789
C     1)  DATA IS ASSUMED TO BE REAL OR INTEGER DATA WITH NO EMBEDDED   COPE1790
C         BLANKS WITHIN A GIVEN FIELD.                                  COPE1791
C     2)  DATA IS CONSIDERED UNFORMATTED IF                             COPE1792
C         A)  A COMMA IS FOUND                                          COPE1793
C         B)  LAST NON-BLANK CHARACTER IS IN COLUMN 1-10 AND THERE IS   COPE1794
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C             NO DECIMAL AND IT IS NOT RIGHT JUSTIFIED.                   COPE1795
C                                                                         COPE1796
      IFORM=0                                                             COPE1797
C     SEARCH FOR LAST NON-BLANK CHARACTER AND SEARCH FOR COMMA.           COPE1798
C    CALCULATE NUMBER OF NON-BLANK SETS.                                  COPE1799
      INON=0                                                              COPE1800
      KNON=0                                                              COPE1801
      LST=0                                                               COPE1802
      DO 10 I=1,80                                                        COPE1803
      IF (A(I).EQ.COMMA) GO TO 20                                         COPE1804
      JNON=INON                                                           COPE1805
      IF (A(I).EQ.BLANK) INON=0                                           COPE1806
      IF (A(I).NE.BLANK) INON=1                                           COPE1807
      IF (INON.GT.JNON) KNON=KNON+1                                       COPE1808
      IF (A(I).NE.BLANK) LST=I                                            COPE1809
10    CONTINUE                                                            COPE1810
C     NO COMMA WAS FOUND.  DATA MAY BE FORMATTED.                         COPE1811
      IF (LST.GE.10) GO TO 90                                             COPE1812
C     IF MORE THAN ONE SETS OF CHARACTERS, DATA IS ASSUMED FORMATTED.     COPE1813
      IF (KNON.GT.1) GO TO 90                                             COPE1814
20    CONTINUE                                                            COPE1815
C     DATA IS UNFORMATTED.                                                COPE1816
      K2=10                                                               COPE1817
      NFLD=0                                                              COPE1818
      I=0                                                                 COPE1819
30    CONTINUE                                                            COPE1820
      I=I+1                                                               COPE1821
      IF (I.GT.80) GO TO 110                                              COPE1822
C     IGNORE LEADING BLANKS.                                              COPE1823
      IF (A(I).EQ.BLANK) GO TO 30                                         COPE1824
C     CALCULATE NUMBER OF NON-BLANK CHARACTERS IN THIS FIELD.             COPE1825
      JJ=0                                                                COPE1826
      DO 40 J=I,80                                                        COPE1827
      IF (A(J).EQ.COMMA.OR.A(J).EQ.BLANK) GO TO 50                        COPE1828
      JJ=JJ+1                                                             COPE1829
40    C(JJ)=A(J)                                                          COPE1830
50    NFLD=NFLD+1                                                         COPE1831
      I=I+JJ                                                              COPE1832
C     BLANK FIELD NFLD OF B.                                              COPE1833
      K1=K2-9                                                             COPE1834
      DO 60 K=K1,K2                                                       COPE1835
60    B(K)=BLANK                                                          COPE1836
C     STORE C IN FIELD NFLD OF B, RIGHT JUSTIFIED.                        COPE1837
      IF (JJ.EQ.0) GO TO 80                                               COPE1838
      J1=JJ                                                               COPE1839
      K=K2                                                                COPE1840
      DO 70 L=1,JJ                                                        COPE1841
      B(K)=C(J1)                                                          COPE1842
      K=K-1                                                               COPE1843
70    J1=J1-1                                                             COPE1844
80    K2=K2+10                                                            COPE1845
      GO TO 30                                                            COPE1846
90    CONTINUE                                                            COPE1847
C     FORMATTED INPUT.  STORE A DIRECTLY IN B.                            COPE1848
      IFORM=1                                                             COPE1849
      NFLD=8                                                              COPE1850
      DO 100 I=1,80                                                       COPE1851
100   B(I)=A(I)                                                           COPE1852
110   CONTINUE                                                            COPE1853
      RETURN                                                              COPE1854
      END                                                                 COPE1855
      SUBROUTINE COPE09                                                   COPE1856
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCOPE1857
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCOPE1858
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                                 COPE1859
      COMMON /COPES2/ RA(5000),IA(1000)                                   COPE1860
      COMMON /COPES3/ SGNOPT,NCALC,IOBJ,NSV,NSOBJ,NCONA,N2VX,M2VX,N2VY,MCOPE1861
     12VY,N2VAR,IPSENS,IP2VAR,IPDBG,NACMX1,NDVTOT,LOCR(25),LOCI(25),ISCRCOPE1862
     21,ISCR2,NXAPRX,NPS,NPFS,NPA,NF,INOM,IPAPRX,KMIN,KMAX,XFACT1,XFACT2COPE1863
     3,NAN2,NAN3,NPMAX,NPTOT,JNOM,MAXTRM                                  COPE1864
      COMMON /GLOBCM/ ARRAY(1500)                                         COPE1865
C     ******************************************************************COPE1866
C                       ROUTINE TO DO APPROXIMATE OPTIMIZATION.           COPE1867
C     ******************************************************************COPE1868
C                                                                         COPE1869
C     BY G. N. VANDERPLAATS                                 JAN., 1979.   COPE1870
C     NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                    COPE1871
C                                                                         COPE1872
      NFDGSV=NFDG                                                         COPE1873
      NFDG=1                                                              COPE1874
      IF (NFDGSV.LT.0) NFDG=0                                             COPE1875
      CTMIN=ABS(CTMIN)                                                    COPE1876
      CTLMIN=ABS(CTLMIN)                                                  COPE1877
      IF (CTMIN.LE.0.) CTMIN=.0005                                        COPE1878
      IF (CTLMIN.LE.0.) CTLMIN=.0001                                      COPE1879
      IF (ABS(CT).LE.0.) CT=-.01                                          COPE1880
      IF (ABS(CTL).LE.0.) CTL=-.001                                       COPE1881
      IF (DELFUN.LE.0.) DELFUN=.0001                                      COPE1882
      IF (IPDBG.LT.1) IPRINT=0                                            COPE1883
      IF (ITMAX.LT.50) ITMAX=50                                           COPE1884
      NSIDE=1                                                             COPE1885
      KOUNT=0                                                             COPE1886
C     ------------------------------------------------------------------COPE1887
C                           ARRAY STARTING LOCATIONS.                     COPE1888
C     ------------------------------------------------------------------COPE1889
      NN1=NXAPRX+2                                                        COPE1890
      NXV=LOCR(23)                                                        COPE1891
      NVLB=NXV+NN1                                                        COPE1892
      NVUB=NVLB+NN1                                                       COPE1893
      NXNOM=NVUB+NN1                                                      COPE1894
      NDX=NXNOM+NXAPRX                                                    COPE1895
      NFNOM=NDX+NDV                                                       COPE1896
      NFNEW=NFNOM+NF                                                      COPE1897
      NBTAY=NFNEW+NF                                                      COPE1898
      NBR=NXAPRX+(NXAPRX*(NXAPRX+1))/2                                    COPE1899
      IF (MAXTRM.LT.3) NBR=MAXTRM*NXAPRX                                  COPE1900
      NTMP=NBTAY+NBR*NF                                                   COPE1901
      NBLU=LOCR(6)                                                        COPE1902
      NISC=LOCI(4)                                                        COPE1903
      NIGFN=LOCI(23)                                                      COPE1904
      NIDV=NIGFN+NCONA                                                    COPE1905
      IF (KMAX.LT.0) GO TO 160                                            COPE1906
C     CONMIN ARRAYS.                                                      COPE1907
C     DIMENSIONS.                                                         COPE1908
      NN1=NDV+2                                                           COPE1909
      NN2=2*NDV+NCON                                                      COPE1910
      NN3=NACMX1                                                          COPE1911
      NN4=NN3                                                             COPE1912
      IF (NDV.GT.NN4) NN4=NDV                                             COPE1913
      NN5=2*NN4                                                           COPE1914
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C     SCAL, DF, G, A, S, G1, G2, C, B, ISC, IC, NS1.                  COPE1915
      NNSCAL=LOCR(4)                                                  COPE1916
      NDF=NTMP                                                        COPE1917
      NG=NDF+NN1                                                      COPE1918
      NA=NG+NN2                                                       COPE1919
      NS=NA+NN1*NN3                                                   COPE1920
      NG1=NS+NN1                                                      COPE1921
      NG2=NG1+NN2                                                     COPE1922
      NC=NG2+NN2                                                      COPE1923
      NB=NC+NN4                                                       COPE1924
      NISC=LOCI(4)                                                    COPE1925
      NIC=NIDV+NXAPRX                                                 COPE1926
      NMS1=NIC+NN3                                                    COPE1927
C     ----------------------------------------------------------------COPE1928
C                    DETERMINE IOBJA, ARRAYS IGFN AND IDV.            COPE1929
C     ----------------------------------------------------------------COPE1930
C     IOBJA.                                                          COPE1931
      M6=LOCI(6)                                                      COPE1932
      DO 10 I=1,NF                                                    COPE1933
      J=IA(M6)                                                        COPE1934
      IOBJA=I                                                         COPE1935
      IF (J.EQ.IOBJ) GO TO 20                                         COPE1936
10    M6=M6+1                                                         COPE1937
C     ERROR - IOBJA NOT FOUND.                                        COPE1938
20    CONTINUE                                                        COPE1939
      IF (NCONA.EQ.0) GO TO 60                                        COPE1940
C     IGFN ARRAY.                                                     COPE1941
      M3=LOCI(3)                                                      COPE1942
      M23=LOCI(23)                                                    COPE1943
      DO 50 I=1,NCONA                                                 COPE1944
C     GLOBAL LOCATIONS OF CONSTRAINED PARAMETERS.                     COPE1945
      J=IA(M3)                                                        COPE1946
      M3=M3+1                                                         COPE1947
C     LOCAL VARIABLE, F, LOCATION.                                    COPE1948
      M6=LOCI(6)                                                      COPE1949
      DO 30 K=1,NF                                                    COPE1950
      KK=K                                                            COPE1951
      L=IA(M6)                                                        COPE1952
      IF (L.EQ.J) GO TO 40                                            COPE1953
30    M6=M6+1                                                         COPE1954
C     ERROR - CONSTRAINED VARIABLE IS NOT AN APPROXIMATE FUNCTION.    COPE1955
40    CONTINUE                                                        COPE1956
      IA(M23)=KK                                                      COPE1957
50    M23=M23+1                                                       COPE1958
60    CONTINUE                                                        COPE1959
C     IDV ARRAY.                                                      COPE1960
      N3=NIDV                                                         COPE1961
      N5=LOCI(5)                                                      COPE1962
      DO 90 I=1,NXAPRX                                                COPE1963
      IA(N3)=0                                                        COPE1964
C     GLOBAL LOCATION.                                                COPE1965
      II=IA(N5)                                                       COPE1966
      N5=N5+1                                                         COPE1967
C     FIND CORRESPONDING DESIGN VARIABLE.                             COPE1968
      N1=LOCI(1)                                                      COPE1969
      N2=LOCI(2)                                                      COPE1970
      DO 70 J=1,NDVTOT                                                COPE1971
      IF (IA(N1).EQ.II) GO TO 80                                      COPE1972
      N1=N1+1                                                         COPE1973
70    N2=N2+1                                                         COPE1974
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C     THIS APPROXIMATING VARIABLE IS NOT A DESIGN VARIABLE.           COPE1975
      GO TO 90                                                        COPE1976
80    CONTINUE                                                        COPE1977
C     DESIGN VARIABLE NUMBER.                                         COPE1978
      IA(N3)=IA(N2)                                                   COPE1979
90    N3=N3+1                                                         COPE1980
C     CHECK TO BE SURE EACH INDEPENDENT DESIGN VARIABLE IS ALSO AN    COPE1981
C     APPROXIMATING VARIABLE.                                         COPE1982
      DO 120 I=1,NDV                                                  COPE1983
      N1=LOCI(1)                                                      COPE1984
      N2=LOCI(2)                                                      COPE1985
      DO 110 J=1,NDVTOT                                               COPE1986
C     IS THIS DESIGN VARIABLE I.                                      COPE1987
      IF (IA(N2).NE.I) GO TO 110                                      COPE1988
C     YES.                                                            COPE1989
C     GLOBAL VARIABLE NUMBER.                                         COPE1990
      IGLOB=IA(N1)                                                    COPE1991
      N1=N1+1                                                         COPE1992
      N5=LOCI(5)                                                      COPE1993
      DO 100 K=1,NXAPRX                                               COPE1994
C     IS THIS THE SAME AS IGLOB.                                      COPE1995
      IF (IA(N5).EQ.IGLOB) GO TO 120                                  COPE1996
C     NO.                                                             COPE1997
100   N5=N5+1                                                         COPE1998
110   N2=N2+1                                                         COPE1999
C     ERROR - DESIGN VARIABLE IS NOT AN APPROXIMATING VARIABLE.       COPE2000
120   CONTINUE                                                        COPE2001
C     ----------------------------------------------------------------COPE2002
C                   BEGIN SEQUENTIAL APPROXIMATE OPTIMIZATION.        COPE2003
C     ----------------------------------------------------------------COPE2004
      ICK1=0                                                          COPE2005
      ICK2=0                                                          COPE2006
      ICK3=0                                                          COPE2007
130   CONTINUE                                                        COPE2008
      KOUNT=KOUNT+1                                                   COPE2009
      IF (IPAPRX.LT.1.OR.IPAPRX.EQ.3) GO TO 160                       COPE2010
      IF (KMAX.LT.0) GO TO 160                                        COPE2011
C     PRINT INITIAL INFORMATION.                                      COPE2012
C     TITLE.                                                          COPE2013
      IF (KOUNT.GT.1) GO TO 150                                       COPE2014
      WRITE (6,670)                                                   COPE2015
C     OBJECTIVE FUNCTION.                                             COPE2016
      WRITE (6,550) IOBJA                                             COPE2017
      IF (NCONA.EQ.0) GO TO 140                                       COPE2018
C     CONSTRAINTS.                                                    COPE2019
      WRITE (6,560)                                                   COPE2020
      N1=NIGFN                                                        COPE2021
      N2=N1+NCONA-1                                                   COPE2022
      WRITE (6,570) (IA(I),I=N1,N2)                                   COPE2023
140   CONTINUE                                                        COPE2024
C     DESIGN VARIABLES.                                               COPE2025
      WRITE (6,580)                                                   COPE2026
      N1=NIDV                                                         COPE2027
      N2=N1+NXAPRX-1                                                  COPE2028
      WRITE (6,570) (IA(I),I=N1,N2)                                   COPE2029
150   CONTINUE                                                        COPE2030
C     ITERATION NUMBER.                                               COPE2031
      WRITE (6,680) KOUNT                                             COPE2032
160   CONTINUE                                                        COPE2033
      NP=NPTOT-1                                                      COPE2034
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C     ------------------------------------------------------------------COPE2035
C              SET UP ARRAYS XNOM, FNOM, XI, Y.                         COPE2036
C     ------------------------------------------------------------------COPE2037
      NXI=NTMP                                                          COPE2038
      NY=NXI+NXAPRX*NPTOT                                               COPE2039
      NWGHT=NY+NF*NPTOT                                                 COPE2040
      IF (KMAX.LT.0.AND.INOM.LT.1) INOM=1                               COPE2041
      CALL COPE10 (RA(NXI),RA(NY),RA(NXNOM),RA(NFNOM),NPTOT,KOUNT,RA(NBLCOPE2042
     1U),IA(NIGFN),IOBJA,IA(NISC),NXAPRX,NF,NCONA,SGNOPT,CTMIN,CTLMIN,ISCOPE2043
     2CR2,RA(NWGHT),INOM,NPMAX,JNOM)                                    COPE2044
      IF (KMAX.LT.0) GO TO 170                                          COPE2045
C     CURRENT OBJECTIVE.                                                COPE2046
      N1=NFNOM+IOBJA-1                                                  COPE2047
      OBJSAV=-RA(N1)*SGNOPT                                             COPE2048
      IF (KOUNT.LT.2.AND.DABFUN.LE.0.) DABFUN=.001*ABS(OBJSAV)          COPE2049
      IF (DABFUN.LT.1.0E-10) DABFUN=1.0E-10                             COPE2050
      IF (IPAPRX.LT.1.OR.IPAPRX.EQ.3) GO TO 170                         COPE2051
C     PRINT CURRENT NOMINAL.                                            COPE2052
      WRITE (6,690) INOM                                                COPE2053
      N2=NXNOM+NXAPRX-1                                                 COPE2054
      WRITE (6,700) (RA(I),I=NXNOM,N2)                                  COPE2055
      WRITE (6,710)                                                     COPE2056
      N2=NFNOM+NF-1                                                     COPE2057
      WRITE (6,700) (RA(I),I=NFNOM,N2)                                  COPE2058
  170 CONTINUE                                                          COPE2059
C     ------------------------------------------------------------------COPE2060
C               LEAST SQUARES FIT FOR TAYLER SERIES EXPANSION.          COPE2061
C     ------------------------------------------------------------------COPE2062
      NX1=NXAPRX                                                        COPE2063
      M=NX1+(NX1*(NX1+1))/2                                             COPE2064
      IF (M.GT.NP) M=NP                                                 COPE2065
      IF (NP.LT.NXAPRX) M=NXAPRX                                        COPE2066
      MMAX=NXAPRX*MAXTRM                                                COPE2067
      IF(MAXTRM.GT.2) MMAX=M                                            COPE2068
      IF (M.GT.MMAX) M=MMAX                                             COPE2069
      NAA=NWGHT+NP                                                      COPE2070
      NFF=NAA+(M*(M+1))/2                                               COPE2071
      NGG=NFF+M                                                         COPE2072
      CALL COPE12 (RA(NXI),RA(NY),NX1,NP,NF,M,RA(NBTAY),RA(NAA),RA(NFF),COPE2073
     1RA(NGG),NXAPRX,NF,NBR,RA(NWGHT),NER)                              COPE2074
      IF (NER.GT.0) WRITE (6,590)                                       COPE2075
      IF (KMAX.LT.0) GO TO 530                                          COPE2076
      IF (IPAPRX.LT.2.AND.IPAPRX.NE.4) GO TO 190                        COPE2077
C     PRINT TAYLER SERIES COEFFICIENTS.                                 COPE2078
      WRITE (6,720)                                                     COPE2079
      N3=LOCI(6)                                                        COPE2080
      N1=NBTAY                                                          COPE2081
      DO 180 J=1,NF                                                     COPE2082
      N2=N1+M-1                                                         COPE2083
      WRITE (6,600) J,IA(N3)                                            COPE2084
      WRITE (6,700) (RA(I),I=N1,N2)                                     COPE2085
      N1=N1+NBR                                                         COPE2086
      N3=N3+1                                                           COPE2087
  180 CONTINUE                                                          COPE2088
  190 CONTINUE                                                          COPE2089
      IF (KOUNT.GT.KMAX) GO TO 470                                      COPE2090
C     ------------------------------------------------------------------COPE2091
C                      INITIALIZE XV, DX, VLB, VUB.                     COPE2092
C     ------------------------------------------------------------------COPE2093
      N1=NXV                                                            COPE2094
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      DO 200 I=1,NXAPRX                                                 COPE2095
      RA(N1)=0.                                                         COPE2096
  200 N1=N1+1                                                           COPE2097
      N2=NVLB                                                           COPE2098
      N3=NVUB                                                           COPE2099
      N4=NXNOM                                                          COPE2100
      N5=LOCP(2)                                                        COPE2101
      N6=LOCR(3)                                                        COPE2102
      N7=LOCR(7)                                                        COPE2103
      N8=NDX                                                            COPE2104
      L1=M-NDV                                                          COPE2105
      L2=L1-NDV                                                         COPE2106
      ICK=ICK1+ICK2+ICK3                                                COPE2107
      DO 210 I=1,NDV                                                    COPE2108
      RA(N8)=0.                                                         COPE2109
      XFACT=1.                                                          COPE2110
      IF (I.LE.L1) XFACT=XFACT1                                         COPE2111
      L2=L2-NDV+I                                                       COPE2112
      IF (L2.GE.0) XFACT=XFACT2                                         COPE2113
C     REDUCE BOUNDS IF ANY ICK.GT.0.                                    COPE2114
      IF (ICK.GT.0) XFACT=.5                                            COPE2115
      DX=XFACT*PA(N7)                                                   COPE2116
      XX=RA(N4)                                                         COPE2117
      DXL=XX-RA(N5)                                                     COPE2118
      IF (DXL.GT.DX) DXL=DX                                             COPE2119
      DXU=RA(N6)-XX                                                     COPE2120
      IF (DXU.GT.DX) DXU=DX                                             COPE2121
      RA(N2)=-DXL                                                       COPE2122
      RA(N3)=DXU                                                        COPE2123
      N2=N2+1                                                           COPE2124
      N3=N3+1                                                           COPE2125
      N4=N4+1                                                           COPE2126
      N5=N5+1                                                           COPE2127
      N6=N6+1                                                           COPE2128
      N7=N7+1                                                           COPE2129
  210 N8=N8+1                                                           COPE2130
      IF (IPAPRX.LT.2.AND.IPAPRX.NE.4) GO TO 220                        COPE2131
      WRITE (6,610)                                                     COPE2132
      N1=NVLB+NDV-1                                                     COPE2133
      WRITE (6,700) (RA(I),I=NVLB,N1)                                   COPE2134
      WRITE (6,620)                                                     COPE2135
      N1=NVUB+NDV-1                                                     COPE2136
      WRITE (6,700) (RA(I),I=NVUB,N1)                                   COPE2137
  220 CONTINUE                                                          COPE2138
C     ------------------------------------------------------------------COPE2139
C                       OPTIMIZE APPROXIMATE FUNCTION.                  COPE2140
C     ------------------------------------------------------------------COPE2141
C     OPTIMIZATION.                                                     COPE2142
      IGOTO=0                                                           COPE2143
C     CALL CONMIN (X,VLB,VUB,G,SCAL,DF,A,S,G1,G2,B,C,ISC,IC,MS1,N1,N2,N3COPE2144
C    *,N4,N5)                                                           COPE2145
  230 CONTINUE                                                          COPE2146
      CALL CONMIN (RA(NDX),RA(NVLB),RA(NVUB),RA(NG),RA(NNSCAL),RA(NDF),RCOPE2147
     1A(NA),RA(NS),RA(NG1),RA(NG2),RA(NB),RA(NC),IA(NISC),IA(NIC),IA(NMSCOPE2148
     21),NN1,NN2,NN3,NN4,NN5)                                           COPE2149
C     TRANSFER VARIABLES FROM DX TO XV.                                 COPE2150
      N1=NIDV                                                           COPE2151
      N2=NXV                                                            COPE2152
      DO 240 I=1,NXAPRX                                                 COPE2153
      II=IA(N1)                                                         COPE2154
      N4=NDX+II-1                                                       COPE2155
      IF (II.GT.0.AND.II.LE.NDV) RA(N2)=RA(N4)                          COPE2156
      N1=N1+1                                                           COPE2157
      N2=N2+1                                                           COPE2158
240   N3=N3+1                                                           COPE2159
C     APPROXIMATE ANALYSIS.                                             COPE2160
      CALL COPE15 (RA(NXV),RA(NG),RA(NDF),RA(NA),IA(NISC),IA(NIC),NN1,RACOPE2161
     1(NBLU),NX1,IOBJA,M,RA(NFNOM),RA(NFNEW),RA(NBTAY),NBR,IA(NIGFN),CT,COPE2162
     2CTL,INFO,NAC,NCONA,NDV,NF,OBJ,SGNOPT)                             COPE2163
      IF (IGOTO.GT.0) GO TO 230                                         COPE2164
C     IF DESIGN PRODUCED ZERO DELTA-X TWICE IN A ROW AND KOUNT.GE.KMIN, COPE2165
C     TERMINATE.                                                        COPE2166
      ICK1=ICK1+1                                                       COPE2167
      SUM=0.                                                            COPE2168
      N1=NXV                                                            COPE2169
      DO 250 I=1,NDV                                                    COPE2170
      SUM=SUM+RA(N1)**2                                                 COPE2171
250   N1=N1+1                                                           COPE2172
      IF (SUM.GT.1.0E-10) ICK1=0                                        COPE2173
      IF (IPAPRX.GT.0.AND.IPAPRX.NE.3) WRITE (6,730)                    COPE2174
      IF (ICK1.GE.2.AND.KOUNT.GE.KMIN) GO TO 360                        COPE2175
C     ------------------------------------------------------------------COPE2176
C              INSURE NEW X-VECTOR IS INDEPENDENT                       COPE2177
C     ------------------------------------------------------------------COPE2178
      JJJ=0                                                             COPE2179
260   JJJ=JJJ+1                                                         COPE2180
C     NOMINAL X-VECTOR.                                                 COPE2181
      N1=NTMP                                                           COPE2182
      N2=NXNOM                                                          COPE2183
      N3=NXV                                                            COPE2184
      DO 270 I=1,NXAPRX                                                 COPE2185
      RA(N1)=RA(N2)+RA(N3)                                              COPE2186
      N1=N1+1                                                           COPE2187
      N2=N2+1                                                           COPE2188
270   N3=N3+1                                                           COPE2189
C     READ X-VECTORS ONE AT A TIME AND COMPARE TO XNOM.                 COPE2190
      REWIND ISCR2                                                      COPE2191
      N1=NTMP+NXAPRX                                                    COPE2192
      N2=N1+NXAPRX-1                                                    COPE2193
      N3=N2+1                                                           COPE2194
      N4=N3+NF-1                                                        COPE2195
      DO 290 J=1,NPTOT                                                  COPE2196
      KK=J                                                              COPE2197
C     X-VECTOR.                                                         COPE2198
      READ (ISCR2) (PA(I),I=N1,N2)                                      COPE2199
C     Y-VECTOR.  NOT USED.  READ TO POSITION ISCR2.                     COPE2200
      READ (ISCR2) (RA(I),I=N3,N4)                                      COPE2201
C     COMPARE X WITH XNOM.                                              COPE2202
      N5=N1                                                             COPE2203
      N6=NTMP                                                           COPE2204
      SUM=0.                                                            COPE2205
      DO 280 I=1,NXAPRX                                                 COPE2206
      SUM=SUM+(RA(N5)-PA(N6))**2                                        COPE2207
      N5=N5+1                                                           COPE2208
280   N6=N6+1                                                           COPE2209
      IF (SUM.LT.1.0E-10) GO TO 300                                     COPE2210
290   CONTINUE                                                          COPE2211
      GO TO 360                                                         COPE2212
300   CONTINUE                                                          COPE2213
C     THIS DESIGN IS SAME AS A PREVIOUS DESIGN.                         COPE2214
C     MODIFY DELTA-X VECTOR.                                            COPE2215
      N6=NVUB                                                           COPE2216
      N7=NXV                                                            COPE2217
      N8=NVLB                                                           COPE2218
      N9=NXV+NDV-1                                                      COPE2219
      IF (IPAPRX.LT.1.OR.IPAPRX.EQ.3) GO TO 310                         COPE2220
      WRITE (6,630)                                                     COPE2221
      WRITE (6,740)                                                     COPE2222
      WRITE (6,700) (RA(I),I=N7,N9)                                     COPE2223
      WRITE (6,750)                                                     COPE2224
      N9=NTMP+NXAPRX-1                                                  COPE2225
      WRITE (6,700) (RA(I),I=NTMP,N9)                                   COPE2226
      WPITE (6,640)                                                     COPE2227
310   CONTINUE                                                          COPE2228
      AMULT=.01*FLOAT(JJJ)                                              COPE2229
      DO 320 I=1,NDV                                                    COPE2230
      BU=RA(N6)                                                         COPE2231
      BL=PA(N8)                                                         COPE2232
      IF (BL.LT.-1.0E+15) BL=0.                                         COPE2233
      IF (BU.GT.1.0E+15) BU=0.                                          COPE2234
      DB=ABS(BU-BL)                                                     COPE2235
      IF (DB.LT.1.0E-6) DB=.1                                           COPE2236
      DX=RA(N7)+AMULT*DB                                                COPE2237
      IF (DX.GT.RA(N6)) DX=DX-2.*AMULT*DB                               COPE2238
      IF (DX.LT.RA(N8)) DX=DX+1.5*AMULT*DB                              COPE2239
      RA(N7)=DX                                                         COPE2240
      N6=N6+1                                                           COPE2241
      N7=N7+1                                                           COPE2242
      N8=N8+1                                                           COPE2243
320   CONTINUE                                                          COPE2244
      CALL COPE15 (RA(NXV),RA(NG),RA(NDF),RA(NA),IA(NISC),IA(NIC),NN1,RACOPE2245
     1(NBLU),NX1,IOBJA,M,RA(NFNOM),RA(NFNEW),RA(NBTAY),NBR,IA(NIGFN),CT,COPE2246
     2CTL,INFO,NAC,NCONA,NDV,NF,OBJ,SGNOPT)                             COPE2247
      IF (JJJ.LT.4) GO TO 260                                           COPE2248
C     FOUR TRIES HAVE FAILED TO PRODUCE A USABLE X-VECTOR.              COPE2249
C     USE LATEST TRY.                                                   COPE2250
C     POSITION ISCR2 IF NEEDED.                                         COPE2251
      IF (KK.EQ.NPTOT) GO TO 340                                        COPE2252
      KK=KK+1                                                           COPE2253
      DO 330 J=KK,NPTOT                                                 COPE2254
      READ (ISCR2) (RA(I),I=N1,N2)                                      COPE2255
330   READ (ISCR2) (RA(I),I=N3,N4)                                      COPE2256
340   CONTINUE                                                          COPE2257
      IF (IPAPRX.LT.1.OR.IPAPRX.EQ.3) GO TO 350                         COPE2258
      IF (JJJ.EQ.4) WRITE (6,650)                                       COPE2259
350   CONTINUE                                                          COPE2260
360   CONTINUE                                                          COPE2261
C     ------------------------------------------------------------------COPE2262
C                            UPDATE ANALYSIS.                           COPE2263
C     ------------------------------------------------------------------COPE2264
C     XNOM.                                                             COPE2265
      N1=NXNOM                                                          COPE2266
      N2=NXV                                                            COPE2267
      DO 370 I=1,NXAPRX                                                 COPE2268
      RA(N1)=RA(N1)+RA(N2)                                              COPE2269
      N1=N1+1                                                           COPE2270
370   N2=N2+1                                                           COPE2271
C     GLOBAL VARIABLES.                                                 COPE2272
      N3=NXNOM                                                          COPE2273
      N4=NIDV                                                           COPE2274
      DO 410 I=1,NXAPRX
C     DESIGN VARIABLE NUMBER.
      II=IA(N4)
      IF (II.EQ.0) GO TO 400
C     DESIGN VARIABLE UPDATE.
      N1=LOCI(1)
      N2=LOCI(2)
      N5=LOCR(5)
      DO 390 J=1,NDVTOT
      IF (IA(N2).NE.II) GO TO 380
C     UPDATE VARIABLE J.
      JJ=IA(N1)
      ARRAY(JJ)=RA(N3)*RA(N5)
380   N1=N1+1
      N2=N2+1
      N5=N5+1
390   CONTINUE
400   N3=N3+1
410   N4=N4+1
      IF (IPAPRX.LT.1.OR.IPAPRX.EQ.3) GO TO 420
C     PRINT APPROXIMATE OPTIMIZATION INFORMATION.
      WRITE (6,740)
      N2=NXV+NDV-1
      WRITE (6,700) (RA(I),I=NXV,N2)
      WRITE (6,750)
      N2=NXNOM+NXAPRX-1
      WRITE (6,700) (RA(I),I=NXNOM,N2)
      WRITE (6,760)
      N2=NFNEW+NF-1
      WRITE (6,700) (RA(I),I=NFNEW,N2)
420   CONTINUE
      IF ((ICK1.GE.2.AND.KOUNT.GE.KMIN).AND.(IPAPRX.GT.0.AND.IPAPRX.NE.3
     1)) WRITE (6,540)
      IF (ICK1.GE.2.AND.KOUNT.GE.KMIN) GO TO 460
      ICALC=2
      NAN2=NAN2+1
      CALL ANALIZ (ICALC)
C     NEW FUNCTION VALUES.
      N1=NFNOM
      M6=LOCI(6)
      DO 430 I=1,NF
      II=IA(M6)
      M6=M6+1
      RA(N1)=ARRAY(II)
430   N1=N1+1
      IF (IPDBG.LT.1) GO TO 440
C     DEBUG OUTPUT.
      NAN3=NAN3+1
      ICALC=3
      CALL ANALIZ (ICALC)
440   CONTINUE
      IF (IPAPRX.LT.1.OR.IPAPRX.EQ.3) GO TO 450
C     PRINT PRECISE FUNCTION VALUES.
      WRITE (6,770)
      N2=NFNOM+NF-1
      WRITE (6,700) (RA(I),I=NFNOM,N2)
450   CONTINUE
C     NEW OBJECTIVE.
      N1=NFNOM+IOBJA-1
      OBJ=-RA(N1)*SGNOPT
C     ------------------------------------------------------------------
C                          WRITE NEW X AND F VALUES ON ISCR2.
C     ------------------------------------------------------------------
C     X-VECTOR.
      N1=NXNOM+NXAPRX-1
      WRITE (ISCR2) (RA(I),I=NXNOM,N1)
C     FUNCTIONS.
      N1=NFNOM+NF-1
      WRITE (ISCR2) (RA(I),I=NFNOM,N1)
C     UPDATE PARAMETERS.
      NPTOT=NPTOT+1
      IF (JJJ.LT.2.OR.KOUNT.LT.KMIN) INOM=NPTOT
C     ------------------------------------------------------------------
C                               CONVERGENCE CHECK.
C     ------------------------------------------------------------------
      IF (KOUNT.LT.KMIN) GO TO 130
      ICK2=ICK2+1
      ICK3=ICK3+1
      DEL=ABS(OBJ)
      IF (DEL.LT.1.0E-6) DEL=1.0E-6
      DEL=(OBJ-OBJSAV)/DEL
      DEL=ABS(DEL)
      DEL=(OBJ-OBJSAV)/DEL
      DEL=ABS(DEL)
      IF (DEL.GT.DELFUN) ICK2=0
      DEL=ABS(OBJ-OBJSAV)
      IF (DEL.GT.DABFUN) ICK3=0
      IF (ICK2.GE.2.OR.ICK3.GE.2) GO TO 460
      IF (KOUNT.LT.KMAX) GO TO 130
460   CONTINUE
C     ------------------------------------------------------------------
C                              FINAL INFORMATION.
C     ------------------------------------------------------------------
      IF (IPAPRX.GT.0.AND.IPAPRX.NE.3) WRITE (6,660)
C     GO BACK AND PICK BEST DESIGN.
      INOM=0
      KOUNT=KMAX+1
      IF (KOUNT.LT.JNOM) KOUNT=JNOM+1
      CTSAV=CT
      CTLSAV=CTL
      IF (ABS(CT).LT.1.0E-10) CT=-.004
      IF (ABS(CTL).LT.1.0E-10) CTL=-.001
      GO TO 160
470   CONTINUE
      CT=CTSAV
      CTL=CTLSAV
C     STORE FINAL VALUES OF XNOM IN GLOBAL ARRAY.
      N3=NXNOM
      N4=NIDV
      DO 510 I=1,NXAPRX
C     DESIGN VARIABLE NUMBER.
      II=IA(N4)
      IF (II.EQ.0) GO TO 500
C     DESIGN VARIABLE UPDATE.
      N1=LOCI(1)
      N2=LOCI(2)
      N5=LOCR(5)
      DO 490 J=1,NDVTOT
      IF (IA(N2).NE.II) GO TO 480
C     UPDATE VARIABLE J.
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      JJ=IA(N1)                                                         COPE2395
      ARRAY(JJ)=RA(N3)*RA(N5)                                           COPE2396
480   N1=N1+1                                                           COPE2397
      N2=N2+1                                                           COPE2398
      N5=N5+1                                                           COPE2399
490   CONTINUE                                                          COPE2400
500   N3=N3+1                                                           COPE2401
510   N4=N4+1                                                           COPE2402
C     STORE FINAL VALUES OF FNOM IN GLOBAL ARRAY.                       COPE2403
      M6=LOCI(6)                                                        COPE2404
      N1=NFNOM                                                          COPE2405
      DO 520 I=1,NF                                                     COPE2406
      II=IA(M6)                                                         COPE2407
      M6=M6+1                                                           COPE2408
      ARRAY(II)=RA(N1)                                                  COPE2409
520   N1=N1+1                                                           COPE2410
530   CONTINUE                                                          COPE2411
      RETURN                                                            COPE2412
C     ------------------------------------------------------------------COPE2413
C                                FORMATS                                COPE2414
C     ------------------------------------------------------------------COPE2415
540   FORMAT (//5X,71HTWO CONSECUTIVE APPROXIMATE OPTIMIZATIONS HAVE PROCOPE2416
     1DUCED THE SAME DESIGN//5X,23HOPTIMIZATION TERMINATED)             COPE2417
550   FORMAT (/5X,22HAPPROXIMATING FUNCTION,I5,17H IS THE OBJECTIVE)    COPE2418
560   FORMAT (/5X,51HAPPROXIMATING FUNCTIONS ASSOCIATED WITH CONSTRAINTSCOPE2419
     1)                                                                 COPE2420
570   FORMAT (5X,10I5)                                                  COPE2421
580   FORMAT (//5X,63HDESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATCOPE2422
     1ING VARIABLES)                                                    COPE2423
590   FORMAT (//5X,59H* * LEAST SQUARES FIT TO APPROXIMATION DATA IS SINCOPE2424
     1GULAR * */5X,24HRESULTS MAY NOT BE VALID)                         COPE2425
600   FORMAT (/5X,15HFUNCTION NUMBER,I5,25H   GLOBAL VARIABLE NUMBER,I5/COPE2426
     15X,12HCOEFFICIENTS)                                               COPE2427
610   FORMAT (/5X,44HSIDE CONSTRAINTS ON APPROXIMATE OPTIMIZATION//5X,12COPE2428
     1HLOWER BOUNDS)                                                    COPE2429
620   FORMAT (/5X,12HUPPER BOUNDS)                                      COPE2430
630   FORMAT (//5X,76HOPTIMIZATION HAS PRODUCED AN X-VECTOR WHICH IS THECOPE2431
     1 SAME AS A PREVIOUS DESIGN)                                       COPE2432
640   FORMAT (/5X,51HTHE FOLLOWING DESIGN IS NOT THE APPROXIMATE OPTIMUMCOPE2433
     1)                                                                 COPE2434
650   FORMAT (/5X,60HFOUR ATTEMPTS HAVE FAILED TO PRODUCE AN INDEPENDENTCOPE2435
     1 X-VECTOR/5X,52HOPTIMIZATION WILL CONTINUE WITH MOST RECENT X-VECTCOPE2436
     2OR)                                                               COPE2437
660   FORMAT (1H1,4X,40HFINAL RESULT OF APPROXIMATE OPTIMIZATION)       COPE2438
670   FORMAT (1H1,4X,42HAPPROXIMATE OPTIMIZATION ITERATION HISTORY)     COPE2439
680   FORMAT (///5X,22HBEGIN ITERATION NUMBER,I5)                       COPE2440
690   FORMAT (/5X,23HNOMINAL DESIGN NUMBER =,I5//5X,8HX-VECTOR)         COPE2441
700   FORMAT (5X,5E13.5)                                                COPE2442
710   FORMAT (/5X,15HFUNCTION VALUES)                                   COPE2443
720   FORMAT (//5X,26HTAYLOR SERIES COEFFICIENTS)                       COPE2444
730   FORMAT (//5X,35HRESULTS OF APPROXIMATE OPTIMIZATION)              COPE2445
740   FORMAT (/5X,14HDELTA-X VECTOR)                                    COPE2446
750   FORMAT (/5X,8HX-VECTOR)                                           COPE2447
760   FORMAT (/5X,27HAPPPOXIMATE FUNCTION VALUES)                       COPE2448
770   FORMAT (/5X,23HPRECISE FUNCTION VALUES)                           COPE2449
      END                                                               COPE2450
      SUBROUTINE COPE10 (XI,Y,XNOM,FNOM,NPTOT,KOUNT,BLU,IGFN,IOBJA,ISC,NCOPE2451
     1XAPRX,NF,NCONA,SGNOPT,CTMIN,CTLMIN,ISCR2,WGHT,INOM,NPMAX,JNOM)    COPE2452
      DIMENSION XI(NXAPRX,1), Y(NF,1), XNOM(1), FNOM(1), BLU(4,1), IGFN(COPE2453
     11), ISC(1), WGHT(1)                                               COPE2454
C     ******************************************************************COPE2455
C        ROUTINE TO SET UP ARRAYS FOR TAYLER SERIES EXPANSION.          COPE2456
C     ******************************************************************COPE2457
C                                                                       COPE2458
C     BY G. N. VANDERPLAATS                                 JAN., 1979. COPE2459
C     NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE2460
C                                                                       COPE2461
      REWIND ISCR2                                                      COPE2462
      DO 10 J=1,NPTOT                                                   COPE2463
      READ (ISCR2) (XI(I,J),I=1,NXAPRX)                                 COPE2464
10    READ (ISCR2) (Y(I,J),I=1,NF)                                      COPE2465
C     ------------------------------------------------------------------COPE2466
C                          FIND BEST NOMINAL IF REQUIRED.               COPE2467
C     ------------------------------------------------------------------COPE2468
      IF (KOUNT.LE.1.AND.INOM.GT.0) GO TO 20                            COPE2469
      IF (KOUNT.GT.1.AND.KOUNT.LE.JNOM) GO TO 20                        COPE2470
      CALL COPE11 (NPTOT,Y,NF,INOM,BLU,NCONA,IGFN,IOBJA,SGNOPT,CTMIN,CTLCOPE2471
     1MIN,ISC)                                                          COPE2472
20    CONTINUE                                                          COPE2473
C     ------------------------------------------------------------------COPE2474
C                            CREATE XNOM AND FNOM.                      COPE2475
C     ------------------------------------------------------------------COPE2476
      DO 30 I=1,NXAPRX                                                  COPE2477
30    XNOM(I)=XI(I,INOM)                                                COPE2478
      DO 40 I=1,NF                                                      COPE2479
40    FNOM(I)=Y(I,INOM)                                                 COPE2480
      NP=NPTOT-1                                                        COPE2481
      IF (INOM.EQ.NPTOT) GO TO 80                                       COPE2482
C     ------------------------------------------------------------------COPE2483
C                                SHIFT XI AND Y.                        COPE2484
C     ------------------------------------------------------------------COPE2485
      DO 70 J=INOM,NP                                                   COPE2486
      DO 50 I=1,NXAPRX                                                  COPE2487
50    XI(I,J)=XI(I,J+1)                                                 COPE2488
      DO 60 I=1,NF                                                      COPE2489
60    Y(I,J)=Y(I,J+1)                                                   COPE2490
70    CONTINUE                                                          COPE2491
80    CONTINUE                                                          COPE2492
C     ------------------------------------------------------------------COPE2493
C                 REPLACE XI BY DELTA-XI AND Y BY DELTA-Y.              COPE2494
C     ------------------------------------------------------------------COPE2495
      DO 110 J=1,NP                                                     COPE2496
      DO 90 I=1,NXAPRX                                                  COPE2497
90    XI(I,J)=XI(I,J)-XNOM(I)                                           COPE2498
      DO 100 I=1,NF                                                     COPE2499
100   Y(I,J)=Y(I,J)-FNOM(I)                                             COPE2500
110   CONTINUE                                                          COPE2501
C     ------------------------------------------------------------------COPE2502
C                              WEIGHTING FACTORS.                       COPE2503
C     ------------------------------------------------------------------COPE2504
      SMAX=1.0E-10                                                      COPE2505
      DO 130 J=1,NP                                                     COPE2506
      SUM=0.                                                            COPE2507
      DO 120 I=1,NXAPRX                                                 COPE2508
120   SUM=SUM+XI(I,J)**2                                                COPE2509
      IF (SUM.GT.SMAX) SMAX=SUM                                         COPE2510
130   WGHT(J)=SQRT(SUM)                                                 COPE2511
      SMAX=SQRT(SMAX)                                                   COPE2512
      DO 140 I=1,NP                                                     COPE2513
140   WGHT(I)=2.-WGHT(I)/SMAX                                           COPE2514
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      IF (NP.LE.NPMAX) RETURN                                           COPE2515
C     ------------------------------------------------------------------COPE2516
C            REDUCE THE NUMBER OF DESIGNS TO NPMAX.                     COPE2517
C     ------------------------------------------------------------------COPE2518
      NPMX1=NPMAX+1                                                     COPE2519
      NPSAV=NP                                                          COPE2520
      DO 200 II=NPMX1,NPSAV                                             COPE2521
C     FIND DESIGN WITH MINIMUM WEIGHTING FACTOR.                        COPE2522
      WMIN=WGHT(1)                                                      COPE2523
      IMN=1                                                             COPE2524
      DO 150 I=2,NP                                                     COPE2525
      IF (WGHT(I).GE.WMIN) GO TO 150                                    COPE2526
      WMIN=WGHT(I)                                                      COPE2527
      IMN=I                                                             COPE2528
150   CONTINUE                                                          COPE2529
      IF (IMN.EQ.NP) GO TO 190                                          COPE2530
C     SHIFT XI, Y AND WGHT.                                             COPE2531
      NPM1=NP-1                                                         COPE2532
      DO 180 J=IMN,NPM1                                                 COPE2533
      DO 160 I=1,NXAPRX                                                 COPE2534
160   XI(I,J)=XI(I,J+1)                                                 COPE2535
      DO 170 I=1,NF                                                     COPE2536
170   Y(I,J)=Y(I,J+1)                                                   COPE2537
180   WGHT(I)=WGHT(I+1)                                                 COPE2538
190   NP=NP-1                                                           COPE2539
200   CONTINUE                                                          COPE2540
      RETURN                                                            COPE2541
      END                                                               COPE2542
      SUBROUTINE COPE11 (NPTOT,Y,NYR,INOM,BLU,NCONA,IGFN,IOBJA,SGNOPT,CTCOPE2543
     1MIN,CTLMIN,ISC)                                                   COPE2544
      DIMENSION Y(NYR,1), BLU(4,1), IGFN(1), ISC(1)                     COPE2545
C     ******************************************************************COPE2546
C     ROUTINE TO DETERMINE NOMINAL DESIGN FOR APPROXIMATE OPTIMIZATION. COPE2547
C     ******************************************************************COPE2548
C                                                                       COPE2549
C     BY G. N. VANDERPLAATS                                 JAN., 1979. COPE2550
C     NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE2551
C     NOMINAL DESIGN IS THE ONE WITH LOWEST OBJECTIVE SATISFYING ALL    COPE2552
C     CONSTRAINTS.  IF ALL DESIGNS VIOLATE CONSTRAINTS, THE DESIGN WITH COPE2553
C     THE LEAST VIOLATION IS FOUND.                                     COPE2554
C     I1 IS DESIGN WITH LOWEST MAXIMUM CONSTRAINT VALUE.                COPE2555
C     I2 IS THE DESIGN WITH THE LOWEST OBJECTIVE SATISFYING ALL         COPE2556
C     CONSTRAINTS.                                                      COPE2557
      CT1=ABS(CTMIN)                                                    COPE2558
      IF (CT1.LT.0.004) CT1=0.004                                       COPE2559
      CTL1=ABS(CTLMIN)                                                  COPE2560
      IF (CTL1.LT.0.001) CTL1=0.001                                     COPE2561
C     ------------------------------------------------------------------COPE2562
C                           FIND MAXIMUM OBJECTIVE.                     COPE2563
C     ------------------------------------------------------------------COPE2564
      OBJMAX=-Y(IOBJA,1)*SGNOPT                                         COPE2565
      DO 10 J=2,NPTOT                                                   COPE2566
      OBJ=-Y(IOBJA,J)*SGNOPT                                            COPE2567
      IF (OBJ.GT.OBJMAX) OBJMAX=OBJ                                     COPE2568
10    CONTINUE                                                          COPE2569
C     ------------------------------------------------------------------COPE2570
C     NOW FIND DESIGN VARIABLE WITH LOWEST OBJECTIVE SATISFYING ALL     COPE2571
C     CONSTRAINTS AND DESIGN WITH LEAST CONSTRAINT VIOLATION.           COPE2572
C     ------------------------------------------------------------------COPE2573
      GMAX=1.0E+20                                                      COPE2574
      I1=1                                                              COPE2575
      I2=0                                                              COPE2576
      DO 50 J=1,NPTOT                                                   COPE2577
C     OBJECTIVE.                                                        COPE2578
      OBJ=-Y(IOBJA,J)*SGNOPT                                            COPE2579
C     CONSTRAINTS.                                                      COPE2580
      ICON=0                                                            COPE2581
      G1=-1.                                                            COPE2582
      DO 30 I=1,NCONA                                                   COPE2583
      II=IGFN(I)                                                        COPE2584
      GG=Y(II,J)                                                        COPE2585
C     LOWER BOUND.                                                      COPE2586
      IF (BLU(1,I).LT.-1.0E+15) GO TO 20                                COPE2587
      ICON=ICON+1                                                       COPE2588
      CT=CT1                                                            COPE2589
      IF (ISC(ICON).GT.0) CT=CTL1                                       COPE2590
      G=(BLU(1,I)-GG)/BLU(2,I)-CT                                       COPE2591
      IF (G.GT.G1) G1=G                                                 COPE2592
C     UPPER BOUND.                                                      COPE2593
20    IF (BLU(3,I).GT.1.0E+15) GO TO 30                                 COPE2594
      ICON=ICON+1                                                       COPE2595
      CT=CT1                                                            COPE2596
      IF (ISC(ICON).GT.0) CT=CTL1                                       COPE2597
      G=(GG-BLU(3,I))/BLU(4,I)-CT                                       COPE2598
      IF (G.GT.G1) G1=G                                                 COPE2599
30    CONTINUE                                                          COPE2600
      IF (G1.LT.0..OR.G1.GT.GMAX) GO TO 40                              COPE2601
      I1=J                                                              COPE2602
      GMAX=G1                                                           COPE2603
40    IF (OBJ.GT.OBJMAX.OR.G1.GT.0.) GO TO 50                           COPE2604
      I2=J                                                              COPE2605
      OBJMAX=OBJ                                                        COPE2606
50    CONTINUE                                                          COPE2607
      INOM=I1                                                           COPE2608
      IF (I2.GT.0) INOM=I2                                              COPE2609
      RETURN                                                            COPE2610
      END                                                               COPE2611
C     SUBROUTINE COPE12                                                 COPE2612
C     ******************************************************************COPE2613
C     ROUTINE TO PERFORM A LEAST SQUARES FIT OF AN ARBITRARY FUNCTION OFCOPE2614
C     NV VARIABLES.                                                     COPE2615
C     Y = F(X1,X2,...,XNX) = B(1)*F(1) + B(2)*F(2) + ... + B(M)*F(M)    COPE2616
C     ******************************************************************COPE2617
C                                                                       COPE2618
C     BY G. N. VANDERPLAATS                              JAN., 1979.    COPE2619
C     NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE2620
C     ARGUEMENTS,                                                       COPE2621
C     X,Y  - INPUT ARRAYS OF OBSERVATIONS OF NP POINTS                  COPE2622
C            X(NX,NP), Y(NF,NP)                                         COPE2623
C     NX   - NUMBER OF INDEPENDENT VARIABLES OF WHICH Y IS A FUNCTION.  COPE2624
C     NP   - NUMBER OF OBSERVATION POINTS.                              COPE2625
C     NF   - NUMBER OF SEPERATE CURVE FITS BEING DONE SIMULTANEOUSLY.   COPE2626
C            THIS IS THE NUMBER OF SETS OF Y VALUES.                    COPE2627
C     M    - NUMBER OF COMPONENTS OF THE FUNCTIONS TO BE FITTED.        COPE2628
C     B    - APRAY OF M COEFFICIENTS OF FUNCTIONAL FIT TO DATE.         COPE2629
C     A    - M(M+1)/2 WORK VECTOR.                                      COPE2630
C     F    - WORK VECTOR - F(M).                                        COPE2631
C     G    - WORK VECTOR - G(NF).                                       COPE2632
C     NXR  - DIMENSIONED ROWS OF X.                                     COPE2633
C     NYR  - DIMENSIONED ROWS OF Y.                                     COPE2634
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C     NBR  - DIMENSIONED ROWS OF B.                                     COPE2635
C     WGHT - ARRAY OF WEIGHTING FACTORS - WGHT(NP).                     COPE2636
C     NER  - ERROR FLAG.  IF NER.GT.0, DIAGONAL ELEMENT NER OF A IS     COPE2637
C            LESS THAN 1.0E-10.                                         COPE2638
C                                                                       COPE2639
C     USER SUPPLIED SUBROUTINE, COPE13.                                 COPE2640
C     USAGE                                                             COPE2641
C     CALL COPE13(XI,F,NX,M)                                            COPE2642
C     ROUTINE TO EVALUATE COMPONENTS F(1),...,F(M) WHICH ARE TO BE      COPE2643
C     FITTED TO DATA.                                                   COPE2644
C     TO DATA.  ROUTINE EVALUATES THE FUNCTIONS FOR A SINGLE VECTOR OF  COPE2645
C     XI AND STORES THE RESULTING VALUES IN VECTOR F.                   COPE2646
C     ARGUEMENTS.                                                       COPE2647
C     XI   - VECTOR OF INDEPENDENT VARIABLES AT WHICH FUNCTIONS ARE     COPE2648
C            TO BE EVALUATED.                                           COPE2649
C     F    - VECTOR OF FUNCTION VALUES.                                 COPE2650
C     NX   - NUMBER OF INDEPENDENT VARIABLES OF WHICH Y IS A FUNCTION.  COPE2651
C     M    - NUMBER OF FUNCTION COMPONENTS, ALSO REQUIRED DIMENSION OF FCOPE2652
C                                                                       COPE2653
      SUBROUTINE COPE12 (X,Y,NX,NP,NF,M,B,A,F,G,NXR,NYR,NBR,WGHT,NER)   COPE2654
      DIMENSION X(NXR,1), Y(NYR,1), B(NBR,1), A(1), F(1), G(1)          COPE2655
      DIMENSION WGHT(1)                                                 COPE2656
      IF (NX.LE.NP) GO TO 50                                            COPE2657
C     SPECIAL CASE.  FEWER OBSERVATIONS THAN DESIGN VARIABLES.  USE     COPE2658
C     AVERAGE FINITE DIFFERENCE FOR FIRST ORDER EXPANSION.              COPE2659
      NP1=NP+1                                                          COPE2660
      AP=FLOAT(NP)                                                      COPE2661
      DO 20 I=1,NX                                                      COPE2662
      X(I,NP1)=AP                                                       COPE2663
      DO 10 J=1,NP                                                      COPE2664
      IF (ABS(X(I,J)).GT.1.0E-10) GO TO 10                              COPE2665
      X(I,NP1)=X(I,NP1)-1.                                              COPE2666
      X(I,J)=1.0E+20                                                    COPE2667
   10 CONTINUE                                                          COPE2668
      IF (X(I,NP1).LT.1.) X(I,NP1)=1.                                   COPE2669
   20 CONTINUE                                                          COPE2670
      DO 40 I=1,NX                                                      COPE2671
      DO 40 J=1,NF                                                      COPE2672
      B(I,J)=0.                                                         COPE2673
      DO 30 K=1,NP                                                      COPE2674
   30 B(I,J)=B(I,J)+Y(J,K)/X(I,K)                                       COPE2675
   40 B(I,J)=B(I,J)/X(I,NP1)                                            COPE2676
      NER=0                                                             COPE2677
      RETURN                                                            COPE2678
   50 CONTINUE                                                          COPE2679
C     GENERAL CASE.  DO LEAST SQUARES FIT.                              COPE2680
C     A=B=0.                                                            COPE2681
      DO 60 J=1,NF                                                      COPE2682
      DO 60 I=1,M                                                       COPE2683
   60 B(I,J)=0.                                                         COPE2684
      L=(M*(M+1))/2                                                     COPE2685
      DO 70 J=1,L                                                       COPE2686
   70 A(J)=0.                                                           COPE2687
C     LOWER TRIANGLE OF A IN SYMMETRIC MODE.                            COPE2688
      DO 100 K=1,NP                                                     COPE2689
      WGHTK=WGHT(K)                                                     COPE2690
      CALL COPE13 (X(1,K),F,NX,M)                                       COPE2691
      L=0                                                               COPE2692
      DO 80 J=1,M                                                       COPE2693
      DO 80 I=1,J                                                       COPE2694
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      L=L+1                                                             COPE2695
   80 A(L)=A(L)+F(I)*F(J)*WGHTK                                         COPE2696
C     Y*F                                                               COPE2697
      DO 90 L=1,NF                                                      COPE2698
      YLK=Y(L,K)*WGHTK                                                  COPE2699
      DO 90 I=1,M                                                       COPE2700
   90 B(I,L)=B(I,L)+YLK*F(I)                                            COPE2701
  100 CONTINUE                                                          COPE2702
C     SOLVE FOR B.                                                      COPE2703
      IF (M.LE.1) GO TO 200                                             COPE2704
C     LDU DECOMPOSITION.                                                COPE2705
      MM1=M-1                                                           COPE2706
      KK=0                                                              COPE2707
      DO 110 K=1,MM1                                                    COPE2708
      NER=K                                                             COPE2709
      KK=KK+K                                                           COPE2710
      IF (ABS(A(KK)).LT.1.0E-20) GO TO 220                              COPE2711
      FACT=1./A(KK)                                                     COPE2712
      A(KK)=FACT                                                        COPE2713
      KP1=K+1                                                           COPE2714
      KJ=KK                                                             COPE2715
      DO 110 J=KP1,M                                                    COPE2716
      KJ=KJ+J-1                                                         COPE2717
      GG=A(KJ)*FACT                                                     COPE2718
      KI=KK                                                             COPE2719
      IJ=KJ                                                             COPE2720
      DO 110 I=KP1,J                                                    COPE2721
      IJ=IJ+1                                                           COPE2722
      KI=KI+I-1                                                         COPE2723
      A(IJ)=A(IJ)-A(KI)*GG                                              COPE2724
  110 CONTINUE                                                          COPE2725
      KK=KK+M                                                           COPE2726
      NER=M                                                             COPE2727
      IF (ABS(A(KK)).LT.1.0E-20) GO TO 220                              COPE2728
      A(KK)=1./A(KK)                                                    COPE2729
C     FORWARD SUBSTITUTION                                              COPE2730
      MP1=M+1                                                           COPE2731
      KK=0                                                              COPE2732
      DO 130 K=1,MM1                                                    COPE2733
      KP1=K+1                                                           COPE2734
      KK=KK+K                                                           COPE2735
      AKK=A(KK)                                                         COPE2736
      DO 120 L=1,NF                                                     COPE2737
  120 B(K,L)=B(K,L)*AKK                                                 COPE2738
      KI=KK                                                             COPE2739
      DO 130 I=KP1,M                                                    COPE2740
      KI=KI+I-1                                                         COPE2741
      AKI=A(KI)                                                         COPE2742
      DO 130 J=1,NF                                                     COPE2743
      B(I,J)=B(I,J)-AKI*B(K,J)                                          COPE2744
  130 CONTINUE                                                          COPE2745
      KK=KK+M                                                           COPE2746
      AKK=A(KK)                                                         COPE2747
      DO 140 J=1,NF                                                     COPE2748
  140 B(M,J)=B(M,J)*AKK                                                 COPE2749
C     BACK SUBSTITUTION.                                                COPE2750
      DO 190 I=2,M                                                      COPE2751
      J=MP1-I                                                           COPE2752
      JJ=J*(J+1)/2                                                      COPE2753
      JK=JJ                                                             COPE2754
      JP1=J+1                                                           COPE2755
      DO 150 L=1,NF                                                     COPE2756
150   G(L)=0.                                                           COPE2757
      DO 170 K=JP1,M                                                    COPE2758
      JK=JK+K-1                                                         COPE2759
      AJK=A(JK)                                                         COPE2760
      DO 160 L=1,NF                                                     COPE2761
160   G(L)=G(L)+AJK*B(K,L)                                              COPE2762
170   CONTINUE                                                          COPE2763
      AJJ=A(JJ)                                                         COPE2764
      DO 180 L=1,NF                                                     COPE2765
180   B(J,L)=B(J,L)-AJJ*G(L)                                            COPE2766
190   CONTINUE                                                          COPE2767
      NER=0                                                             COPE2768
      RETURN                                                            COPE2769
200   CONTINUE                                                          COPE2770
      AKK=A(1)                                                          COPE2771
      NER=1                                                             COPE2772
      IF (ABS(AKK).LT.1.0E-20) GO TO 220                                COPE2773
      AKK=1./AKK                                                        COPE2774
      DO 210 J=1,NF                                                     COPE2775
210   B(1,J)=B(1,J)*AKK                                                 COPE2776
      NER=0                                                             COPE2777
      RETURN                                                            COPE2778
220   CONTINUE                                                          COPE2779
      RETURN                                                            COPE2780
      END                                                               COPE2781
      SUBROUTINE COPE13 (X,F,NX,M)                                      COPE2782
      DIMENSION X(1), F(1)                                              COPE2783
C     ******************************************************************COPE2784
C     ROUTINE TO CALCULATE F VALUES FOR LEAST SQUARES FIT TO QUADRATIC  COPE2785
C     Y-Y0 ■ DY-TRANSPOSE TIMES X + (1/2 X-TRANSPOSE TIMES H TIMES X.   COPE2786
C     ******************************************************************COPE2787
C                                                                       COPE2788
C     BY G. N. VANDERPLAATS                              JAN., 1979.    COPE2789
C     X CONTAINS X-X0.                                                  COPE2790
C     M = MAXIMUM NUMBER OF COEFFICIENTS TO BE CALCULATED.              COPE2791
C         M .LE. NX + (NX+1)/2.                                         COPE2792
C     DY COEF.                                                          COPE2793
      DO 10 I=1,NX                                                      COPE2794
10    F(I)=X(I)                                                         COPE2795
C     H COEF. = X1*X1, X2*X2, ... XN*XN,  X1*X2... X1*XN...             COPE2796
      II=NX                                                             COPE2797
C     ------------------------------------------------------------------COPE2798
C                                 DIAGONAL ELEMENTS.                    COPE2799
C     ------------------------------------------------------------------COPE2800
      DO 20 I=1,NX                                                      COPE2801
      II=II+1                                                           COPE2802
      IF (II.GT.M) GO TO 40                                             COPE2803
20    F(II)=.5*(X(I)**2)                                                COPE2804
      IF (NX.LT.2) RETURN                                               COPE2805
C     ------------------------------------------------------------------COPE2806
C                             OFF-DIAGONAL ELEMENTS.                    COPE2807
C     ------------------------------------------------------------------COPE2808
      NXM1=NX-1                                                         COPE2809
      DO 30 I=1,NXM1                                                    COPE2810
      IP1=I+1                                                           COPE2811
      DO 30 J=IP1,NX                                                    COPE2812
      II=II+1                                                           COPE2813
      IF (II.GT.M) GO TO 40                                             COPE2814
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30    F(II)=X(I)*X(J)                                                   COPE2815
40    CONTINUE                                                          COPE2816
      RETURN                                                            COPE2817
      END                                                               COPE2818
      SUBROUTINE COPE14 (NXAPRX,NF,NPTOT,RA,IA,LOCR,LOCI,TITLE,INOM,NDV,COPE2819
     1IPAPRX,ISCR2,MAXTRM)                                              COPE2820
      DIMENSION RA(1), IA(1), LOCR(1), LOCI(1), TITLE(1)                COPE2821
C     ******************************************************************COPE2822
C     ROUTINE TO PRINT RESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION.    COPE2823
C     ******************************************************************COPE2824
C                                                                       COPE2825
C     BY G. N. VANDERPLAATS                              JAN., 1979.    COPE2826
C     NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE2827
C                                                                       COPE2828
C     ------------------------------------------------------------------COPE2829
C                               TITLE.                                  COPE2830
C     ------------------------------------------------------------------COPE2831
      WRITE (6,90) (TITLE(I),I=1,20)                                    COPE2832
C     ------------------------------------------------------------------COPE2833
C                 GLOBAL LOCATION OF X AND F(X)                         COPE2834
C     ------------------------------------------------------------------COPE2835
C     GLOBAL LOCATIONS OF X.                                            COPE2836
      M5=LOCI(5)                                                        COPE2837
      MM5=M5+NXAPRX-1                                                   COPE2838
      WRITE (6,100)                                                     COPE2839
      WRITE (6,110) (IA(I),I=M5,MM5)                                    COPE2840
C     GLOBAL LOCATIONS OF F(X).                                         COPE2841
      M6=LOCI(6)                                                        COPE2842
      MM6=M6+NF-1                                                       COPE2843
      WRITE (6,140)                                                     COPE2844
      WRITE (6,110) (IA(I),I=M6,MM6)                                    COPE2845
C     ------------------------------------------------------------------COPE2846
C                 X-VALUES AND FUNCTIONS, F(X)                          COPE2847
C     ------------------------------------------------------------------COPE2848
C     X-VALUES.                                                         COPE2849
      N1=LOCR(23)+3*NXAPRX+6                                            COPE2850
      N2=N1+NXAPRX-1                                                    COPE2851
      WRITE (6,120) NPTOT,INOM                                          COPE2852
      WRITE (6,130) (RA(I),I=N1,N2)                                     COPE2853
C     F(X) VALUES.                                                      COPE2854
      N1=N1+NXAPRX+NDV                                                  COPE2855
      N2=N1+NF-1                                                        COPE2856
      WRITE (6,150)                                                     COPE2857
      WRITE (6,130) (RA(I),I=N1,N2)                                     COPE2858
C     ------------------------------------------------------------------COPE2859
C                       TAYLER SERIES COEFFICIENTS.                     COPE2860
C     ------------------------------------------------------------------COPE2861
      WRITE (6,170)                                                     COPE2862
      NP=NPTOT-1                                                        COPE2863
      NBTAY=N1+2*NF                                                     COPE2864
      NBR=NXAPRX+(NXAPRX*(NXAPRX+1))/2                                  COPE2865
      IF (MAXTRM.LT.3) NBR=MAXTRM*NXAPRX                                COPE2866
      DO 30 JJ=1,NF                                                     COPE2867
      M6=LOCI(6)+JJ-1                                                   COPE2868
      M6=IA(M6)                                                         COPE2869
      WRITE (6,80) JJ,M6                                                COPE2870
C     LINEAR TERMS.                                                     COPE2871
      N2=NXAPRX                                                         COPE2872
      IF (NP.LT.N2) N2=NP                                               COPE2873
      N2=N2+NBTAY-1                                                     COPE2874
      WRITE (6,160)                                                     COPE2875
      WRITE (6,130) (RA(I),I=NBTAY,N2)                                  COPE2876
      IF (NP.LE.NXAPRX) GO TO 20                                        COPE2877
      IF (MAXTRM.LT.2) GO TO 20                                         COPE2878
C     NON-LINEAR TERMS.                                                 COPE2879
C     N1 = LOCATION OF FIRST DIAGONAL ELEMENT.                          COPE2880
      N1=N2+1                                                           COPE2881
C     N2 = LOCATION OF LAST DIAGONAL ELEMENT.                           COPE2882
      N2=NXAPRX                                                         COPE2883
      IF (N2.GT.NP) N2=NP                                               COPE2884
      N2=N2+N1-1                                                        COPE2885
C     N3=LOCATION OF FIRST OFF-DIAGONAL ELEMENT.                        COPE2886
      N3=N2+1                                                           COPE2887
C     N4=LOCATION OF LAST OFF-DIAGONAL ELEMENT.                         COPE2888
      N4=NBR                                                            COPE2889
      IF (N4.GT.NP) N4=NP                                               COPE2890
      N4=N4-2*NXAPRX+N3-1                                               COPE2891
C     LL = LOCATION OF LAST OFF-DIAGONAL ELEMENT - THIS ROW.            COPE2892
      WRITE (6,190)                                                     COPE2893
      II=1                                                              COPE2894
      DO 10 I=N1,N2                                                     COPE2895
      WRITE (6,180) II                                                  COPE2896
      II=II+1                                                           COPE2897
      LL=N3+NXAPRX-II                                                   COPE2898
      IF (LL.GT.N4) LL=N4                                               COPE2899
      IF (LL.LT.N3) WRITE (6,130) RA(I)                                 COPE2900
      IF (LL.GE.N3) WRITE (6,130) RA(I),(RA(J),J=N3,LL)                 COPE2901
10    N3=LL+1                                                           COPE2902
20    CONTINUE                                                          COPE2903
      NBTAY=NBTAY+NBR                                                   COPE2904
30    CONTINUE                                                          COPE2905
      IF (IPAPRX.LT.3) RETURN                                           COPE2906
      REWIND ISCR2                                                      COPE2907
      WRITE (6,50)                                                      COPE2908
      DO 40 I=1,NPTOT                                                   COPE2909
C     X-VECTOR.                                                         COPE2910
      READ (ISCR2) (RA(J),J=1,NXAPRX)                                   COPE2911
      WRITE (6,60) I                                                    COPE2912
      WRITE (6,130) (RA(J),J=1,NXAPRX)                                  COPE2913
C     FUNCTION VALUES.                                                  COPE2914
      READ (ISCR2) (RA(J),J=1,NF)                                       COPE2915
      WRITE (6,70)                                                      COPE2916
      WRITE (6,130) (RA(J),J=1,NF)                                      COPE2917
40    CONTINUE                                                          COPE2918
      RETURN                                                            COPE2919
C     ------------------------------------------------------------------COPE2920
C                                  FORMATS                              COPE2921
C     ------------------------------------------------------------------COPE2922
50    FORMAT (///5X,18HSUMMARY OF DESIGNS)                              COPE2923
60    FORMAT (/5X,13HDESIGN NUMBER,I5/5X,8HX-VECTOR)                    COPE2924
70    FORMAT (/5X,15HFUNCTION VALUES)                                   COPE2925
80    FORMAT (//5X,9HPARAMETER,I5,18H = GLOBAL VARIABLE,I5)             COPE2926
90    FORMAT (1H1,4X,44HRESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION///5COPE2927
     1X,5HTITLE/5X,20A4)                                                COPE2928
100   FORMAT (///5X,31HGLOBAL LOCATIONS OF X-VARIABLES)                 COPE2929
110   FORMAT (5X,10I5)                                                  COPE2930
120   FORMAT (//5X,25HAPPROXIMATION IS BASED ON,I5,8H DESIGNS//5X,31HNOMCOPE2931
     1INAL DESIGN IS DESIGN NUMBER,I5//5X,21HVALUES OF X-VARIABLES)     COPE2932
130   FORMAT (5X,5E13.4)                                                COPE2933
140   FORMAT (//5X,35HGLOBAL LOCATIONS OF FUNCTIONS, F(X))              COPE2934
150   FORMAT (//5X,25HVALUES OF FUNCTIONS, F(X))                        COPE2935
160   FORMAT (/5X,19HLINEAR TERMS, DEL F)                               COPE2936
170   FORMAT (///5X,39HCOEFFICIENTS OF TAYLOR SERIES EXPANSION)         COPE2937
180   FORMAT (/5X,3HROW,I5)                                             COPE2938
190   FORMAT (//5X,51HNON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENCOPE2939
     1T)                                                                COPE2940
      END                                                               COPE2941
      SUBROUTINE COPE15 (XV,G,DF,A,ISC,IC,NN1,BLU,NX1,IOBJA,M,FNOM,FNEW,COPE2942
     1BTAY,NBR,IGFN,CT,CTL,INFO,NAC,NCONA,NDV,NF,OBJ,SGNOPT)            COPE2943
      DIMENSION XV(1), FNOM(1), FNEW(1), A(NN1,1), BTAY(NBR,1), DF(1), ICOPE2944
     1GFN(1), ISC(1), IC(1), G(1), BLU(4,1)                             COPE2945
C     ******************************************************************COPE2946
C             FUNCTION EVALUATION FOR APPROXIMATE OPTIMIZATION.         COPE2947
C     ******************************************************************COPE2948
C     BY G. N. VANDERPLAATS                                 JAN., 1979.COPE2949
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE2950
C                                                                       COPE2951
C     ------------------------------------------------------------------COPE2952
C                                 OBJECTIVE.                            COPE2953
C     ------------------------------------------------------------------COPE2954
      CALL COPE16 (NX1,XV,NF,FNOM,FNEW,BTAY,NBR,M)                      COPE2955
      OBJ=-FNEW(IOBJA)*SGNOPT                                           COPE2956
      IF (INFO.EQ.1) GO TO 20                                           COPE2957
C     GRADIENT OF OBJECTIVE.                                            COPE2958
      CALL COPE17 (NX1,XV,IOBJA,BTAY,NBR,M,DF)                          COPE2959
      DO 10 I=1,NDV                                                     COPE2960
10    DF(I)=-DF(I)*SGNOPT                                               COPE2961
20    CONTINUE                                                          COPE2962
      IF (NCONA.LE.0) GO TO 80                                          COPE2963
C     ------------------------------------------------------------------COPE2964
C                                CONSTRAINTS.                           COPE2965
C     ------------------------------------------------------------------COPE2966
      IF (INFO.EQ.2) NAC=0                                              COPE2967
      ICON=0                                                            COPE2968
      DO 70 I=1,NCONA                                                   COPE2969
      J=IGFN(I)                                                         COPE2970
      GG=FNEW(J)                                                        COPE2971
C     LOWER BOUND.                                                      COPE2972
      IF (BLU(1,I).LT.-1.0E+15) GO TO 40                                COPE2973
      ICON=ICON+1                                                       COPE2974
      G(ICON)=(BLU(1,I)-GG)/BLU(2,I)                                    COPE2975
      IF (INFO.EQ.1) GO TO 40                                           COPE2976
C     IS THIS CONSTRAINT ACTIVE OR VIOLATED.                            COPE2977
      CTI=CT                                                            COPE2978
      IF (ISC(ICON).GT.0) CTI=CTL                                       COPE2979
      IF (G(ICON).LT.CTI) GO TO 40                                      COPE2980
C     ACTIVE CONSTRAINT. CALCULATE GRADIENT.                            COPE2981
      NAC=NAC+1                                                         COPE2982
      IC(NAC)=ICON                                                      COPE2983
      MM=M                                                              COPE2984
      IF (ISC(ICON).GT.0) MM=NDV                                        COPE2985
      CALL COPE17 (NX1,XV,J,BTAY,NBR,MM,A(1,NAC))                       COPE2986
      FF=1./BLU(2,I)                                                    COPE2987
      DO 30 K=1,NDV                                                     COPE2988
30    A(K,NAC)=-A(K,NAC)*FF                                             COPE2989
40    IF (BLU(3,I).GT.1.0E+15) GO TO 60                                 COPE2990
      ICON=ICON+1                                                       COPE2991
      G(ICON)=(GG-BLU(3,I))/BLU(4,I)                                    COPE2992
      IF (INFO.EQ.1) GO TO 60                                           COPE2993
C     IS THIS CONSTRAINT ACTIVE OR VIOLATED.                            COPE2994
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      CTI=CT                                                            COPE2995
      IF (ISC(ICON).GT.0) CTI=CTL                                       COPE2996
      IF (G(ICON).LT.CTI) GO TO 60                                      COPE2997
C     ACTIVE CONSTRAINT. CALCULATE GRADIENT.                            COPE2998
      NAC=NAC+1                                                         COPE2999
      IC(NAC)=ICON                                                      COPE3000
      MM=M                                                              COPE3001
      IF (ISC(ICON).GT.0) MM=NDV                                        COPE3002
      CALL COPE17 (NX1,XV,J,BTAY,NBR,MM,A(1,NAC))                       COPE3003
      FF=1./BLU(4,I)                                                    COPE3004
      DO 50 K=1,NDV                                                     COPE3005
50    A(K,NAC)=A(K,NAC)*FF                                              COPE3006
60    CONTINUE                                                          COPE3007
70    CONTINUE                                                          COPE3008
80    CONTINUE                                                          COPE3009
      RETURN                                                            COPE3010
      END                                                               COPE3011
      SUBROUTINE COPE16 (NX,X,NF,FNOM,FNEW,B,NBR,M)                     COPE3012
C     ******************************************************************COPE3013
C     ROUTINE TO EVALUATE FUNCTIONS APPROXIMATED BY TAYLER SERIES       COPE3014
C     EXPANSION UP TO SECOND ORDER.                                     COPE3015
C     ******************************************************************COPE3016
C     BY G. N. VANDERPLAATS                          MAR., 1978.        COPE3017
C     NAVAL SHIP R AND D CENTER.                                        COPE3018
C                                                                       COPE3019
C     F = F0 + DELF TIMES X + X-TRANSPOSE TIMES DEL2F TIMES X.          COPE3020
C     ARGUEMENTS.                                                       COPE3021
C     NX   - NUMBER OF INDEPENDENT VARIABLES CONTAINED IN X.            COPE3022
C     X    - VECTOR OF DELTA VARIABLES X-XNOM.  DIMENSIONED X(NX)       COPE3023
C     NF   - NUMBER OF FUNCTIONS TO BE EVALUATED.                       COPE3024
C     FNOM - NOMINAL FUNCTION VALUES ABOUT WHICH TAYLER SERIES EXPANSIONCOPE3025
C     WAS DONE.                                                         COPE3026
C     FNEW - NEW APPROXIMATED VALUES. - OUTPUT.  DIMENSIONED FNEW(NF)   COPE3027
C     B    - MATRIX OF TAYLER SERIES COEFFICIENTS.                      COPE3028
C            B(I,J) CONTAINS DEL F, I=1,NX.                             COPE3029
C            B(NX+I,J) CONTAINS DEL2 TERMS,  I = 1,NX*(NX+1)/2.         COPE3030
C            MINIMUM DIMENSIONS - B(M,NF).                              COPE3031
C     NBR  - DIMENSIONED ROWS OF B.                                     COPE3032
C     M    - TOTAL NUMBER OF COEFFICIENTS CURRENTLY USED.               COPE3033
C                                                                       COPE3034
      DIMENSION X(1), FNOM(1), FNEW(1), B(NBR,1)                        COPE3035
      DO 50 J=1,NF                                                      COPE3036
C     ------------------------------------------------------------------COPE3037
C                               CONSTANT TERM.                          COPE3038
C     ------------------------------------------------------------------COPE3039
      F=FNOM(J)                                                         COPE3040
C     ------------------------------------------------------------------COPE3041
C                           FIRST ORDER TERMS.                          COPE3042
C     ------------------------------------------------------------------COPE3043
      DO 10 I=1,NX                                                      COPE3044
      IF (I.GT.M) GO TO 40                                              COPE3045
10    F=F+B(I,J)*X(I)                                                   COPE3046
C     ------------------------------------------------------------------COPE3047
C                          SECOND ORDER TERMS.                          COPE3048
C     ------------------------------------------------------------------COPE3049
C                                                                       COPE3050
C     ------------------------------------------------------------------COPE3051
C                          DIAGONAL ELEMENTS.                           COPE3052
C     ------------------------------------------------------------------COPE3053
      II=NX                                                             COPE3054
      DO 20 I=1,NX                                                      COPE3055
      II=II+1                                                           COPE3056
      IF (II.GT.M) GO TO 40                                             COPE3057
20    F=F+.5*B(II,J)*(X(I)**2)                                          COPE3058
C     ------------------------------------------------------------------COPE3059
C                         OFF-DIAGONAL ELEMENTS.                        COPE3060
C     ------------------------------------------------------------------COPE3061
      IF (NX.LT.2) GO TO 40                                             COPE3062
      NXM1=NX-1                                                         COPE3063
      DO 30 I=1,NXM1                                                    COPE3064
      IP1=I+1                                                           COPE3065
      XX=X(I)                                                           COPE3066
      DO 30 K=IP1,NX                                                    COPE3067
      II=II+1                                                           COPE3068
      IF (II.GT.M) GO TO 40                                             COPE3069
30    F=F+B(II,J)*XX*X(K)                                               COPE3070
40    CONTINUE                                                          COPE3071
50    FNEW(J)=F                                                         COPE3072
      RETURN                                                            COPE3073
      END                                                               COPE3074
      SUBPOUTINE COPE17 (NX,X,J,B,NBR,M,GRAD)                           COPE3075
C     ******************************************************************COPE3076
C     ROUTINE TO CALCULATE GRADIENT OF THE J-TH FUNCTION APPROXIMATED   COPE3077
C     BY TAYLER SERIES EXPANSION UP TO SECOND ORDER.                    COPE3078
C     ******************************************************************COPE3079
C     BY G. N. VANDERPLAATS                          APRIL, 1978.       COPE3080
C     NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE3081
C                                                                       COPE3082
C     F ■ F0 + DELF TIMES X + .5 X-TRANSPOSE TIMES DEL2F TIMES X.       COPE3083
C     AGRUEMENTS.                                                       COPE3084
C     NX   - NUMBER OF INDEPENDENT VARIABLES CONTAINED IN X.            COPE3085
C     X    - VECTOR OF DELTA VARIABLES X-XNOM.  DIMENSIONED X(NX).      COPE3086
C     J    - FUNCTION FOR WHICH GRADIENT INFORMATION IS CALCULATED.     COPE3087
C     B    - MATRIX OF TAYLER SERIES COEFFICIENTS.                      COPE3088
C           B(I,J) CONTAINS DELF, I = 1,NX.                             COPE3099
C            B(NX+I,J) CONTAINS DEL2 TERMS, I = 1,NS*(NX+1)/2.          COPE3090
C            MINIMUM DIMENSIONS - B(M,NF).                              COPE3091
C     NBR  - DIMENSIONED POWS OF B.                                     COPE3092
C     M    - TOTAL NUMBER OF COEFFICIENTS CURRENTLY USED.               COPE3093
C     GRAD - GRADIENT OF J-TH FUNCTION.  OUTPUT.                        COPE3094
C                                                                       COPE3095
      DIMENSION X(1), B(NBR,1), GRAD(1)                                 COPE3096
C     ------------------------------------------------------------------COPE3097
C                           FIRST ORDER TERMS.                          COPE3098
C     ------------------------------------------------------------------COPE3099
      DO 10 I=1,NX                                                      COPE3100
      IF (I.GT.M) GO TO 40                                              COPE3101
10    GRAD(I)=B(I,J)                                                    COPE3102
C     ------------------------------------------------------------------COPE3103
C                          SECOND ORDER TERMS.                          COPE3104
C     ------------------------------------------------------------------COPE3105
      II=NX                                                             COPE3106
C     ------------------------------------------------------------------COPE3107
C                          DIAGONAL ELEMENTS.                           COPE3108
C     ------------------------------------------------------------------COPE3109
      DO 20 I=1,NX                                                      COPE3110
      II=II+1                                                           COPE3111
      IF (II.GT.M) GO TO 40                                             COPE3112
20    GPAD(I)=GRAD(I)+B(II,J)*X(I)                                      COPE3113
C     ------------------------------------------------------------------COPE3114
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C                         OFF-DIAGONAL ELEMENTS.                        COPE3115
C     ------------------------------------------------------------------COPE3116
      IF (NX.LT.2) GO TO 40                                             COPE3117
      NXM1=NX-1                                                         COPE3118
      DO 30 I=1,NXM1                                                    COPE3119
      IP1=I+1                                                           COPE3120
      DO 30 K=IP1,NX                                                    COPE3121
      II=II+1                                                           COPE3122
      IF (II.GT.M) GO TO 40                                             COPE3123
      GRAD(I)=GRAD(I)+B(II,J)*X(K)                                      COPE3124
30    GRAD(K)=GRAD(K)+B(II,J)*X(I)                                      COPE3125
40    CONTINUE                                                          COPE3126
      RETURN                                                            COPE3127
      END                                                               COPE3128
      SUBROUTINE COPE18 (IOBJ,NDVTOT,NCONA,RA,IA,LOCR,LOCI,ARRAY)       COPE3129
C     ******************************************************************COPE3130
C                 ROUTINE TO PRINT OPTIMIZATION RESULTS                 COPE3131
C     ******************************************************************COPE3132
C     BY G. N. VANDERPLAATS                             MAR., 1979      COPE3133
C     NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  COPE3134
      DIMENSION RA(1), IA(1), LOCR(1), LOCI(1), ARRAY(1)                COPE3135
C     OBJECTIVE FUNCTION AND DESIGN VARIABLES.                          COPE3136
      WRITE (6,30) IOBJ,ARRAY(IOBJ)                                     COPE3137
      N2=LOCR(2)                                                        COPE3138
      N3=LOCR(3)                                                        COPE3139
      N5=LOCR(5)                                                        COPE3140
      M2=LOCI(2)                                                        COPE3141
      DO 10 I=1,NDVTOT                                                  COPE3142
C     DESIGN VARIABLE NUMBER.                                           COPE3143
      IDV=IA(M2)                                                        COPE3144
      N2=LOCR(2)+IDV-1                                                  COPE3145
      N3=LOCR(3)+IDV-1                                                  COPE3146
      M2=M2+1                                                           COPE3147
C     GLOBAL LOCATION.                                                  COPE3148
      IG=IA(I)                                                          COPE3149
C     MULTIPLIER.                                                       COPE3150
      AMULT=RA(N5)                                                      COPE3151
      N5=N5+1                                                           COPE3152
C     LOWER BOUND.                                                      COPE3153
      BL=AMULT*RA(N2)                                                   COPE3154
C     VALUE.                                                            COPE3155
      XX=ARRAY(IG)                                                      COPE3156
C     UPPER BOUND.                                                      COPE3157
      BU=AMULT*RA(N3)                                                   COPE3158
      WRITE (6,40) I,IDV,IG,BL,XX,BU                                    COPE3159
10    CONTINUE                                                          COPE3160
      IF (NCONA.EQ.0) RETURN                                            COPE3161
C     CONSTRAINTS.                                                      COPE3162
      WRITE (6,50)                                                      COPE3163
      M3=LOCI(3)                                                        COPE3164
      N6=LOCR(6)                                                        COPE3165
      ID=1                                                              COPE3166
      IF (RA(N6).LT.-1.0E+15.AND.RA(N6+2).GT.1.0E+15) ID=0              COPE3167
      DO 20 I=1,NCONA                                                   COPE3168
C     GLOBAL LOCATION.                                                  COPE3169
      IG=IA(M3)                                                         COPE3170
      M3=M3+1                                                           COPE3171
C     LOWER BOUND.                                                      COPE3172
      BL=RA(N6)                                                         COPE3173
C     VALUE.                                                            COPE3174
      XX=ARRAY(IG)                                                      COPE3175
C     UPPER BOUND.                                                      COPE3176
      BU=RA(N6+2)                                                       COPE3177
      N6=N6+4                                                           COPE3178
C     IDENTIFICATION NUMBER.                                            COPE3179
      JD=ID                                                             COPE3180
      IF (BL.GT.-1.0E+15) ID=ID+1                                       COPE3181
      IF (BU.LT.1.0E+15) ID=ID+1                                        COPE3182
      WRITE (6,60) JD,IG,BL,XX,BU                                       COPE3183
20    CONTINUE                                                          COPE3184
      RETURN                                                            COPE3185
C     ------------------------------------------------------------------COPE3186
C                                  FORMATS                              COPE3187
C     ------------------------------------------------------------------COPE3188
30    FORMAT (1H1,4X,20HOPTIMIZATION RESULTS///5X,18HOBJECTIVE FUNCTION/COPE3189
     15X,15HGLOBAL LOCATION,I5,5X,14HFUNCTION VALUE,E12.5///5X,16HDESIGNCOPE3190
     2 VARIABLES//14X,5HD. V.,5X,6HGLOBAL,7X,5HLOWER,23X,5HUPPER/8X,2HIDCOPE3191
     3,5X,3HNO.,5X,8HVAR. NO.,6X,5HBOUND,9X,5HVALUE,9X,5HBOUND)        COPE3192
40    FORMAT (I10,I7,I11,3X,3E14.5)                                     COPE3193
50    FORMAT (///5X,18HDESIGN CONSTRAINTS//15X,6HGLOBAL,7X,5HLOWER,23X,5COPE3194
     1HUPPER/9X,2HID,4X,8HVAR. NO.,6X,5HBOUND,9X,5HVALUE,9X,5HBOUND)   COPE3195
60    FORMAT (I10,I9,3X,3E14.5)                                         COPE3196
      END                                                               COPE3197
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      SUBROUTINE CONMIN (X,VLB,VUB,G,SCAL,DF,A,S,G1,G2,B,C,ISC,IC,MS1,N1CONMIN 2
     1,N2,N3,N4,N5)                                                    CONMIN 3
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCONMIN 4
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCONMIN 5
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                              CONMIN 6
      DIMENSION X(N1), VLB(N1), VUB(N1), G(N2), SCAL(N1), DF(N1), A(N1,NCONMIN 7
     13), S(N1), G1(N2), G2(N2), B(N3,N3), C(N4), ISC(N2), IC(N3), MS1(NCONMIN 8
     25)                                                               CONMIN 9
      COMMON /CONSAV/ DM1,DM2,DM3,DM4,DM5,DM6,DM7,DM8,DM9,DM10,DM11,DM12CONMIN10
     1,DCT,DCTL,PHI,ABOBJ,CTA,CTAM,CTBM,OBJ1,SLOPE,DX,DX1,FI,XI,DFTDF1,ACONMIN11
     2LP,FFF,A1,A2,A3,A4,F1,F2,F3,F4,CV1,CV2,CV3,CV4,APP,ALPCA,ALPFES,ALCONMIN12
     3PLN,ALPMIN,ALPNC,ALPSAV,ALPSID,ALPTOT,RSPACE,IDM1,IDM2,IDM3,JDIR,ICONMIN13
     4OBJ,KOBJ,KCOUNT,NCAL(2),NFEAS,MSCAL,NCOBJ,NVC,KOUNT,ICOUNT,IGOOD1,CONMIN14
     5IGOOD2,IGOOD3,IGOOD4,IBEST,III,NLNC,JGOTO,ISPACE(2)              CONMIN15
C     ROUTINE TO SOLVE CONSTRAINED OR UNCONSTRAINED FUNCTION            CONMIN16
C     MINIMIZATION.                                                     CONMIN17
C     BY G. N. VANDERPLAATS                         APRIL, 1972.        CONMIN18
C     * * * * * * * * * * *   JUNE, 1979 VERSION   * * * * * * * * * * *CONMIN19
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  CONMIN20
C     REFERENCE;  CONMIN - A FORTRAN PROGRAM FOR CONSTRAINED FUNCTION   CONMIN21
C         MINIMIZATION:  USER'S MANUAL,  BY G. N. VANDERPLAATS,         CONMIN22
C         NASA TM X-62,282, AUGUST, 1973.                               CONMIN23
C     STORAGE REQUIREMENTS:                                             CONMIN24
C         PROGRAM - 7000 DECIMAL WORDS (CDC COMPUTER)                   CONMIN25
C         ARRAYS  - APPROX. 2*(NDV**2)+26*NDV+4*NCON,                   CONMIN26
C               WHERE N3 = NDV+2.                                       CONMIN27
C     RE-SCALE VARIABLES IF REQUIRED.                                   CONMIN28
      IF (NSCAL.EQ.0.OR.IGOTO.EQ.0) GO TO 20                            CONMIN29
      DO 10 I=1,NDV                                                     CONMIN30
10    X(I)=C(I)                                                         CONMIN31
20    CONTINUE                                                          CONMIN32
C     CONSTANTS.                                                        CONMIN33
      NDV1=NDV+1                                                        CONMIN34
      NDV2=NDV+2                                                        CONMIN35
      IF (IGOTO.EQ.0) GO TO 40                                          CONMIN36
C     ------------------------------------------------------------------CONMIN37
C                        CHECK FOR UNBOUNDED SOLUTION                   CONMIN38
C     ------------------------------------------------------------------CONMIN39
C     STOP IF OBJ IS LESS THAN -1.0E+40                                 CONMIN40
      IF (OBJ.GT.-1.0E+40) GO TO 30                                     CONMIN41
      WRITE (6,980)                                                     CONMIN42
      GO TO 810                                                         CONMIN43
30    CONTINUE                                                          CONMIN44
      GO TO (160,390,380,670,690),IGOTO                                 CONMIN45
C     ------------------------------------------------------------------CONMIN46
C                        SAVE INPUT CONTROL PARAMETERS                  CONMIN47
C     ------------------------------------------------------------------CONMIN48
40    CONTINUE                                                          CONMIN49
      IF (IPRINT.GT.0) WRITE (6,1220)                                   CONMIN50
      IF (LINOBJ.EQ.0.OR.(NCON.GT.0.OR.NSIDE.GT.0)) GO TO 50            CONMIN51
C     TOTALLY UNCONSTRAINED FUNCTION WITH LINEAR OBJECTIVE.             CONMIN52
C     SOLUTION IS UNBOUNDED.                                            CONMIN53
      WRITE (6,970) LINOBJ,NCON,NSIDE                                   CONMIN54
      RETURN                                                            CONMIN55
50    CONTINUE                                                          CONMIN56
      IDM1=ITRM                                                         CONMIN57
      IDM2=ITMAX                                                        CONMIN58
      IDM3=ICNDIR                                                       CONMIN59
      DM1=DELFUN                                                        CONMIN60
      DM2=DABFUN                                                        CONMIN61
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      DM3=CT                                                            CONMIN62
      DM4=CTMIN                                                         CONMIN63
      DM5=CTL                                                           CONMIN64
      DM6=CTLMIN                                                        CONMIN65
      DM7=THETA                                                         CONMIN66
      DM8=PHI                                                           CONMIN67
      DM9=FDCH                                                          CONMIN68
      DM10=FDCHM                                                        CONMIN69
      DM11=ABOBJ1                                                       CONMIN70
      DM12=ALPHAX                                                       CONMIN71
C     ------------------------------------------------------------------CONMIN72
C                                  DEFAULTS                             CONMIN73
C     ------------------------------------------------------------------CONMIN74
      IF (ITRM.LE.0) ITRM=3                                             CONMIN75
      IF (ITMAX.LE.0) ITMAX=20                                          CONMIN76
      NDV1=NDV+1                                                        CONMIN77
      IF (ICNDIR.EQ.0) ICNDIR=NDV1                                      CONMIN78
      IF (DELFUN.LE.0.) DELFUN=.0001                                    CONMIN79
      CT=-ABS(CT)                                                       CONMIN80
      IF (CT.GE.0.) CT=-.1                                              CONMIN81
      CTMIN=ABS(CTMIN)                                                  CONMIN82
      IF (CTMIN.LE.0.) CTMIN=.004                                       CONMIN83
      CTL=-ABS(CTL)                                                     CONMIN84
      IF (CTL.GE.0.) CTL=-0.01                                          CONMIN85
      CTLMIN=ABS(CTLMIN)                                                CONMIN86
      IF (CTLMIN.LE.0.) CTLMIN=.001                                     CONMIN87
      IF (THETA.LE.0.) THETA=1.                                         CONMIN88
      IF (ABOBJ1.LE.0.) ABOBJ1=.1                                       CONMIN89
      IF (ALPHAX.LE.0.) ALPHAX=.1                                       CONMIN90
      IF (FDCH.LE.0.) FDCH=.01                                          CONMIN91
      IF (FDCHM.LE.0.) FDCHM=.01                                        CONMIN92
C     ------------------------------------------------------------------CONMIN93
C                        INITIALIZE INTERNAL PARAMETERS                 CONMIN94
C     ------------------------------------------------------------------CONMIN95
      INFOG=0                                                           CONMIN96
      ITER=0                                                            CONMIN97
      JDIR=0                                                            CONMIN98
      IOBJ=0                                                            CONMIN99
      KOBJ=0                                                            CONMI100
      NDV2=NDV+2                                                        CONMI101
      KCOUNT=0                                                          CONMI102
      NCAL(1)=0                                                         CONMI103
      NCAL(2)=0                                                         CONMI104
      NAC=0                                                             CONMI105
      NFEAS=0                                                           CONMI106
      MSCAL=NSCAL                                                       CONMI107
      CT1=ITRM                                                          CONMI108
      CT1=1./CT1                                                        CONMI109
      DCT=(CTMIN/ABS(CT))**CT1                                          CONMI110
      DCTL=(CTLMIN/ABS(CTL))**CT1                                       CONMI111
      PHI=5.                                                            CONMI112
      ABOBJ=ABOBJ1                                                      CONMI113
      NCOBJ=0                                                           CONMI114
      CTAM=ABS(CTMIN)                                                   CONMI115
      CTBM=ABS(CTLMIN)                                                  CONMI116
C     CALCULATE NUMBER OF LINEAR CONSTRAINTS, NLNC.                     CONMI117
      NLNC=0                                                            CONMI118
      IF (NCON.EQ.0) GO TO 70                                           CONMI119
      DO 60 I=1,NCON                                                    CONMI120
      IF (ISC(I).GT.0) NLNC=NLNC+1                                      CONMI121
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60    CONTINUE                                                          CONMI122
70    CONTINUE                                                          CONMI123
C     ------------------------------------------------------------------CONMI124
C          CHECK TO BE SURE THAT SIDE CONSTRAINTS APE SATISFIED         CONMI125
C     ------------------------------------------------------------------CONMI126
      IF (NSIDE.EQ.0) GO TO 110                                         CONMI127
      DO 100 I=1,NDV                                                    CONMI128
      IF (VLB(I).LE.VUB(I)) GO TO 80                                    CONMI129
      XX=.5*(VLB(I)+VUB(I))                                             CONMI130
      X(I)=XX                                                           CONMI131
      VLB(I)=XX                                                         CONMI132
      VUB(I)=XX                                                         CONMI133
      WRITE (6,1120) I                                                  CONMI134
80    CONTINUE                                                          CONMI135
      XX=X(I)-VLB(I)                                                    CONMI136
      IF (XX.GE.0.) GO TO 90                                            CONMI137
C     LOWER BOUND VIOLATED.                                             CONMI138
      WRITE (6,1130) X(I),VLB(I),I                                      CONMI139
      X(I)=VLB(I)                                                       CONMI140
      GO TO 100                                                         CONMI141
90    CONTINUE                                                          CONMI142
      XX=VUB(I)-X(I)                                                    CONMI143
      IF (XX.GE.0.) GO TO 100                                           CONMI144
      WRITE (6,1140) X(I),VUB(I),I                                      CONMI145
      X(I)=VUB(I)                                                       CONMI146
100   CONTINUE                                                          CONMI147
110   CONTINUE                                                          CONMI148
C     ------------------------------------------------------------------CONMI149
C                         INITIALIZE SCALING VECTOR, SCAL               CONMI150
C     ------------------------------------------------------------------CONMI151
      IF (NSCAL.EQ.0) GO TO 150                                         CONMI152
      IF (NSCAL.LT.0) GO TO 130                                         CONMI153
      DO 120 I=1,NDV                                                    CONMI154
120   SCAL(I)=1.                                                        CONMI155
      GO TO 150                                                         CONMI156
130   CONTINUE                                                          CONMI157
      DO 140 I=1,NDV                                                    CONMI158
      SI=ABS(SCAL(I))                                                   CONMI159
      IF (SI.LT.1.0E-20) SI=1.0E-5                                      CONMI160
      SCAL(I)=SI                                                        CONMI161
      SI=1./SI                                                          CONMI162
      X(I)=X(I)*SI                                                      CONMI163
      IF (NSIDE.EQ.0) GO TO 140                                         CONMI164
      VLB(I)=VLB(I)*SI                                                  CONMI165
      VUB(I)=VUB(I)*SI                                                  CONMI166
140   CONTINUE                                                          CONMI167
150   CONTINUE                                                          CONMI168
C     ------------------------------------------------------------------CONMI169
C     ***** CALCULATE INITIAL FUNCTION AND CONSTRAINT VALUES  *****     CONMI170
C     ------------------------------------------------------------------CONMI171
      INFO=1                                                            CONMI172
      NCAL(1)=1                                                         CONMI173
      IGOTO=1                                                           CONMI174
      GO TO 950                                                         CONMI175
160   CONTINUE                                                          CONMI176
      OBJ1=OBJ                                                          CONMI177
      IF (DABFUN.LE.0.) DABFUN=.001*ABS(OBJ)                            CONMI178
      IF (DABFUN.LT.1.0E-10) DADFUN=1.0E-10                             CONMI179
      IF (IPRINT.LE.0) GO TO 270                                        CONMI180
C     ------------------------------------------------------------------CONMI181
C                         PRINT INITIAL DESIGN INFORMATION              CONMI182
C     ------------------------------------------------------------------CONMI183
      IF (IPRINT.LE.1) GO TO 230                                        CONMI184
      IF (NSIDE.EQ.0.AND.NCON.EQ.0) WRITE (6,1290)                      CONMI185
      IF (NSIDE.NE.0.OR.NCON.GT.0) WRITE (6,1230)                       CONMI186
      WRITE (6,1240) IPRINT,NDV,ITMAX,NCON,NSIDE,ICNDIR,NSCAL,NFDG,LINOBCONMI187
     1J,ITRM,N1,N2,N3,N4,N5                                             CONMI188
      WRITE (6,1260) CT,CTMIN,CTL,CTLMIN,THETA,PHI,DELFUN,DABFUN        CONMI189
      WRITE (6,1250) FDCH,FDCHM,ALPHAX,ABOBJ1                           CONMI190
      IF (NSIDE.EQ.0) GO TO 190                                         CONMI191
      WRITE (6,1270)                                                    CONMI192
      DO 170 I=1,NDV,6                                                  CONMI193
      M1=MIN0(NDV,I+5)                                                  CONMI194
170   WRITE (6,1010) I,(VLB(J),J=I,M1)                                  CONMI195
      WRITE (6,1280)                                                    CONMI196
      DO 180 I=1,NDV,6                                                  CONMI197
      M1=MIN0(NDV,I+5)                                                  CONMI198
180   WRITE (6,1010) I,(VUB(J),J=I,M1)                                  CONMI199
190   CONTINUE                                                          CONMI200
      IF (NSCAL.GE.0) GO TO 200                                         CONMI201
      WRITE (6,1300)                                                    CONMI202
      WRITE (6,1460) (SCAL(I),I=1,NDV)                                  CONMI203
200   CONTINUE                                                          CONMI204
      IF (NCON.EQ.0) GO TO 230                                          CONMI205
      IF (NLNC.EQ.0.OR.NLNC.EQ.NCON) GO TO 220                          CONMI206
      WRITE (6,1020)                                                    CONMI207
      DO 210 I=1,NCON,15                                                CONMI208
      M1=MIN0(NCON,I+14)                                                CONMI209
210   WRITE (6,1030) I,(ISC(J),J=I,M1)                                  CONMI210
      GO TO 230                                                         CONMI211
220   IF (NLNC.EQ.NCON) WRITE (6,1040)                                  CONMI212
      IF (NLNC.EQ.0) WRITE (6,1050)                                     CONMI213
230   CONTINUE                                                          CONMI214
      WRITE (6,1440) OBJ                                                CONMI215
      WRITE (6,1450)                                                    CONMI216
      DO 240 I=1,NDV                                                    CONMI217
      X1=1.                                                             CONMI218
      IF (NSCAL.NE.0) X1=SCAL(I)                                        CONMI219
240   G1(I)=X(I)*X1                                                     CONMI220
      DO 250 I=1,NDV,6                                                  CONMI221
      M1=MIN0(NDV,I+5)                                                  CONMI222
250   WRITE (6,1010) I,(G1(J),J=I,M1)                                   CONMI223
      IF (NCON.EQ.0) GO TO 270                                          CONMI224
      WRITE (6,1470)                                                    CONMI225
      DO 260 I=1,NCON,6                                                 CONMI226
      M1=MIN0(NCON,I+5)                                                 CONMI227
260   WRITE (6,1010) I,(G(J),J=I,M1)                                    CONMI228
270   CONTINUE                                                          CONMI229
      IF (IPRINT.GT.1) WRITE (6,1360)                                   CONMI230
C     ------------------------------------------------------------------CONMI231
C     *******************  BEGIN MINIMIZATION  ************************CONMI232
C     ------------------------------------------------------------------CONMI233
280   CONTINUE                                                          CONMI234
      ITER=ITER+1                                                       CONMI235
      IF (ABOBJ1.LT..0001) ABOBJ1=.0001                                 CONMI236
      IF (ABOBJ1.GT..2) ABOBJ1=.2                                       CONMI237
      IF (ALPHAX.GT.1.) ALPHAX=1.                                       CONMI238
      IF (ALPHAX.LT..001) ALPHAX=.001                                   CONMI239
      IF (IPRINT.GT.2) WRITE (6,1310) ITER                              CONMI240
      IF (IPRINT.GT.3.AND.NCON.GT.0) WRITE (6,1320) CT,CTL,PHI          CONMI241
      CTA=ABS(CT)                                                       CONMI242
      IF (NCOBJ.EQ.0) GO TO 340                                         CONMI243
C     ------------------------------------------------------------------CONMI244
C     NO MOVE ON LAST ITERATION.  DELETE CONSTRAINTS THAT ARE NO        CONMI245
C     LONGER ACTIVE.                                                    CONMI246
C     ------------------------------------------------------------------CONMI247
      NNAC=NAC                                                          CONMI248
      DO 290 I=1,NNAC                                                   CONMI249
      IF (IC(I).GT.NCON) NAC=NAC-1                                      CONMI250
290   CONTINUE                                                          CONMI251
      IF (NAC.LE.0) GO TO 420                                           CONMI252
      NNAC=NAC                                                          CONMI253
      DO 330 I=1,NNAC                                                   CONMI254
300   NIC=IC(I)                                                         CONMI255
      CT1=CT                                                            CONMI256
      IF (ISC(NIC).GT.0) CT1=CTL                                        CONMI257
      IF (G(NIC).GT.CT1) GO TO 330                                      CONMI258
      NAC=NAC-1                                                         CONMI259
      IF (I.GT.NAC) GO TO 420                                           CONMI260
      DO 320 K=I,NAC                                                    CONMI261
      II=K+1                                                            CONMI262
      DO 310 J=1,NDV2                                                   CONMI263
310   A(J,K)=A(J,II)                                                    CONMI264
320   IC(K)=IC(II)                                                      CONMI265
      GO TO 300                                                         CONMI266
330   CONTINUE                                                          CONMI267
      GO TO 420                                                         CONMI268
340   CONTINUE                                                          CONMI269
      IF (MSCAL.LT.NSCAL.OR.NSCAL.EQ.0) GO TO 360                       CONMI270
      IF (NSCAL.LT.0.AND.KCOUNT.LT.ICNDIR) GO TO 360                    CONMI271
      MSCAL=0                                                           CONMI272
      KCOUNT=0                                                          CONMI273
C     ------------------------------------------------------------------CONMI274
C                              SCALE VARIABLES                          CONMI275
C     ------------------------------------------------------------------CONMI276
      DO 350 I=1,NDV                                                    CONMI277
      SI=SCAL(I)                                                        CONMI278
      XI=SI*X(I)                                                        CONMI279
      SIB=SI                                                            CONMI280
      IF (NSCAL.GT.0) SI=ABS(XI)                                        CONMI281
      IF (SI.LT.1.0E-10) GO TO 350                                      CONMI282
      SCAL(I)=SI                                                        CONMI283
      SI=1./SI                                                          CONMI284
      X(I)=XI*SI                                                        CONMI285
      IF (NSIDE.EQ.0) GO TO 350                                         CONMI286
      VLB(I)=SIB*SI*VLB(I)                                              CONMI287
      VUB(I)=SIB*SI*VUB(I)                                              CONMI288
350   CONTINUE                                                          CONMI289
      IF (IPRINT.LT.4.OR.(NSCAL.LT.0.AND.ITER.GT.1)) GO TO 360          CONMI290
      WRITE (6,1330)                                                    CONMI291
      WRITE (6,1460) (SCAL(I),I=1,NDV)                                  CONMI292
360   CONTINUE                                                          CONMI293
      MSCAL=MSCAL+1                                                     CONMI294
      NAC=0                                                             CONMI295
C     ------------------------------------------------------------------CONMI296
C          OBTAIN GRADIENTS OF OBJECTIVE AND ACTIVE CONSTRAINTS         CONMI297
C     ------------------------------------------------------------------CONMI298
      INFO=2                                                            CONMI299
      NCAL(2)=NCAL(2)+1                                                 CONMI300
      IF (NFDG.NE.1) GO TO 370                                          CONMI301
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      IGOTO=2                                                           CONMI302
      GO TO 950                                                         CONMI303
370   CONTINUE                                                          CONMI304
      JGOTO=0                                                           CONMI305
380   CONTINUE                                                          CONMI306
      CALL CNMN01 (JGOTO,X,DF,G,ISC,IC,A,G1,VLB,VUB,SCAL,C,NCAL,DX,DX1,FCONMI307
     1I,XI,III,N1,N2,N3,N4)                                             CONMI308
      IGOTO=3                                                           CONMI309
      IF (JGOTO.GT.0) GO TO 950                                         CONMI310
390   CONTINUE                                                          CONMI311
      INFO=1                                                            CONMI312
      IF (NAC.GE.N3) GO TO 810                                          CONMI313
      IF (NSCAL.EQ.0.OR.NFDG.EQ.0) GO TO 420                            CONMI314
C     ------------------------------------------------------------------CONMI315
C                              SCALE GRADIENTS                          CONMI316
C     ------------------------------------------------------------------CONMI317
C     SCALE GRADIENT OF OBJECTIVE FUNCTION.                             CONMI318
      DO 400 I=1,NDV                                                    CONMI319
400   DF(I)=DF(I)*SCAL(I)                                               CONMI320
      IF (NFDG.EQ.2.OR.NAC.EQ.0) GO TO 420                              CONMI321
C     SCALE GRADIENTS OF ACTIVE CONSTRAINTS.                            CONMI322
      DO 410 J=1,NDV                                                    CONMI323
      SCJ=SCAL(J)                                                       CONMI324
      DO 410 I=1,NAC                                                    CONMI325
410   A(J,I)=A(J,I)*SCJ                                                 CONMI326
420   CONTINUE                                                          CONMI327
      IF (IPRINT.LT.3.OR.NCON.EQ.0) GO TO 470                           CONMI328
C     ------------------------------------------------------------------CONMI329
C                                   PRINT                               CONMI330
C     ------------------------------------------------------------------CONMI331
C     PRINT ACTIVE AND VIOLATED CONSTRAINT NUMBERS.                     CONMI332
      M1=0                                                              CONMI333
      M2=N3                                                             CONMI334
      IF (NAC.EQ.0) GO TO 450                                           CONMI335
      DO 440 I=1,NAC                                                    CONMI336
      J=IC(I)                                                           CONMI337
      IF (J.GT.NCON) GO TO 440                                          CONMI338
      GI=G(J)                                                           CONMI339
      C1=CTAM                                                           CONMI340
      IF (ISC(J).GT.0) C1=CTBM                                          CONMI341
      GI=GI-C1                                                          CONMI342
      IF (GI.GT.0.) GO TO 430                                           CONMI343
C     ACTIVE CONSTRAINT.                                                CONMI344
      M1=M1+1                                                           CONMI345
      MS1(M1)=J                                                         CONMI346
      GO TO 440                                                         CONMI347
430   M2=M2+1                                                           CONMI348
C     VIOLATED CONSTRAINT.                                              CONMI349
      MS1(M2)=J                                                         CONMI350
440   CONTINUE                                                          CONMI351
450   M3=M2-N3                                                          CONMI352
      WRITE (6,1060) M1                                                 CONMI353
      IF (M1.EQ.0) GO TO 460                                            CONMI354
      WRITE (6,1070)                                                    CONMI355
      WRITE (6,1480) (MS1(I),I=1,M1)                                    CONMI356
460   WRITE (6,1080) M3                                                 CONMI357
      IF (M3.EQ.0) GO TO 470                                            CONMI358
      WRITE (6,1070)                                                    CONMI359
      M3=N3+1                                                           CONMI360
      WRITE (6,1480) (MS1(I),I=M3,M2)                                   CONMI361
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470   CONTINUE                                                          CONMI362
C     ------------------------------------------------------------------CONMI363
C           CALCULATE GRADIENTS OF ACTIVE SIDE CONSTRAINTS              CONMI364
C     ------------------------------------------------------------------CONMI365
      IF (NSIDE.EQ.0) GO TO 530                                         CONMI366
      MCN1=NCON                                                         CONMI367
      M1=0                                                              CONMI368
      DO 510 I=1,NDV                                                    CONMI369
C     LOWER BOUND.                                                      CONMI370
      XI=X(I)                                                           CONMI371
      XID=VLB(I)                                                        CONMI372
      X12=ABS(XID)                                                      CONMI373
      IF (X12.LT.1.) X12=1.                                             CONMI374
      GI=(XID-XI)/X12                                                   CONMI375
      IF (GI.LT.-1.0E-6) GO TO 490                                      CONMI376
      M1=M1+1                                                           CONMI377
      MS1(M1)=-I                                                        CONMI378
      NAC=NAC+1                                                         CONMI379
      IF (NAC.GE.N3) GO TO 810                                          CONMI380
      MCN1=MCN1+1                                                       CONMI381
      DO 480 J=1,NDV                                                    CONMI382
480   A(J,NAC)=0.                                                       CONMI383
      A(I,NAC)=-1.                                                      CONMI384
      IC(NAC)=MCN1                                                      CONMI385
      G(MCN1)=GI                                                        CONMI386
      ISC(MCN1)=1                                                       CONMI387
C     UPPER BOUND.                                                      CONMI388
490   XID=VUB(I)                                                        CONMI389
      X12=ABS(XID)                                                      CONMI390
      IF (X12.LT.1.) X12=1.                                             CONMI391
      GI=(XI-XID)/X12                                                   CONMI392
      IF (GI.LT.-1.0E-6) GO TO 510                                      CONMI393
      M1=M1+1                                                           CONMI394
      MS1(M1)=I                                                         CONMI395
      NAC=NAC+1                                                         CONMI396
      IF (NAC.GE.N3) GO TO 810                                          CONMI397
      MCN1=MCN1+1                                                       CONMI398
      DO 500 J=1,NDV                                                    CONMI399
500   A(J,NAC)=0.                                                       CONMI400
      A(I,NAC)=1.                                                       CONMI401
      IC(NAC)=MCN1                                                      CONMI402
      G(MCN1)=GI                                                        CONMI403
      ISC(MCN1)=1                                                       CONMI404
510   CONTINUE                                                          CONMI405
C     ------------------------------------------------------------------CONMI406
C                                   PRINT                               CONMI407
C     ------------------------------------------------------------------CONMI408
C     PRINT ACTIVE SIDE CONSTRAINT NUMBERS.                             CONMI409
      IF (IPRINT.LT.3) GO TO 530                                        CONMI410
      WRITE (6,1090) M1                                                 CONMI411
      IF (M1.EQ.0) GO TO 530                                            CONMI412
      WRITE (6,1100)                                                    CONMI413
      WRITE(6,1480) (MS1(J),J=1,M1)                                     CONMI414
530   CONTINUE                                                          CONMI415
C     PRINT GRADIENTS OF ACTIVE AND VIOLATED CONSTRAINTS.               CONMI416
      IF (IPRINT.LT.4) GO TO 570                                        CONMI417
      WRITE (6,1340)                                                    CONMI418
      DO 540 I=1,NDV,6                                                  CONMI419
      M1=MIN0(NDV,I+5)                                                  CONMI420
540   WRITE (6,1010) I,(DF(J),J=I,M1)                                   CONMI421
      IF (NAC.EQ.0) GO TO 570                                           CONMI422
      WRITE (6,1350)                                                    CONMI423
      DO 560 I=1,NAC                                                    CONMI424
      M1=IC(I)                                                          CONMI425
      M2=M1-NCON                                                        CONMI426
      M3=0                                                              CONMI427
      IF (M2.GT.0) M3=IABS(MS1(M2))                                     CONMI428
      IF (M2.LE.0) WRITE (6,990) M1                                     CONMI429
      IF (M2.GT.0) WRITE (6,1000) M3                                    CONMI430
      DO 550 K=1,NDV,6                                                  CONMI431
      M1=MIN0(NDV,K+5)                                                  CONMI432
550   WRITE (6,1010) K,(A(J,I),J=K,M1)                                  CONMI433
560   WRITE (6,1360)                                                    CONMI434
570   CONTINUE                                                          CONMI435
C     ------------------------------------------------------------------CONMI436
C     ******************  DETERMINE SEARCH DIRECTION *******************CONMI437
C     ------------------------------------------------------------------CONMI438
      ALP=1.0E+20                                                       CONMI439
      IF (NAC.GT.0) GO TO 580                                           CONMI440
C     ------------------------------------------------------------------CONMI441
C                         UNCONSTRAINED FUNCTION                        CONMI442
C     ------------------------------------------------------------------CONMI443
C     FIND DIRECTION OF STEEPEST DESCENT OR CONJUGATE DIRECTION.        CONMI444
      NVC=0                                                             CONMI445
      NFEAS=0                                                           CONMI446
      KCOUNT=KCOUNT+1                                                   CONMI447
C     IF KCOUNT.GT.ICNDIR  RESTART CONJUGATE DIRECTION ALGORITHM.       CONMI448
      IF (KCOUNT.GT.ICNDIR.OR.IOBJ.EQ.2) KCOUNT=1                       CONMI449
      IF (KCOUNT.EQ.1) JDIR=0                                           CONMI450
C     IF JDIR = 0 FIND DIRECTION OF STEEPEST DESCENT.                   CONMI451
      CALL CNMN02 (JDIR,SLOPE,DFTDF1,DF,S,N1)                           CONMI452
      GO TO 630                                                         CONMI453
580   CONTINUE                                                          CONMI454
C     ------------------------------------------------------------------CONMI455
C                          CONSTRAINED FUNCTION                         CONMI456
C     ------------------------------------------------------------------CONMI457
C     FIND USABLE-FEASIBLE DIRECTION.                                   CONMI458
      KCOUNT=0                                                          CONMI459
      JDIR=0                                                            CONMI460
      PHI=10.*PHI                                                       CONMI461
      IF (PHI.GT.1000.) PHI=1000.                                       CONMI462
C     CALCULATE DIRECTION, S.                                           CONMI463
      CALL CNMN05 (G,DF,A,S,B,C,SLOPE,PHI,ISC,IC,MS1,NVC,N1,N2,N3,N4,N5)CONMI464
      IF (IPRINT.LT.3) GO TO 600                                        CONMI465
      WRITE (6,1370)                                                    CONMI466
      DO 590 I=1,NAC,6                                                  CONMI467
      M1=MIN0(NAC,I+5)                                                  CONMI468
590   WRITE (6,1010) I,(A(NDV1,J),J=I,M1)                               CONMI469
      WRITE (6,1210) S(NDV1)                                            CONMI470
600   CONTINUE                                                          CONMI471
C     ------------------------------------------------------------------CONMI472
C     ****************** ONE-DIMENSIONAL SEARCH ************************CONMI473
C     ------------------------------------------------------------------CONMI474
      IF (S(NDV1).LT.1.0E-6.AND.NVC.EQ.0) GO TO 710                     CONMI475
C     ------------------------------------------------------------------CONMI476
C                  FIND ALPHA TO OBTAIN A FEASIBLE DESIGN               CONMI477
C     ------------------------------------------------------------------CONMI478
      IF (NVC.EQ.0) GO TO 630                                           CONMI479
      ALP=-1.                                                           CONMI480
      DO 620 I=1,NAC                                                    CONMI481
      NCI=IC(I)                                                         CONMI482
      C1=G(NCI)                                                         CONMI483
      CTC=CTAM                                                          CONMI484
      IF (ISC(NCI).GT.0) CTC=CTBM                                       CONMI485
      IF (C1.LE.CTC) GO TO 620                                          CONMI486
      ALP1=0.                                                           CONMI487
      DO 610 J=1,NDV                                                    CONMI488
610   ALP1=ALP1+S(J)*A(J,I)                                             CONMI489
      ALP1=ALP1*A(NDV2,I)                                               CONMI490
      IF (ABS(ALP1).LT.1.0E-20) GO TO 620                               CONMI491
      ALP1=-C1/ALP1                                                     CONMI492
      IF (ALP1.GT.ALP) ALP=ALP1                                         CONMI493
620   CONTINUE                                                          CONMI494
630   CONTINUE                                                          CONMI495
C     ------------------------------------------------------------------CONMI496
C                       LIMIT CHANCE TO ABOBJ1*OBJ                      CONMI497
C     ------------------------------------------------------------------CONMI498
      ALP1=1.0E+20                                                      CONMI499
      SI=ABS(OBJ)                                                       CONMI500
      IF (SI.LT..01) SI=.01                                             CONMI501
      IF (ABS(SLOPE).GT.1.0E-20) ALP1=ABOBJ1*SI/SLOPE                   CONMI502
      ALP1=ABS(ALP1)                                                    CONMI503
      IF (NVC.GT.0) ALP1=10.*ALP1                                       CONMI504
      IF (ALP1.LT.ALP) ALP=ALP1                                         CONMI505
C     ------------------------------------------------------------------CONMI506
C            .     LIMIT CHANGE IN VARIABLE TO ALPHAX                   CONMI507
C     ------------------------------------------------------------------CONMI508
      ALP11=1.0E+20                                                     CONMI509
      DO 640 I=1,NDV                                                    CONMI510
      SI=ABS(S(I))                                                      CONMI511
      XI=ABS(X(I))                                                      CONMI512
      IF (SI.LT.1.0E-10.OR.XI.LT.0.1) GO TO 640                         CONMI513
      ALP1=ALPHAX*XI/SI                                                 CONMI514
      IF (ALP1.LT.ALP11) ALP11=ALP1                                     CONMI515
640   CONTINUE                                                          CONMI516
      IF (NVC.GT.0) ALP11=10.*ALP11                                     CONMI517
      IF (ALP11.LT.ALP) ALP=ALP11                                       CONMI518
      IF (ALP.GT.1.0E+20) ALP=1.0E+20                                   CONMI519
      IF (ALP.LE.1.0E-20) ALP=1.0E-20                                   CONMI520
      IF (IPRINT.LT.3) GO TO 660                                        CONMI521
      WRITE (6,1380)                                                    CONMI522
      DO 650 I=1,NDV,6                                                  CONMI523
      M1=MIN0(NDV,I+5)                                                  CONMI524
650   WRITE (6,1010) I,(S(J),J=I,M1)                                    CONMI525
      WRITE (6,1110) SLOPE,ALP                                          CONMI526
660   CONTINUE                                                          CONMI527
      IF (NCON.GT.0.OR.NSIDE.GT.0) GO TO 680                            CONMI528
C     ------------------------------------------------------------------CONMI529
C           DO ONE-DIMENSIONAL SEARCH FOR UNCONSTRAINED FUNCTION        CONMI530
C     ------------------------------------------------------------------CONMI531
      JGOTO=0                                                           CONMI532
670   CONTINUE                                                          CONMI533
      CALL CNMN03 (X,S,SLOPE,ALP,FFF,A1,A2,A3,A4,F1,F2,F3,F4,APP,N1,NCALCONMI534
     1,KOUNT,JGOTO)                                                     CONMI535
      IGOTO=4                                                           CONMI536
      IF (JGOTO.GT.0) GO TO 950                                         CONMI537
      JDIR=1                                                            CONMI538
C     PROCEED TO CONVERGENCE CHECK.                                     CONMI539
      GO TO 700                                                         CONMI540
C     ------------------------------------------------------------------CONMI541
C       SOLVE ONE-DIMENSIONAL SEARCH PROBLEM FOR CONSTRAINED FUNCTION   CONMI542
C     ------------------------------------------------------------------CONMI543
680   CONTINUE                                                          CONMI544
      JGOTO=0                                                           CONMI545
690   CONTINUE                                                          CONMI546
      CALL CNMN06 (X,VLB,VUB,G,SCAL,DF,S,G1,G2,CTAM,CTBM,SLOPE,ALP,A2,A3CONMI547
     1,A4,F1,F2,F3,CV1,CV2,CV3,CV4,ALPCA,ALPFES,ALPLN,ALPMIN,ALPNC,ALPSACONMI548
     2V,ALPSID,ALPTOT,ISC,N1,NC,NCAL,NVC,ICOUNT,IGOOD1,IGOOD2,IGOOD3,IGOCONMI549
     3OD4,IBEST,III,NLNC,JGOTO)                                         CONMI550
      IGOTO=5                                                           CONMI551
      IF (JGOTO.GT.0) GO TO 950                                         CONMI552
      IF (NAC.EQ.0) JDIR=1                                              CONMI553
C     ------------------------------------------------------------------CONMI554
C     ******************     UPDATE ALPHAX    **************************CONMI555
C     ------------------------------------------------------------------CONMI556
700   CONTINUE                                                          CONMI557
710   CONTINUE                                                          CONMI558
      IF (ALP.GT.1.0E+19) ALP=0.                                        CONMI559
C     UPDATE ALPHAX TO BE AVERAGE OF MAXIMUM CHANGE IN X(I)             CONMI560
C     AND ALHPAX.                                                       CONMI561
      ALP11=0.                                                          CONMI562
      DO 720 I=1,NDV                                                    CONMI563
      SI=ABS(S(I))                                                      CONMI564
      XI=ABS(X(I))                                                      CONMI565
      IF (XI.LT.1.0E-10) GO TO 720                                      CONMI566
      ALP1=ALP*SI/XI                                                    CONMI567
      IF (ALP1.GT.ALP11) ALP11=ALP1                                     CONMI568
720   CONTINUE                                                          CONMI569
      ALP11=.5*(ALP11+ALPHAX)                                           CONMI570
      ALP12=5.*ALPHAX                                                   CONMI571
      IF (ALP11.GT.ALP12) ALP11=ALP12                                   CONMI572
      ALPHAX=ALP11                                                      CONMI573
      NCOBJ=NCOBJ+1                                                     CONMI574
C     ABSOLUTE CHANGE IN OBJECTIVE.                                     CONMI575
      OBJD=OBJ1-OBJ                                                     CONMI576
      OBJB=ABS(OBJD)                                                    CONMI577
      IF (OBJB.LT.1.0E-10) OBJB=0.                                      CONMI578
      IF (NAC.EQ.0.OR.OBJB.GT.0.) NCOBJ=0                               CONMI579
      IF (NCOBJ.GT.1) NCOBJ=0                                           CONMI580
C     ------------------------------------------------------------------CONMI581
C                                 PRINT                                 CONMI582
C     ------------------------------------------------------------------CONMI583
C     PRINT MOVE PARAMETER, NEW X-VECTOR AND CONSTRAINTS.               CONMI584
      IF (IPRINT.LT.3) GO TO 730                                        CONMI585
      WRITE (6,1390) ALP                                                CONMI586
730   IF (IPRINT.LT.2) GO TO 800                                        CONMI587
      IF (OBJB.GT.0.) GO TO 740                                         CONMI588
      IF (IPRINT.EQ.2) WRITE (6,1400) ITER,OBJ                          CONMI589
      IF (IPRINT.GT.2) WRITE (6,1410) OBJ                               CONMI590
      GO TO 760                                                         CONMI591
740   IF (IPRINT.EQ.2) GO TO 750                                        CONMI592
      WRITE (6,1420) OBJ                                                CONMI593
      GO TO 760                                                         CONMI594
750   WRITE (6,1430) ITER,OBJ                                           CONMI595
760   WRITE (6,1450)                                                    CONMI596
      DO 770 I=1,NDV                                                    CONMI597
      FF1=1.                                                            CONMI598
      IF (NSCAL.NE.0) FF1=SCAL(I)                                       CONMI599
770   G1(I)=FF1*X(I)                                                    CONMI600
      DO 780 I=1,NDV,6                                                  CONMI601
      M1=MINO(NDV,I+5)                                                  CONMI602
780   WRITE (6,1010) I,(G1(J),J=I,M1)                                   CONMI603
      IF (NCON.EQ.0) GO TO 800                                          CONMI604
      WRITE (6,1470)                                                    CONMI605
      DO 790 I=1,NCON,6                                                 CONMI606
      M1=MINO(NCON,I+5)                                                 CONMI607
790   WRITE (6,1010) I,(G(J),J=I,M1)                                    CONMI608
800   CONTINUE                                                          CONMI609
C     ------------------------------------------------------------------CONMI610
C                              CHECK FEASABILITY                        CONMI611
C     ------------------------------------------------------------------CONMI612
      IF(NCON.LE.0) GO TO 808                                           CONMI613
      DO 804 I=1,NCON                                                   CONMI614
      C1=CTAM                                                           CONMI615
      IF(ISC(I).GT.0) C1=CTBM                                           CONMI616
      IF(G(I).LE.C1) GO TO 804                                          CONMI617
      NFEAS=NFEAS+1                                                     CONMI618
      GO TO 806                                                         CONMI619
804   CONTINUE                                                          CONMI620
      IF(NFEAS.GT.0) ABOBJ1=.05                                         CONMI621
      NFEAS=0                                                           CONMI622
      PHI=5.                                                            CONMI623
806   IF(NFEAS.GE.10) GO TO 810                                         CONMI624
808   CONTINUE                                                          CONMI625
C     ------------------------------------------------------------------CONMI626
C                              CHECK CONVERGENCE                        CONMI627
C     ------------------------------------------------------------------CONMI628
C     STOP IF ITER EQUALS ITMAX.                                        CONMI629
      IF (ITER.GE.ITMAX) GO TO 810                                      CONMI630
C     ------------------------------------------------------------------CONMI631
C                         ABSOLUTE CHANGE IN OBJECTIVE                  CONMI632
C     ------------------------------------------------------------------CONMI633
      OBJB=ABS(OBJD)                                                    CONMI634
      KOBJ=KOBJ+1                                                       CONMI635
      IF (OBJB.GE.DABFUN.OR.NFEAS.GT.0) KOBJ=0                          CONMI636
C     ------------------------------------------------------------------CONMI637
C                         RELATIVE CHANGE IN OBJECTIVE                  CONMI638
C     ------------------------------------------------------------------CONMI639
      IF (ABS(OBJ1).GT.1.0E-10) OBJD=OBJD/ABS(OBJ1)                     CONMI640
      ABOBJ1=.5*(ABS(ABOBJ)+ABS(OBJD))                                  CONMI641
      ABOBJ=ABS(OBJD)                                                   CONMI642
      IOBJ=IOBJ+1                                                       CONMI643
      IF(NFEAS.GT.0.OR.OBJD.GE.DELFUN) IOBJ=0                           CONMI644
      IF (IOBJ.GE.ITRM.OR.KOBJ.GE.ITRM) GO TO 810                       CONMI645
      OBJ1=OBJ                                                          CONMI646
C     ------------------------------------------------------------------CONMI647
C          REDUCE CT IF OBJECTIVE FUNCTION IS CHANGING SLOWLY           CONMI648
C     ------------------------------------------------------------------CONMI649
      IF (IOBJ.LT.1.OR.NAC.EQ.0) GO TO 280                              CONMI650
      CT=DCT*CT                                                         CONMI651
      CTL=CTL*DCTL                                                      CONMI652
      IF (ABS(CT).LT.CTMIN) CT=-CTMIN                                   CONMI653
      IF (ABS(CTL).LT.CTLMIN) CTL=-CTLMIN                               CONMI654
      GO TO 280                                                         CONMI655
810   CONTINUE                                                          CONMI656
      IF (NAC.GE.N3) WRITE (6,1490)                                     CONMI657
C     ------------------------------------------------------------------CONMI658
C     ****************  FINAL FUNCTION INFORMATION  ********************CONMI659
C     ------------------------------------------------------------------CONMI660
      IF (NSCAL.EQ.0) GO TO 830                                         CONMI661
C     UN-SCALE THE DESIGN VARIABLES.                                    CONMI662
      DO 820 I=1,NDV                                                    CONMI663
      XI=SCAL(I)                                                        CONMI664
      IF (NSIDE.EQ.0) GO TO 820                                         CONMI665
      VLB(I)=XI*VLB(I)                                                  CONMI666
      VUB(I)=XI*VUB(I)                                                  CONMI667
820   X(I)=XI*X(I)                                                      CONMI668
C     ------------------------------------------------------------------CONMI669
C                             PRINT FINAL RESULTS                       CONMI670
C     ------------------------------------------------------------------CONMI671
830   IF (IPRINT.EQ.0.OR.NAC.GE.N3) GO TO 940                           CONMI672
      WRITE (6,1500)                                                    CONMI673
      WRITE (6,1420) OBJ                                                CONMI674
      WRITE (6,1450)                                                    CONMI675
      DO 840 I=1,NDV,6                                                  CONMI676
      M1=MINO(NDV,I+5)                                                  CONMI677
840   WRITE (6,1010) I,(X(J),J=I,M1)                                    CONMI678
      IF (NCON.EQ.0) GO TO 900                                          CONMI679
      WRITE (6,1470)                                                    CONMI680
      DO 850 I=1,NCON,6                                                 CONMI681
      M1=MINO(NCON,I+5)                                                 CONMI682
850   WRITE (6,1010) I,(G(J),J=I,M1)                                    CONMI683
C     DETERMINE WHICH CONSTRAINTS ARE ACTIVE AND PRINT.                 CONMI684
      NAC=0                                                             CONMI685
      NVC=0                                                             CONMI686
      DO 870 I=1,NCON                                                   CONMI687
      CTA=CTAM                                                          CONMI688
      IF (ISC(I).GT.0) CTA=CTBM                                         CONMI689
      GI=G(I)                                                           CONMI690
      IF (GI.GT.CTA) GO TO 860                                          CONMI691
      IF (GI.LT.CT.AND.ISC(I).EQ.0) GO TO 870                           CONMI692
      IF (GI.LT.CTL.AND.ISC(I).GT.0) GO TO 870                          CONMI693
      NAC=NAC+1                                                         CONMI694
      IC(NAC)=I                                                         CONMI695
      GO TO 870                                                         CONMI696
860   NVC=NVC+1                                                         CONMI697
      MS1(NVC)=I                                                        CONMI698
870   CONTINUE                                                          CONMI699
      WRITE (6,1060) NAC                                                CONMI700
      IF (NAC.EQ.0) GO TO 880                                           CONMI701
      WRITE (6,1070)                                                    CONMI702
      WRITE (6,1480) (IC(J),J=1,NAC)                                    CONMI703
880   WRITE (6,1080) NVC                                                CONMI704
      IF (NVC.EQ.0) GO TO 890                                           CONMI705
      WRITE (6,1070)                                                    CONMI706
      WRITE (6,1480) (MS1(J),J=1,NVC)                                   CONMI707
890   CONTINUE                                                          CONMI708
900   CONTINUE                                                          CONMI709
      IF (NSIDE.EQ.0) GO TO 930                                         CONMI710
C     DETERMINE WHICH SIDE CONSTRAINTS ARE ACTIVE AND PRINT.            CONMI711
      NAC=0                                                             CONMI712
      DO 920 I=1,NDV                                                    CONMI713
      XI=X(I)                                                           CONMI714
      XID=VLB(I)                                                        CONMI715
      X12=ABS(XID)                                                      CONMI716
      IF (X12.LT.1.) X12=1.                                             CONMI717
      GI=(XID-XI)/X12                                                   CONMI718
      IF (GI.LT.-1.0E-6) GO TO 910                                      CONMI719
      NAC=NAC+1                                                         CONMI720
      MS1(NAC)=-I                                                       CONMI721
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910   XID=VUB(I)                                                       CONMI722
      X12=ABS(XID)                                                     CONMI723
      IF (X12.LT.1.) X12=1.                                            CONMI724
      GI=(XI-XID)/X12                                                  CONMI725
      IF (GI.LT.-1.0E-6) GO TO 920                                     CONMI726
      NAC=NAC+1                                                        CONMI727
      MS1(NAC)=I                                                       CONMI728
920   CONTINUE                                                         CONMI729
      WRITE (6,1090) NAC                                               CONMI730
      IF (NAC.EQ.0) GO TO 930                                          CONMI731
      WRITE (6,1100)                                                   CONMI732
      WRITE (6,1480) (MS1(J),J=1,NAC)                                  CONMI733
930   CONTINUE                                                         CONMI734
      WRITE (6,1150)                                                   CONMI735
      IF (ITER.GE.ITMAX) WRITE (6,1160)                                CONMI736
      IF (NFEAS.GE.10) WRITE (6,1170)                                  CONMI737
      IF (IOBJ.GE.ITRM) WRITE (6,1180) ITRM                            CONMI738
      IF (KOBJ.GE.ITRM) WRITE (6,1190) ITRM                            CONMI739
      WRITE (6,1200) ITER                                              CONMI740
      WRITE (6,1510) NCAL(1)                                           CONMI741
      IF (NCON.GT.0) WRITE (6,1520) NCAL(1)                            CONMI742
      IF (NFDG.NE.0) WRITE (6,1530) NCAL(2)                            CONMI743
      IF (NCON.GT.0.AND.NFDG.EQ.1) WRITE (6,1540) NCAL(2)              CONMI744
C     -----------------------------------------------------------------CONMI745
C                      RE-SET BASIC PARAMETERS TO INPUT VALUES         CONMI746
C     -----------------------------------------------------------------CONMI747
940   ITRM=IDM1                                                        CONMI748
      ITMAX=IDM2                                                       CONMI749
      ICNDIR=IDM3                                                      CONMI750
      DELFUN=DM1                                                       CONMI751
      DABFUN=DM2                                                       CONMI752
      CT=DM3                                                           CONMI753
      CTMIN=DM4                                                        CONMI754
      CTL=DM5                                                          CONMI755
      CTLMIN=DM6                                                       CONMI756
      THETA=DM7                                                        CONMI757
      PHI=DM8                                                          CONMI758
      FDCH=DM9                                                         CONMI759
      FDCHM=DM10                                                       CONMI760
      ABOBJ1=DM11                                                      CONMI761
      ALPHAX=DM12                                                      CONMI762
      IGOTO=0                                                          CONMI763
950   CONTINUE                                                         CONMI764
      IF (NSCAL.EQ.0.OR.IGOTO.EQ.0) RETURN                             CONMI765
C     UN-SCALE VARIABLES.                                              CONMI766
      DO 960 I=1,NDV                                                   CONMI767
      C(I)=X(I)                                                        CONMI768
960   X(I)=X(I)*SCAL(I)                                                CONMI769
      RETURN                                                           CONMI770
C     -----------------------------------------------------------------CONMI771
C                                FORMATS                               CONMI772
C     -----------------------------------------------------------------CONMI773
C                                                                      CONMI774
C                                                                      CONMI775
970   FORMAT (///5X,72HA COMPLETELY UNCONSTRAINED FUNCTION WITH A LINEARCONMI776
     1 OBJECTIVE IS SPECIFIED//10X,8HLINOBJ =,I5/10X,8HNCON   =,I5/10X,8CONMI777
     2HNSIDE  =,I5//5X,35HCONTROL RETURNED TO CALLING PROGRAM)         CONMI778
980   FORMAT (///5X,56HCONMIN HAS ACHIEVED A SOLUTION OF OBJ LESS THAN -CONMI779
     11.0E+40/5X,32HSOLUTION APPEARS TOABE UNBOUNDED/5X,26HOPTIMIZATION CONMI780
     2IS TERMINATED)                                                   CONMI781
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990   FORMAT (5X,17HCONSTRAINT NUMBER,I5)                              CONMI782
1000  FORMAT (5X,27HSIDE CONSTRAINT ON VARIABLE,I5)                    CONMI783
1010  FORMAT (3X,I5,1H),2X,6E13.5)                                     CONMI784
1020  FORMAT (/5X,35HLINEAR CONSTRAINT IDENTIFIERS (ISC)/5X,36HNON-ZERO CONMI785
     1INDICATES LINEAR CONSTRAINT)                                     CONMI786
1030  FORMAT (3X,I5,1H),2X,15I5)                                       CONMI787
1040  FORMAT (/5X,26HALL CONSTRAINTS ARE LINEAR)                       CONMI788
1050  FORMAT (/5X,30HALL CONSTRAINTS ARE NON-LINEAR)                   CONMI789
1060  FORMAT (/5X,9HTHERE ARE,I5,19H ACTIVE CONSTRAINTS)               CONMI790
1070  FORMAT (5X,22HCONSTRAINT NUMBERS ARE)                            CONMI791
1080  FORMAT (/5X,9HTHERE ARE,I5,21H VIOLATED CONSTRAINTS)             CONMI792
1090  FORMAT (/5X,9HTHERE ARE,I5,24H ACTIVE SIDE CONSTRAINTS)          CONMI793
1100  FORMAT (5X,43HDECISION VARIABLES AT LOWER OR UPPER BOUNDS,30H (MINCONMI794
     1US INDICATES LOWER BOUND))                                       CONMI795
1110  FORMAT (/5X,22HONE-DIMENSIONAL SEARCH/5X,15HINITIAL SLOPE =,E12.4,CONMI796
     12X,16HPROPOSED ALPHA =,E12.4)                                    CONMI797
1120  FORMAT (///5X,35H* * CONMIN DETECTS VLB(I).GT.VUB(I)/5X,57HFIX IS CONMI798
     1SET X(I)=VLB(I)=VUB(I) = .5*(VLB(I)+VUB(I) FOR I =,I5)           CONMI799
1130  FORMAT (///5X,41H* * CONMIN DETECTS INITIAL X(I).LT.VLB(I)/5X,6HX(CONMI800
     1I) =,E12.4,2X,8HVLB(I) =,E12.4/5X,35HX(I) IS SET EQUAL TO VLB(I) FCONMI801
     2OR I =,I5)                                                       CONMI802
1140  FORMAT (///5X,41H* * CONMIN DETECTS INITIAL X(I).GT.VUB(I)/5X,6HX(CONMI803
     1I) =,E12.4,2X,8HVUB(I) =,E12.4/5X,35HX(I) IS SET EQUAL TO VUB(I) FCONMI804
     2OR I =,I5)                                                       CONMI805
1150  FORMAT (/5X,21HTERMINATION CRITERION)                            CONMI806
1160  FORMAT (10X,17HITER EQUALS ITMAX)                                CONMI807
1170  FORMAT (10X,62HTEN CONSECUTIVE ITERATIONS FAILED TO PRODUCE A FEASCONMI808
     1IBLE DESIGN)                                                     CONMI809
1180  FORMAT (10X,43HABS(1-OBJ(I-1)/OBJ(I)) LESS THAN DELFUN FOR,I3,11H CONMI810
     1ITERATIONS)                                                      CONMI811
1190  FORMAT (10X,43HABS(OBJ(I)-OBJ(I-1))   LESS THAN DABFUN FOR,I3,11H CONMI812
     1ITERATIONS)                                                      CONMI813
1200  FORMAT (/5X,22HNUMBER OF ITERATIONS =,I5)                        CONMI814
1210  FORMAT (/5X,28HCONSTRAINT PARAMETER, BETA =,E14.5)               CONMI815
1220  FORMAT (1H1,////12X,27(2H* )/12X,1H*,51X,1H*/12X,1H*,20X,11HC O N CONMI816
     1M I N,20X,1H*/12X,1H*,51X,1H*/12X,1H*,15X,21H FORTRAN PROGRAM FOR CONMI817
     2,15X,1H*/12X,1H*,51X,1H*/12X,1H*,9X,33HCONSTRAINED FUNCTION MINIMICONMI818
     3ZATION,9X,1H*/12X,1H*,51X,1H*/12X,27(2H* ))                      CONMI819
1230  FORMAT (////5X,33HCONSTRAINED FUNCTION MINIMIZATION//5X,18HCONTROLCONMI820
     1 PARAMETERS)                                                     CONMI821
1240  FORMAT (/5X,60HIPRINT  NDV    ITMAX    NCON    NSIDE  ICNDIR   NSCCONMI822
     1AL   NFDG/8I8//5X,12HLINOBJ  ITRM,5X,2HN1,6X,2HN2,6X,2HN3,6X,2HN4,CONMI823
     26X,2HN5/8I8)                                                     CONMI824
1250  FORMAT (/9X,4HFDCH,12X,5HFDCHM,11X,6HALPHAX,10X,6HABOBJ1/1X,4(2X,ECONMI825
     114.5))                                                           CONMI826
1260  FORMAT (/9X,2HCT,14X,5HCTMIN,11X,3HCTL,13X,6HCTLMIN/1X,4(2X,E14.5)CONMI827
     1//9X,5HTHETA,11X,3HPHI,13X,6HDELFUN,10X,6HDABFUN/1X,4(2X,E14.5))  CONMI828
1270  FORMAT (/5X,40HLOWER BOUNDS ON DECISION VARIABLES (VLB))         CONMI829
1280  FORMAT (/5X,40HUPPER BOUNDS ON DECISION VARIABLES (VUB))         CONMI830
1290  FORMAT (////5X,35HUNCONSTRAINED FUNCTION MINIMIZATION//5X,18HCONTRCONMI831
     1OL PARAMETERS)                                                   CONMI832
1300  FORMAT (/5X,21HSCALING VECTOR (SCAL))                            CONMI833
1310  FORMAT (////5X,22HBEGIN ITERATION NUMBER,I5)                     CONMI834
1320  FORMAT (/5X,4HCT =,E14.5,5X,5HCTL =,E14.5,5X,5HPHI =,E14.5)      CONMI835
1330  FORMAT (/5X,25HNEW SCALING VECTOR (SCAL))                        CONMI836
1340  FORMAT (/5X,15HGRADIENT OF OBJ)                                  CONMI837
1350  FORMAT (/5X,44HGRADIENTS OF ACTIVE AND VIOLATED CONSTRAINTS)     CONMI838
1360  FORMAT (1H )                                                     CONMI839
1370  FORMAT (/5X,37HPUSH-OFF FACTORS, (THETA(I), I=1,NAC))            CONMI840
1380  FORMAT (/5X,27HSEARCH DIRECTION (S-VECTOR))                      CONMI841
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 1390 FORMAT (/5X,18HCALCULATED ALPHA =,E14.5)                            CONMI842
 1400 FORMAT (////5X,6HITER =,I5,5X,5HOBJ =,E14.5,5X,16HNO CHANGE IN OBJCONMI843
     1)                                                                  CONMI844
 1410 FORMAT (/5X,5HOBJ =,E15.6,5X,16HNO CHANGE ON OBJ)                  CONMI845
 1420 FORMAT (/5X,5HOBJ =,E15.6)                                         CONMI846
 1430 FORMAT (////5X,6HITER =,I5,5X,5HOBJ =,E14.5)                       CONMI847
 1440 FORMAT (//5X,28HINITIAL FUNCTION INFORMATION//5X,5HOBJ =,E15.6)    CONMI848
 1450 FORMAT (/5X,29HDECISION VARIABLES (X-VECTOR))                      CONMI849
 1460 FORMAT (3X,7E13.4)                                                 CONMI850
 1470 FORMAT (/5X,28HCONSTRAINT VALUES (G-VECTOR))                       CONMI851
 1480 FORMAT (5X,15I5)                                                   CONMI852
 1490 FORMAT (/5X,59HTHE NUMBER OF ACTIVE AND VIOLATED CONSTRAINTS EXCEECONMI853
     1DS N3-1./5X,66HDIMENSIONED SIZE OF MATRICES A AND B AND VECTOR IC CONMI854
     2IS INSUFFICIENT/5X,61HOPTIMIZATION TERMINATED AND CONTROL RETURNEDCONMI855
     3 TO MAIN PROGRAM.)                                                 CONMI856
 1500 FORMAT (1H1,////4X,30HFINAL OPTIMIZATION INFORMATION)              CONMI857
 1510 FORMAT (/5X,32HOBJECTIVE FUNCTION WAS EVALUATED,8X,I5,2X,5HTIMES) CONMI858
 1520 FORMAT (/5X,35HCONSTRAINT FUNCTIONS WERE EVALUATED,I10,2X,5HTIMES)CONMI859
 1530 FORMAT (/5X,36HGRADIENT OF OBJECTIVE WAS CALCULATED,I9,2X,5HTIMES)CONMI860
 1540 FORMAT (/5X,40HGRADIENTS OF CONSTRAINTS WERE CALCULATED,I5,2X,5HTICONMI861
     1MES)                                                               CONMI862
      END                                                                CONMI863
      SUBROUTINE CNMN01 (JGOTO,X,DF,G,ISC,IC,A,G1,VLB,VUB,SCAL,C,NCAL,DXCONMI864
     1,DX1,FI,XI,III,N1,N2,N3,N4)                                        CONMI865
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCONMI866
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCONMI867
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                                CONMI868
      DIMENSION X(N1), DF(N1), G(N2), ISC(N2), IC(N3), A(N1,N3), G1(N2),CONMI869
     1 VLB(N1), VUB(N1), SCAL(N1), NCAL(2), C(N4)                        CONMI870
C     ROUTINE TO CALCULATE GRADIENT INFORMATION BY FINITE DIFFERENCE.    CONMI871
C     BY G. N. VANDERPLAATS                         JUNE, 1972.          CONMI872
C     NASA-AMES RESEARCH CENTER,  MOFFETT FIELD, CALIF.                  CONMI873
      IF (JGOTO.EQ.1) GO TO 10                                           CONMI874
      IF (JGOTO.EQ.2) GO TO 70                                           CONMI875
      INFOG=0                                                            CONMI876
      INF=INFO                                                           CONMI877
      NAC=0                                                              CONMI878
      IF (LINOBJ.NE.0.AND.ITER.GT.1) GO TO 10                            CONMI879
C     ------------------------------------------------------------------CONMI880
C                          GRADIENT OF LINEAR OBJECTIVE                  CONMI881
C     ------------------------------------------------------------------CONMI882
      IF (NFDG.EQ.2) JGOTO=1                                             CONMI883
      IF (NFDG.EQ.2) RETURN                                              CONMI884
 10   CONTINUE                                                           CONMI885
      JGOTO=0                                                            CONMI886
      IF (NFDG.EQ.2.AND.NCON.EQ.0) RETURN                                CONMI887
      IF (NCON.EQ.0) GO TO 40                                            CONMI888
C     ------------------------------------------------------------------CONMI889
C        * * * DETERMINE WHICH CONSTRAINTS ARE ACTIVE OR VIOLATED * * *  CONMI890
C     ------------------------------------------------------------------CONMI891
      DO 20 I=1,NCON                                                     CONMI892
      IF (G(I).LT.CT) GO TO 20                                           CONMI893
      IF (ISC(I).GT.0.AND.G(I).LT.CTL) GO TO 20                          CONMI894
      NAC=NAC+1                                                          CONMI895
      IF (NAC.GE.N3) RETURN                                              CONMI896
      IC(NAC)=I                                                          CONMI897
 20   CONTINUE                                                           CONMI898
      IF (NFDG.EQ.2.AND.NAC.EQ.0) RETURN                                 CONMI899
      IF ((LINOBJ.GT.0.AND.ITER.GT.1).AND.NAC.EQ.0) RETURN               CONMI900
C     ------------------------------------------------------------------CONMI901
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C                         STOPE VALUES OF CONSTRAINTS IN G1              CONMI902
C     ------------------------------------------------------------------CONMI903
      DO 30 I=1,NCON                                                     CONMI904
 30   G1(I)=G(I)                                                         CONMI905
 40   CONTINUE                                                           CONMI906
      JGOTO=0                                                            CONMI907
      IF (NAC.EQ.0.AND.NFDG.EQ.2) RETURN                                 CONMI908
C     ------------------------------------------------------------------CONMI909
C                            CALCULATE GRADIENTS                         CONMI910
C     ------------------------------------------------------------------CONMI911
      INFOG=1                                                            CONMI912
      INFO=1                                                             CONMI913
      FI=OBJ                                                             CONMI914
      III=0                                                              CONMI915
 50   III=III+1                                                          CONMI916
      XI=X(III)                                                          CONMI917
      DX=FDCH*XI                                                         CONMI918
      DX=ABS(DX)                                                         CONMI919
      FDCH1=FDCHM                                                        CONMI920
      IF (NSCAL.NE.0) FDCH1=FDCHM/SCAL(III)                              CONMI921
      IF (DX.LT.FDCH1) DX=FDCH1                                          CONMI922
      X1=XI+DX                                                           CONMI923
      IF (NSIDE.EQ.0) GO TO 60                                           CONMI924
      IF (X1.GT.VUB(III)) DX=-DX                                         CONMI925
 60   DX1=1./DX                                                          CONMI926
      X(III)=XI+DX                                                       CONMI927
      NCAL(1)=NCAL(1)+1                                                  CONMI928
C     ------------------------------------------------------------------CONMI929
C                           FUNCTION EVALUATION                          CONMI930
C     ------------------------------------------------------------------CONMI931
      JGOTO=2                                                            CONMI932
      RETURN                                                             CONMI933
 70   CONTINUE                                                           CONMI934
      X(III)=XI                                                          CONMI935
      IF (NFDG.EQ.0) DF(III)=DX1*(OBJ-FI)                                CONMI936
      IF (NAC.EQ.0) GO TO 90                                             CONMI937
C     ------------------------------------------------------------------CONMI938
C             DETERMINE GRADIENT COMPONENTS OF ACTIVE CONSTRAINTS        CONMI939
C     ------------------------------------------------------------------CONMI940
      DO 80 J=1,NAC                                                      CONMI941
      I1=IC(J)                                                           CONMI942
 80   A(III,J)=DX1*(G(I1)-G1(I1))                                        CONMI943
 90   CONTINUE                                                           CONMI944
      IF (III.LT.NDV) GO TO 50                                           CONMI945
      INFOG=0                                                            CONMI946
      INFO=INF                                                           CONMI947
      JGOTO=0                                                            CONMI948
      OBJ=FI                                                             CONMI949
      IF (NCON.EQ.0) RETURN                                              CONMI950
C     ------------------------------------------------------------------CONMI951
C             STORE CURPENT CONSTRAINT VALUES BACK IN G-VECTOR           CONMI952
C     ------------------------------------------------------------------CONMI953
      DO 100 I=1,NCON                                                    CONMI954
 100  G(I)=G1(I)                                                         CONMI955
      RETURN                                                             CONMI956
      END                                                                CONMI957
      SUBROUTINE CNMN02 (NCALC,SLOPE,DFTDF1,DF,S,N1)                     CONMI958
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCONMI959
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCONMI960
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                                CONMI961
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      DIMENSION DF(N1), S(N1)                                           CONMI962
C     ROUTINE TO DETERMINE CONJUGATE DIRECTION VECTOR OR DIRECTION      CONMI963
C     OF STEEPEST DESCENT FOR UNCONSTRAINED FUNCTION MINIMIZATION.      CONMI964
C     BY G. N. VANDERPLAATS                       APRIL, 1972.          CONMI965
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  CONMI966
C     NCALC ■ CALCULATION CONTROL.                                      CONMI967
C         NCALC = 0,     S = STEEPEST DESCENT.                          CONMI968
C         NCALC = 1,     S = CONJUGATE DIRECTION.                       CONMI969
C     CONJUGATE DIRECTION IS FOUND BY FLETCHER-REEVES ALGORITHM.        CONMI970
C     ------------------------------------------------------------------CONMI971
C                   CALCULATE NORM OF GRADIENT VECTOR                   CONMI972
C     ------------------------------------------------------------------CONMI973
      DFTDF=0.                                                          CONMI974
      DO 10 I=1,NDV                                                     CONMI975
      DFI=DF(I)                                                         CONMI976
10    DFTDF=DFTDF+DFI*DFI                                               CONMI977
C     ------------------------------------------------------------------CONMI978
C     **********                FIND DIRECTION S              **********CONMI979
C     ------------------------------------------------------------------CONMI980
      IF (NCALC.NE.1) GO TO 30                                          CONMI981
      IF (DFTDF1.LT.1.0E-20) GO TO 30                                   CONMI982
C     ------------------------------------------------------------------CONMI983
C                 FIND FLETCHER-REEVES CONJUGATE DIRECTION              CONMI984
C     ------------------------------------------------------------------CONMI985
      BETA=DFTDF/DFTDF1                                                 CONMI986
      SLOPE=0.                                                          CONMI987
      DO 20 I=1,NDV                                                     CONMI988
      DFI=DF(I)                                                         CONMI989
      SI=BETA*S(I)-DFI                                                  CONMI990
      SLOPE=SLOPE+SI*DFI                                                CONMI991
20    S(I)=SI                                                           CONMI992
      GO TO 50                                                          CONMI993
30    CONTINUE                                                          CONMI994
      NCALC=0                                                           CONMI995
C     ------------------------------------------------------------------CONMI996
C                  CALCULATE DIRECTION OF STEEPEST DESCENT              CONMI997
C     ------------------------------------------------------------------CONMI998
      DO 40 I=1,NDV                                                     CONMI999
40    S(I)=-DF(I)                                                       CONM1000
      SLOPE=-DFTDF                                                      CONM1001
50    CONTINUE                                                          CONM1002
C     ------------------------------------------------------------------CONM1003
C                  NORMALIZE S TO MAX ABS VALUE OF UNITY                CONM1004
C     ------------------------------------------------------------------CONM1005
      S1=0.                                                             CONM1006
      DO 60 I=1,NDV                                                     CONM1007
      S2=ABS(S(I))                                                      CONM1008
      IF (S2.GT.S1) S1=S2                                               CONM1009
60    CONTINUE                                                          CONM1010
      IF (S1.LT.1.0E-20) S1=1.0E-20                                     CONM1011
      S1=1./S1                                                          CONM1012
      DFTDF1=DFTDF*S1                                                   CONM1013
      DO 70 I=1,NDV                                                     CONM1014
70    S(I)=S1*S(I)                                                      CONM1015
      SLOPE=S1*SLOPE                                                    CONM1016
      RETURN                                                            CONM1017
      END                                                               CONM1018
      SUBROUTINE CNMN03 (X,S,SLOPE,ALP,FFF,A1,A2,A3,A4,F1,F2,F3,F4,APP,NCONM1019
     11,NCAL,KOUNT,JGOTO)                                               CONM1020
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCONM1021
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCONM1022
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                               CONM1023
      DIMENSION X(N1), S(N1), NCAL(2)                                   CONM1024
C     ROUTINE TO SOLVE ONE-DIMENSIONAL SEARCH IN UNCONSTRAINED          CONM1025
C     MINIMIZATION USING 2-POINT QUADRATIC INTERPOLATION, 3-POINT       CONM1026
C     CUBIC INTERPOLATION AND 4-POINT CUBIC INTERPOLATION.              CONM1027
C     BY G. N. VANDERPLAATS                         APRIL, 1972.        CONM1028
C     NASA-AMES RESEARCH CENTER,  MOFFETT FIELD, CALIF.                 CONM1029
C     ALP = PROPOSED MOVE PARAMETER.                                    CONM1030
C     SLOPE = INITIAL FUNCTION SLOPE = S-TRANSPOSE TIMES DF.            CONM1031
C     SLOPE MUST BE NEGATIVE.                                           CONM1032
C     OBJ = INITIAL FUNCTION VALUE.                                     CONM1033
      ZRO=0.                                                            CONM1034
      IF (JGOTO.EQ.0) GO TO 10                                          CONM1035
      GO TO (50,80,110,140,180,220,270),JGOTO                           CONM1036
C     ------------------------------------------------------------------CONM1037
C                     INITIAL INFORMATION  (ALPHA=0)                    CONM1038
C     ------------------------------------------------------------------CONM1039
10    IF (SLOPE.LT.0.) GO TO 20                                         CONM1040
      ALP=0.                                                            CONM1041
      RETURN                                                            CONM1042
20    CONTINUE                                                          CONM1043
      IF (IPRINT.GT.4) WRITE (6,360)                                    CONM1044
      FFF=OBJ                                                           CONM1045
      AP1=0.                                                            CONM1046
      A1=0.                                                             CONM1047
      F1=OBJ                                                            CONM1048
      A2=ALP                                                            CONM1049
      A3=0.                                                             CONM1050
      F3=0.                                                             CONM1051
      AP=A2                                                             CONM1052
      KOUNT=0                                                           CONM1053
C     ------------------------------------------------------------------CONM1054
C            MOVE A DISTANCE AP*S AND UPDATE FUNCTION VALUE             CONM1055
C     ------------------------------------------------------------------CONM1056
30    CONTINUE                                                          CONM1057
      KOUNT=KOUNT+1                                                     CONM1058
      DO 40 I=1,NDV                                                     CONM1059
40    X(I)=X(I)+AP*S(I)                                                 CONM1060
      IF (IPRINT.GT.4) WRITE (6,370) AP                                 CONM1061
      IF (IPRINT.GT.4) WRITE (6,380) (X(I),I=1,NDV)                     CONM1062
      NCAL(1)=NCAL(1)+1                                                 CONM1063
      JGOTO=1                                                           CONM1064
      RETURN                                                            CONM1065
50    CONTINUE                                                          CONM1066
      F2=OBJ                                                            CONM1067
      IF (IPRINT.GT.4) WRITE (6,390) F2                                 CONM1068
      IF (F2.LT.F1) GO TO 120                                           CONM1069
C     ------------------------------------------------------------------CONM1070
C                     CHECK FOR ILL-CONDITIONING                        CONM1071
C     ------------------------------------------------------------------CONM1072
      IF (KOUNT.GT.5) GO TO 60                                          CONM1073
      FF=2.*ABS(F1)                                                     CONM1074
      IF (F2.LT.FF) GO TO 90                                            CONM1075
      FF=5.*ABS(F1)                                                     CONM1076
      IF (F2.LT.FF) GO TO 60                                            CONM1077
      A2=.5*A2                                                          CONM1078
      AP=-A2                                                            CONM1079
      ALP=A2                                                            CONM1080
      GO TO 30                                                          CONM1081
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60    F3=F2                                                             CONM1082
      A3=A2                                                             CONM1083
      A2=.5*A2                                                          CONM1084
C     ------------------------------------------------------------------CONM1085
C                UPDATE DESIGN VECTOR AND FUNCTION VALUE                CONM1086
C     ------------------------------------------------------------------CONM1087
      AP=A2-ALP                                                         CONM1088
      ALP=A2                                                            CONM1089
      DO 70 I=1,NDV                                                     CONM1090
70    X(I)=X(I)+AP*S(I)                                                 CONM1091
      IF (IPRINT.GT.4) WRITE (6,370) A2                                 CONM1092
      IF (IPRINT.GT.4) WRITE (6,380) (X(I),I=1,NDV)                     CONM1093
      NCAL(1)=NCAL(1)+1                                                 CONM1094
      JGOTO=2                                                           CONM1095
      RETURN                                                            CONM1096
80    CONTINUE                                                          CONM1097
      F2=OBJ                                                            CONM1098
      IF (IPRINT.GT.4) WRITE (6,390) F2                                 CONM1099
C     PROCEED TO CUBIC INTERPOLATION.                                   CONM1100
      GO TO 160                                                         CONM1101
90    CONTINUE                                                          CONM1102
C     ------------------------------------------------------------------CONM1103
C     **********       2-POINT QUADRATIC INTERPOLATION       **********CONM1104
C     ------------------------------------------------------------------CONM1105
      JJ=1                                                              CONM1106
      II=1                                                              CONM1107
      CALL CNMN04 (II,APP,ZRO,A1,F1,SLOPE,A2,F2,ZRO,ZRO,ZRO,ZRO)        CONM1108
      IF (APP.LT.ZRO.OR.APP.GT.A2) GO TO 120                            CONM1109
      F3=F2                                                             CONM1110
      A3=A2                                                             CONM1111
      A2=APP                                                            CONM1112
      JJ=0                                                              CONM1113
C     ------------------------------------------------------------------CONM1114
C                UPDATE DESIGN VECTOR AND FUNCTION VALUE                CONM1115
C     ------------------------------------------------------------------CONM1116
      AP=A2-ALP                                                         CONM1117
      ALP=A2                                                            CONM1118
      DO 100 I=1,NDV                                                    CONM1119
100   X(I)=X(I)+AP*S(I)                                                 CONM1120
      IF (IPRINT.GT.4) WRITE (6,370) A2                                 CONM1121
      IF (IPRINT.GT.4) WRITE (6,380) (X(I),I=1,NDV)                     CONM1122
      NCAL(1)=NCAL(1)+1                                                 CONM1123
      JGOTO=3                                                           CONM1124
      RETURN                                                            CONM1125
110   CONTINUE                                                          CONM1126
      F2=OBJ                                                            CONM1127
      IF (IPRINT.GT.4) WRITE (6,390) F2                                 CONM1128
      GO TO 150                                                         CONM1129
120   A3=2.*A2                                                          CONM1130
C     ------------------------------------------------------------------CONM1131
C                UPDATE DESIGN VECTOR AND FUNCTION VALUE                CONM1132
C     ------------------------------------------------------------------CONM1133
      AP=A3-ALP                                                         CONM1134
      ALP=A3                                                            CONM1135
      DO 130 I=1,NDV                                                    CONM1136
130   X(I)=X(I)+AP*S(I)                                                 CONM1137
      IF (IPRINT.GT.4) WRITE (6,370) A3                                 CONM1138
      IF (IPRINT.GT.4) WRITE (6,380) (X(I),I=1,NDV)                     CONM1139
      NCAL(1)=NCAL(1)+1                                                 CONM1140
      JGOTO=4                                                           CONM1141
      RETURN                                                            CONM1142
140   CONTINUE                                                          CONM1143
      F3=OBJ                                                            CONM1144
      IF (IPRINT.GT.4) WRITE (6,390) F3                                 CONM1145
150   CONTINUE                                                          CONM1146
      IF (F3.LT.F2) GO TO 190                                           CONM1147
160   CONTINUE                                                          CONM1148
C     ------------------------------------------------------------------CONM1149
C     **********       3-POINT CUBIC INTERPOLATION       **********     CONM1150
C     ------------------------------------------------------------------CONM1151
      II=3                                                              CONM1152
      CALL CNMN04 (II,APP,ZRO,A1,F1,SLOPE,A2,F2,A3,F3,ZRO,ZRO)          CONM1153
      IF (APP.LT.ZRO.OR.APP.GT.A3) GO TO 190                            CONM1154
C     ------------------------------------------------------------------CONM1155
C     UPDATE DESIGN VECTOR AND FUNCTION VALUE.                          CONM1156
C     ------------------------------------------------------------------CONM1157
      AP1=APP                                                           CONM1158
      AP=APP-ALP                                                        CONM1159
      ALP=APP                                                           CONM1160
      DO 170 I=1,NDV                                                    CONM1161
170   X(I)=X(I)+AP*S(I)                                                 CONM1162
      IF (IPRINT.GT.4) WRITE (6,370) ALP                                CONM1163
      IF (IPRINT.GT.4) WRITE (6,380) (X(I),I=1,NDV)                     CONM1164
      NCAL(1)=NCAL(1)+1                                                 CONM1165
      JGOTO=5                                                           CONM1166
      RETURN                                                            CONM1167
180   CONTINUE                                                          CONM1168
      IF (IPRINT.GT.4) WRITE (6,390) OBJ                                CONM1169
C     ------------------------------------------------------------------CONM1170
C                          CHECK CONVERGENCE                            CONM1171
C     ------------------------------------------------------------------CONM1172
      AA=1.-APP/A2                                                      CONM1173
      AB2=ABS(F2)                                                       CONM1174
      AB3=ABS(OBJ)                                                      CONM1175
      AB=AB2                                                            CONM1176
      IF (AB3.GT.AB) AB=AB3                                             CONM1177
      IF (AB.LT.1.0E-15) AB=1.0E-15                                     CONM1178
      AB=(AB2-AB3)/AB                                                   CONM1179
      IF (ABS(AB).LT.1.0E-15.AND.ABS(AA).LT..001) GO TO 330             CONM1180
      A4=A3                                                             CONM1181
      F4=F3                                                             CONM1182
      A3=APP                                                            CONM1183
      F3=OBJ                                                            CONM1184
      IF (A3.GT.A2) GO TO 230                                           CONM1185
      A3=A2                                                             CONM1186
      F3=F2                                                             CONM1187
      A2=APP                                                            CONM1188
      F2=OBJ                                                            CONM1189
      GO TO 230                                                         CONM1190
190   CONTINUE                                                          CONM1191
C     ------------------------------------------------------------------CONM1192
C     **********       4-POINT CUBIC INTERPOLATION       **********     CONM1193
C     ------------------------------------------------------------------CONM1194
200   CONTINUE                                                          CONM1195
      A4=2.*A3                                                          CONM1196
C     UPDATE DESIGN VECTOR AND FUNCTION VALUE.                          CONM1197
      AP=A4-ALP                                                         CONM1198
      ALP=A4                                                            CONM1199
      DO 210 I=1,NDV                                                    CONM1200
210   X(I)=X(I)+AP*S(I)                                                 CONM1201
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      IF (IPRINT.GT.4) WRITE (6,370) ALP                                CONM1202
      IF (IPRINT.GT.4) WRITE (6,380) (X(I),I=1,NDV)                     CONM1203
      NCAL(1)=NCAL(1)+1                                                 CONM1204
      JGOTO=6                                                           CONM1205
      RETURN                                                            CONM1206
220   CONTINUE                                                          CONM1207
      F4=OBJ                                                            CONM1208
      IF (IPRINT.GT.4) WRITE (6,390) F4                                 CONM1209
      IF (F4.GT.F3) GO TO 230                                           CONM1210
      A1=A2                                                             CONM1211
      F1=F2                                                             CONM1212
      A2=A3                                                             CONM1213
      F2=F3                                                             CONM1214
      A3=A4                                                             CONM1215
      F3=F4                                                             CONM1216
      GO TO 200                                                         CONM1217
230   CONTINUE                                                          CONM1218
      II=4                                                              CONM1219
      CALL CNMN04 (II,APP,A1,A1,F1,SLOPE,A2,F2,A3,F3,A4,F4)             CONM1220
      IF (APP.GT.A1) GO TO 250                                          CONM1221
      AP=A1-ALP                                                         CONM1222
      ALP=A1                                                            CONM1223
      OBJ=F1                                                            CONM1224
      DO 240 I=1,NDV                                                    CONM1225
240   X(I)=X(I)+AP*S(I)                                                 CONM1226
      GO TO 280                                                         CONM1227
250   CONTINUE                                                          CONM1228
C     ------------------------------------------------------------------CONM1229
C                 UPDATE DESIGN VECTOR AND FUNCTION VALUE               CONM1230
C     ------------------------------------------------------------------CONM1231
      AP=APP-ALP                                                        CONM1232
      ALP=APP                                                           CONM1233
      DO 260 I=1,NDV                                                    CONM1234
260   X(I)=X(I)+AP*S(I)                                                 CONM1235
      IF (IPRINT.GT.4) WRITE (6,370) ALP                                CONM1236
      IF (IPRINT.GT.4) WRITE (6,380) (X(I),I=1,NDV)                     CONM1237
      NCAL(1)=NCAL(1)+1                                                 CONM1238
      JGOTO=7                                                           CONM1239
      RETURN                                                            CONM1240
270   CONTINUE                                                          CONM1241
      IF (IPRINT.GT.4) WRITE (6,390) OBJ                                CONM1242
280   CONTINUE                                                          CONM1243
C     ------------------------------------------------------------------CONM1244
C                     CHECK FOR ILL-CONDITIONING                        CONM1245
C     ------------------------------------------------------------------CONM1246
      IF (OBJ.GT.F2.OR.OBJ.GT.F3) GO TO 290                             CONM1247
      IF (OBJ.LE.F1) GO TO 330                                          CONM1248
      AP=A1-ALP                                                         CONM1249
      ALP=A1                                                            CONM1250
      OBJ=F1                                                            CONM1251
      GO TO 310                                                         CONM1252
290   CONTINUE                                                          CONM1253
      IF (F2.LT.F3) GO TO 300                                           CONM1254
      OBJ=F3                                                            CONM1255
      AP=A3-ALP                                                         CONM1256
      ALP=A3                                                            CONM1257
      GO TO 310                                                         CONM1258
300   OBJ=F2                                                            CONM1259
      AP=A2-ALP                                                         CONM1260
      ALP=A2                                                            CONM1261
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310   CONTINUE                                                          CONM1262
C     ------------------------------------------------------------------CONM1263
C                          UPDATE DESIGN VECTOR                         CONM1264
C     ------------------------------------------------------------------CONM1265
      DO 320 I=1,NDV                                                    CONM1266
320   X(I)=X(I)+AP*S(I)                                                 CONM1267
330   CONTINUE                                                          CONM1268
C     ------------------------------------------------------------------CONM1269
C                       CHECK FOR MULTIPLE MINIMA                       CONM1270
C     ------------------------------------------------------------------CONM1271
      IF (OBJ.LE.FFF) GO TO 350                                         CONM1272
C     INITIAL FUNCTION IS MINIMUM.                                      CONM1273
      DO 340 I=1,NDV                                                    CONM1274
340   X(I)=X(I)-ALP*S(I)                                                CONM1275
      ALP=0.                                                            CONM1276
      OBJ=FFF                                                           CONM1277
350   CONTINUE                                                          CONM1278
      JGOTO=0                                                           CONM1279
      RETURN                                                            CONM1280
C     ------------------------------------------------------------------CONM1281
C                                FORMATS                                CONM1202
C     ------------------------------------------------------------------CONM1283
C                                                                       CONM1284
C                                                                       CONM1285
360   FORMAT (/////5X,60H* * * UNCONSTRAINED ONE-DIMENSIONAL SEARCH INFOCONM1286
     1RMATION * * *)                                                    CONM1287
370   FORMAT (/5X,7HALPHA =,E14.5/5X,8HX-VECTOR)                        CONM1288
380   FORMAT (5X,6E13.5)                                                CONM1289
390   FORMAT (/5X,5HOBJ =,E14.5)                                        CONM1290
      END                                                               CONM1291
      SUBROUTINE CNMN04 (II,XBAR,EPS,X1,Y1,SLOPE,X2,Y2,X3,Y3,X4,Y4)     CONM1292
C     ROUTINE TO FIND FIRST XBAR.GE.EPS CORRESPONDING TO A MINIMUM      CONM1293
C     OF A ONE-DIMENSIONAL REAL FUNCTION BY POLYNOMIEL INTERPOLATION.   CONM1294
C     BY G. N. VANDERPLAATS                         APRIL, 1972.        CONM1295
C     NASA-AMES RESEARCH CENTER,  MOFFETT FIELD, CALIF.                 CONM1296
C                                                                       CONM1297
C     II = CALCULATION CONTROL.                                         CONM1298
C          1:  2-POINT QUADRATIC INTERPOLATION, GIVEN X1, Y1, SLOPE,    CONM1299
C              X2 AND Y2.                                               CONM1300
C          2:  3-POINT QUADRATIC INTERPOLATION, GIVEN X1, Y1, X2, Y2,   CONM1301
C              X3 AND Y3.                                               CONM1302
C          3:  3-POINT CUBIC INTERPOLATION, GIVEN X1, Y1, SLOPE, X2, Y2,CONM1303
C              X3 AND Y3.                                               CONM1304
C          4:  4-POINT CUBIC INTERPOLATION, GIVEN X1, Y1, X2, Y2, X3,   CONM1305
C              Y3, X4 AND Y4.                                           CONM1306
C     EPS MAY BE NEGATIVE.                                              CONM1307
C     IF REQUIRED MINIMUM ON Y DOES NOT EXITS, OR THE FUNCTION IS       CONM1308
C     ILL-CONDITIONED, XBAR = EPS-1.0 WILL BE RETURNED AS AN ERROR      CONM1309
C     INDICATOR.                                                        CONM1310
C     IF DESIRED INTERPOLATION IS ILL-CONDITIONED, A LOWER ORDER        CONM1311
C     INTERPOLATION, CONSISTANT WITH INPUT DATA, WILL BE ATTEMPTED,     CONM1312
C     AND II WILL BE CHANGED ACCORDINGLY.                               CONM1313
      XBAR1=EPS-1.                                                      CONM1314
      XBAR=XBAR1                                                        CONM1315
      X21=X2-X1                                                         CONM1316
      IF (ABS(X21).LT.1.0E-20) RETURN                                   CONM1317
      NSLOP=MOD(II,2)                                                   CONM1318
      GO TO (10,20,40,50),II                                            CONM1319
10    CONTINUE                                                          CONM1320
C     ------------------------------------------------------------------CONM1321
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C                II=1: 2-POINT QUADRATIC INTERPOLATION                  CONM1322
C     ------------------------------------------------------------------CONM1323
      II=1                                                              CONM1324
      DX=X1-X2                                                          CONM1325
      IF (ABS(DX).LT.1.0E-20) RETURN                                    CONM1326
      AA=(SLOPE+(Y2-Y1)/DX)/DX                                          CONM1327
      IF (AA.LT.1.0E-20) RETURN                                         CONM1328
      BB=SLOPE-2.*AA*X1                                                 CONM1329
      XBAR=-.5*BB/AA                                                    CONM1330
      IF (XBAR.LT.EPS) XBAR=XBAR1                                       CONM1331
      RETURN                                                            CONM1332
20    CONTINUE                                                          CONM1333
C     ------------------------------------------------------------------CONM1334
C                II=2: 3-POINT QUADRATIC INTERPOLATION                  CONM1335
C     ------------------------------------------------------------------CONM1336
      II=2                                                              CONM1337
      X21=X2-X1                                                         CONM1338
      X31=X3-X1                                                         CONM1339
      X32=X3-X2                                                         CONM1340
      QQ=X21*X31*X32                                                    CONM1341
      IF (ABS(QQ).LT.1.0E-20) RETURN                                    CONM1342
      AA=(Y1*X32-Y2*X31+Y3*X21)/QQ                                      CONM1343
      IF (AA.LT.1.0E-20) GO TO 30                                       CONM1344
      BB=(Y2-Y1)/X21-AA*(X1+X2)                                         CONM1345
      XBAR=-.5*BB/AA                                                    CONM1346
      IF (XBAR.LT.EPS) XBAR=XBAR1                                       CONM1347
      RETURN                                                            CONM1348
30    CONTINUE                                                          CONM1349
      IF (NSLOP.EQ.0) RETURN                                            CONM1350
      GO TO 10                                                          CONM1351
40    CONTINUE                                                          CONM1352
C     ------------------------------------------------------------------CONM1353
C                   II=3: 3-POINT CUBIC INTERPOLATION                   CONM1354
C     ------------------------------------------------------------------CONM1355
      II=3                                                              CONM1356
      X21=X2-X1                                                         CONM1357
      X31=X3-X1                                                         CONM1358
      X32=X3-X2                                                         CONM1359
      QQ=X21*X31*X32                                                    CONM1360
      IF (ABS(QQ).LT.1.0E-20) RETURN                                    CONM1361
      X11=X1*X1                                                         CONM1362
      DNOM=X2*X2*X31-X11*X32-X3*X3*X21                                  CONM1363
      IF (ABS(DNOM).LT.1.0E-20) GO TO 20                                CONM1364
      AA=((X31*X31*(Y2-Y1)-X21*X21*(Y3-Y1))/(X31*X21)-SLOPE*X32)/DNOM   CONM1365
      IF (ABS(AA).LT.1.0E-20) GO TO 20                                  CONM1366
      BB=((Y2-Y1)/X21-SLOPE-AA*(X2*X2+X1*X2-2.*X11))/X21                CONM1367
      CC=SLOPE-3.*AA*X11-2.*BB*X1                                       CONM1368
      BAC=BB*BB-3.*AA*CC                                                CONM1369
      IF (BAC.LT.0.) GO TO 20                                           CONM1370
      BAC=SQRT(BAC)                                                     CONM1371
      XBAR=(BAC-BB)/(3.*AA)                                             CONM1372
      IF (XBAR.LT.EPS) XBAR=EPS                                         CONM1373
      RETURN                                                            CONM1374
50    CONTINUE                                                          CONM1375
C     ------------------------------------------------------------------CONM1376
C                   II=4: 4-POINT CUBIC INTERPOLATION                   CONM1377
C     ------------------------------------------------------------------CONM1378
      X21=X2-X1                                                         CONM1379
      X31=X3-X1                                                         CONM1380
      X41=X4-X1                                                         CONM1381
      X32=X3-X2                                                         CONM1382
      X42=X4-X2                                                         CONM1383
      X11=X1*X1                                                         CONM1384
      X22=X2*X2                                                         CONM1385
      X33=X3*X3                                                         CONM1386
      X44=X4*X4                                                         CONM1387
      X111=X1*X11                                                       CONM1388
      X222=X2*X22                                                       CONM1389
      Q2=X31*X21*X32                                                    CONM1390
      IF (ABS(Q2).LT.1.0E-30) RETURN                                    CONM1391
      Q1=X111*X32-X222*X31+X3*X33*X21                                   CONM1392
      Q4=X111*X42-X222*X41+X4*X44*X21                                   CONM1393
      Q5=X41*X21*X42                                                    CONM1394
      DNOM=Q2*Q4-Q1*Q5                                                  CONM1395
      IF (ABS(DNOM).LT.1.0E-30) GO TO 60                                CONM1396
      Q3=Y3*X21-Y2*X31+Y1*X32                                           CONM1397
      Q6=Y4*X21-Y2*X41+Y1*X42                                           CONM1398
      AA=(Q2*Q6-Q3*Q5)/DNOM                                             CONM1399
      BB=(Q3-Q1*AA)/Q2                                                  CONM1400
      CC=(Y2-Y1-AA*(X222-X111))/X21-BB*(X1+X2)                          CONM1401
      BAC=BB*BB-3.*AA*CC                                                CONM1402
      IF (ABS(AA).LT.1.0E-20.OR.BAC.LT.0.) GO TO 60                     CONM1403
      BAC=SQRT(BAC)                                                     CONM1404
      XBAR=(BAC-BB)/(3.*AA)                                             CONM1405
      IF (XBAR.LT.EPS) XBAR=XBAR1                                       CONM1406
      RETURN                                                            CONM1407
60    CONTINUE                                                          CONM1408
      IF (NSLOP.EQ.1) GO TO 40                                          CONM1409
      GO TO 20                                                          CONM1410
      END                                                               CONM1411
      SUBROUTINE CNMN05 (G,DF,A,S,B,C,SLOPE,PHI,ISC,IC,MS1,NVC,N1,N2,N3,CONM1412
     1N4,N5)                                                            CONM1413
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCONM1414
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCONM1415
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                               CONM1416
      DIMENSION DF(N1), G(N2), ISC(N2), IC(N3), A(N1,N3), S(N1), C(N4), CONM1417
     1MS1(N5), B(N3,N3)                                                 CONM1418
C     ROUTINE TO SOLVE DIRECTION FINDING PROBLEM IN MODIFIED METHOD OF  CONM1419
C     FEASIBLE DIRECTIONS.                                              CONM1420
C     BY G. N. VANDERPLAATS                               MAY, 1972.    CONM1421
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  CONM1422
C     NORM OF S VECTOR USED HERE IS S-TRANSPOSE TIMES S.LE.1.           CONM1423
C     IF NVC = 0 FIND DIRECTION BY ZOUTENDIJK'S METHOD.  OTHERWISE      CONM1424
C     FIND MODIFIED DIRECTION.                                          CONM1425
C     ------------------------------------------------------------------CONM1426
C     ***  NORMALIZE GRADIENTS, CALCULATE THETA'S AND DETERMINE NVC  ***CONM1427
C     ------------------------------------------------------------------CONM1428
      NDV1=NDV+1                                                        CONM1429
      NDV2=NDV+2                                                        CONM1430
      NAC1=NAC+1                                                        CONM1431
      NVC=0                                                             CONM1432
      THMAX=0.                                                          CONM1433
      CTA=ABS(CT)                                                       CONM1434
      CT1=1./CTA                                                        CONM1435
      CTAM=ABS(CTMIN)                                                   CONM1436
      CTB=ABS(CTL)                                                      CONM1437
      CT2=1./CTB                                                        CONM1438
      CTBM=ABS(CTLMIN)                                                  CONM1439
      A1=1.                                                             CONM1440
      DO 40 I=1,NAC                                                     CONM1441
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C     CALCULATE THETA
      NCI=IC(I)
      NCJ=1
      IF (NCI.LE.NCON) NCJ=ISC(NCI)
      C1=G(NCI)
      CTD=CT1
      CTC=CTAM
      IF (NCJ.LE.0) GO TO 10
      CTC=CTBM
      CTD=CT2
10    IF (C1.GT.CTC) NVC=NVC+1
      THT=0.
      GG=1.+CTD*C1
      IF (NCJ.EQ.0.OR.C1.GT.CTC) THT=THETA*GG*GG
      IF (THT.GT.50.) THT=50.
      IF (THT.GT.THMAX) THMAX=THT
      A(NDV1,I)=THT
C     ------------------------------------------------------------------
C                    NORMALIZE GRADIENTS OF CONSTRAINTS
C     ------------------------------------------------------------------
      A(NDV2,I)=1.
      IF (NCI.GT.NCON) GO TO 40
      A1=0.
      DO 20 J=1,NDV
      A1=A1+A(J,I)**2
20    CONTINUE
      IF (A1.LT.1.0E-20) A1=1.0E-20
      A1=SQRT(A1)
      A(NDV2,I)=A1
      A1=1./A1
      DO 30 J=1,NDV
30    A(J,I)=A1*A(J,I)
40    CONTINUE
C     ------------------------------------------------------------------
C     NORMALIZE GRADIENT OF OBJECTIVE FUNCTION AND STORE IN NAC+1
C     COLUMN OF A
C     ------------------------------------------------------------------
      A1=0.
      DO 50 I=1,NDV
      A1=A1+DF(I)**2
50    CONTINUE
      IF (A1.LT.1.0E-20) A1=1.0E-20
      A1=SQRT(A1)
      A1=1./A1
      DO 60 I=1,NDV
60    A(I,NAC1)=A1*DF(I)
C     BUILD C VECTOR.
      IF (NVC.GT.0) GO TO 80
C     ------------------------------------------------------------------
C                  BUILD C FOR CLASSICAL METHOD
C     ------------------------------------------------------------------
      NDB=NAC1
      A(NDV1,NDB)=1.
      DO 70 I=1,NDB
70    C(I)=-A(NDV1,I)
      GO TO 110
80    CONTINUE
C     ------------------------------------------------------------------
C                   BUILD C FOR MODIFIED METHOD
C     ------------------------------------------------------------------
      NDB=NAC
      A(NDV1,NAC1)=-PHI
C     ------------------------------------------------------------------
C           SCALE THETA'S SO THAT MAXIMUM THETA IS UNITY
C     ------------------------------------------------------------------
      IF (THMAX.GT.0.00001) THMAX=1./THMAX
      DO 90 I=1,NDB
      A(NDV1,I)=A(NDV1,I)*THMAX
90    CONTINUE
      DO 100 I=1,NDB
      C(I)=0.
      DO 100 J=1,NDV1
100   C(I)=C(I)+A(J,I)*A(J,NAC1)
110   CONTINUE
C     ------------------------------------------------------------------
C                          BUILD B MATRIX
C     ------------------------------------------------------------------
      DO 120 I=1,NDB
      DO 120 J=1,NDB
      B(I,J)=0.
      DO 120 K=1,NDV1
120   B(I,J)=B(I,J)-A(K,I)*A(K,J)
C     ------------------------------------------------------------------
C                      SOLVE SPECIAL L. P. PROBLEM
C     ------------------------------------------------------------------
      CALL CNMN08 (NDB,NER,C,MS1,B,N3,N4,N5)
      IF (IPRINT.GT.1.AND.NER.GT.0) WRITE (6,180)
C     CALCULATE RESULTING DIRECTION VECTOR, S.
      SLOPE=0.
C     ------------------------------------------------------------------
C                     USABLE-FEASIBLE DIRECTION
C     ------------------------------------------------------------------
      DO 140 I=1,NDV
      S1=0.
      IF (NVC.GT.0) S1=-A(I,NAC1)
      DO 130 J=1,NDB
130   S1=S1-A(I,J)*C(J)
      SLOPE=SLOPE+S1*DF(I)
140   S(I)=S1
      S(NDV1)=1.
      IF (NVC.GT.0) S(NDV1)=-A(NDV1,NAC1)
      DO 150 J=1,NDB
150   S(NDV1)=S(NDV1)-A(NDV1,J)*C(J)
C     ------------------------------------------------------------------
C                     NORMALIZE S TO MAX ABS OF UNITY
C     ------------------------------------------------------------------
      S1=0.
      DO 160 I=1,NDV
      A1=ABS(S(I))
      IF (A1.GT.S1) S1=A1
160   CONTINUE
      IF (S1.LT.1.0E-10) RETURN
      S1=1./S1
      DO 170 I=1,NDV
170   S(I)=S1*S(I)
      SLOPE=S1*SLOPE
      S(NDV1)=S1*S(NDV1)
      RETURN
C     ------------------------------------------------------------------
C                               FORMATS
```

```
C     ------------------------------------------------------------------CONM1562
C                                                                       CONM1563
C                                                                       CONM1564
180   FORMAT (//5X,46H* * DIRECTION FINDING PROCESS DID NOT CONVERGE/5X,CONM1565
     129H* * S-VECTOR MAY NOT BE VALID)                                 CONM1566
      END                                                               CONM1567
      SUBROUTINE CNMN06 (X,VLB,VUB,G,SCAL,DF,S,G1,G2,CTAM,CTBM,SLOPE,ALPCONM1568
     1,A2,A3,A4,F1,F2,F3,CV1,CV2,CV3,CV4,ALPCA,ALPFES,ALPLN,ALPMIN,ALPNCCONM1569
     2,ALPSAV,ALPSID,ALPTOT,ISC,N1,N2,NCAL,NVC,ICOUNT,IGOOD1,IGOOD2,IGOOCONM1570
     3D3,IGOOD4,IBEST,III,NLNC,JGOTO)                                   CONM1571
      COMMON /CNMN1/ DELFUN,DABFUN,FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,ALPHAXCONM1572
     1,ABOBJ1,THETA,OBJ,NDV,NCON,NSIDE,IPRINT,NFDG,NSCAL,LINOBJ,ITMAX,ITCONM1573
     2RM,ICNDIR,IGOTO,NAC,INFO,INFOG,ITER                               CONM1574
      DIMENSION X(N1), VLB(N1), VUB(N1), G(N2), SCAL(N1), DF(N1), S(N1),CONM1575
     1 G1(N2), G2(N2), ISC(N2), NCAL(2)                                 CONM1576
C     ROUTINE TO SOLVE ONE-DIMENSIONAL SEARCH PROBLEM FOR CONSTRAINED   CONM1577
C     FUNCTION MINIMIZATION.                                            CONM1578
C     BY G. N. VANDERPLAATS                         AUG., 1974.         CONM1579
C     NASA-AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.                  CONM1580
C     OBJ = INITIAL AND FINAL FUNCTION VALUE.                           CONM1581
C     ALP = MOVE PARAMETER.                                             CONM1582
C     SLOPE = INITIAL SLOPE.                                            CONM1583
C                                                                       CONM1584
C     ALPSID = MOVE TO SIDE CONSTRAINT.                                 CONM1585
C     ALPFES = MOVE TO FEASIBLE REGION.                                 CONM1586
C     ALPNC = MOVE TO NEW NON-LINEAR CONSTRAINT.                        CONM1587
C     ALPLN = MOVE TO LINEAR CONSTRAINT.                                CONM1588
C     ALPCA = MOVE TO RE-ENCOUNTER CURRENTLY ACTIVE CONSTRAINT.         CONM1589
C     ALPMIN = MOVE TO MINIMIZE FUNCTION.                               CONM1590
C     ALPTOT = TOTAL MOVE PARAMETER.                                    CONM1591
      ZRO=0.                                                            CONM1592
      IF (JGOTO.EQ.0) GO TO 10                                          CONM1593
      GO TO (140,310,520),JGOTO                                         CONM1594
10    IF (IPRINT.GE.5) WRITE (6,730)                                    CONM1595
      ALPSAV=ALP                                                        CONM1596
      ICOUNT=0                                                          CONM1597
      ALPTOT=0.                                                         CONM1598
C     TOLERANCES.                                                       CONM1599
      CTAM=ABS(CTMIN)                                                   CONM1600
      CTBM=ABS(CTLMIN)                                                  CONM1601
C     PROPOSED MOVE.                                                    CONM1602
20    CONTINUE                                                          CONM1603
C     ------------------------------------------------------------------CONM1604
C     *****  BEGIN SEARCH OR IMPOSE SIDE CONSTRAINT MODIFICATION  ***** CONM1605
C     ------------------------------------------------------------------CONM1606
      A2=ALPSAV                                                         CONM1607
      ICOUNT=ICOUNT+1                                                   CONM1608
      ALPSID=1.0E+20                                                    CONM1609
C     INITIAL ALPHA AND OBJ.                                            CONM1610
      ALP=0.                                                            CONM1611
      F1=OBJ                                                            CONM1612
      KSID=0                                                            CONM1613
      IF (NSIDE.EQ.0) GO TO 70                                          CONM1614
C     ------------------------------------------------------------------CONM1615
C     FIND MOVE TO SIDE CONSTRAINT AND INSURE AGAINST VIOLATION OF      CONM1616
C     SIDE CONSTRAINTS                                                  CONM1617
C     ------------------------------------------------------------------CONM1618
      DO 60 I=1,NDV                                                     CONM1619
      SI=S(I)                                                           CONM1620
      IF (ABS(SI).GT.1.0E-20) GO TO 30                                  CONM1621
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C     ITH COMPONENT OF S IS SMALL.  SET TO ZERO.                        CONM1622
      S(I)=0.                                                           CONM1623
      SLOPE=SLOPE-SI*DF(I)                                              CONM1624
      GO TO 60                                                          CONM1625
30    CONTINUE                                                          CONM1626
      XI=X(I)                                                           CONM1627
      SI=1./SI                                                          CONM1628
      IF (SI.GT.0.) GO TO 40                                            CONM1629
C     LOWER BOUND.                                                      CONM1630
      XI2=VLB(I)                                                        CONM1631
      XI1=ABS(XI2)                                                      CONM1632
      IF (XI1.LT.1.) XI1=1.                                             CONM1633
C     CONSTRAINT VALUE.                                                 CONM1634
      GI=(XI2-XI)/XI1                                                   CONM1635
      IF (GI.GT.-1.0E-6) GO TO 50                                       CONM1636
C     PROPOSED MOVE TO LOWER BOUND.                                     CONM1637
      ALPA=(XI2-XI)*SI                                                  CONM1638
      IF (ALPA.LT.ALPSID) ALPSID=ALPA                                   CONM1639
      GO TO 60                                                          CONM1640
40    CONTINUE                                                          CONM1641
C     UPPER BOUND.                                                      CONM1642
      XI2=VUB(I)                                                        CONM1643
      XI1=ABS(XI2)                                                      CONM1644
      IF (XI1.LT.1.) XI1=1.                                             CONM1645
C     CONSTRAINT VALUE.                                                 CONM1646
      GI=(XI-XI2)/XI1                                                   CONM1647
      IF (GI.GT.-1.0E-6) GO TO 50                                       CONM1648
C     PROPOSED MOVE TO UPPER BOUND.                                     CONM1649
      ALPA=(XI2-XI)*SI                                                  CONM1650
      IF (ALPA.LT.ALPSID) ALPSID=ALPA                                   CONM1651
      GO TO 60                                                          CONM1652
50    CONTINUE                                                          CONM1653
C     MOVE WILL VIOLATE SIDE CONSTRAINT.  SET S(I)=0.                   CONM1654
      SLOPE=SLOPE-S(I)*DF(I)                                            CONM1655
      S(I)=0.                                                           CONM1656
      KSID=KSID+1                                                       CONM1657
60    CONTINUE                                                          CONM1658
C     ALPSID IS UPPER BOUND ON ALPHA.                                   CONM1659
      IF (A2.GT.ALPSID) A2=ALPSID                                       CONM1660
70    CONTINUE                                                          CONM1661
C     ------------------------------------------------------------------CONM1662
C                   CHECK ILL-CONDITIONING                              CONM1663
C     ------------------------------------------------------------------CONM1664
      IF (KSID.EQ.NDV.OR.ICOUNT.GT.10) GO TO 710                        CONM1665
      IF (NVC.EQ.0.AND.SLOPE.GT.0.) GO TO 710                           CONM1666
      ALPFES=-1.                                                        CONM1667
      ALPMIN=-1.                                                        CONM1668
      ALPLN=1.1*ALPSID                                                  CONM1669
      ALPNC=ALPSID                                                      CONM1670
      ALPCA=ALFSID                                                      CONM1671
      IF (NCON.EQ.0) GO TO 90                                           CONM1672
C     STORE CONSTRAINT VALUES IN G1.                                    CONM1673
      DO 80 I=1,NCON                                                    CONM1674
      G1(I)=G(I)                                                        CONM1675
80    CONTINUE                                                          CONM1676
90    CONTINUE                                                          CONM1677
C     ------------------------------------------------------------------CONM1678
C                        MOVE A DISTANCE A2*S                           CONM1679
C     ------------------------------------------------------------------CONM1680
      ALPTOT=ALPTOT+A2                                                  CONM1681
      DO 100 I=1,NDV
      X(I)=X(I)+A2*S(I)
100   CONTINUE
      IF (IPRINT.LT.5) GO TO 130
      WRITE (6,740) A2
      IF (NSCAL.EQ.0) GO TO 120
      DO 110 I=1,NDV
110   G(I)=SCAL(I)*X(I)
      WRITE (6,750) (G(I),I=1,NDV)
      GO TO 130
120   WRITE (6,750) (X(I),I=1,NDV)
C     ------------------------------------------------------------------
C                     UPDATE FUNCTION AND CONSTRAINT VALUES
C     ------------------------------------------------------------------
130   NCAL(1)=NCAL(1)+1
      JGOTO=1
      RETURN
140   CONTINUE
      F2=OBJ
      IF (IPRINT.GE.5) WRITE (6,760) F2
      IF (IPRINT.LT.5.OR.NCON.EQ.0) GO TO 150
      WRITE (6,770)
      WRITE (6,750) (G(I),I=1,NCON)
150   CONTINUE
C     ------------------------------------------------------------------
C                 IDENTIFY ACCAPTABILITY OF DESIGNS F1 AND F2
C     ------------------------------------------------------------------
C     IGOOD = 0 IS ACCAPTABLE.
C     CV = MAXIMUM CONSTRAINT VIOLATION.
      IGOOD1=0
      IGOOD2=0
      CV1=0.
      CV2=0.
      NVC1=0
      IF (NCON.EQ.0) GO TO 170
      DO 160 I=1,NCON
      CC=CTAM
      IF (ISC(I).GT.0) CC=CTBM
      C1=G1(I)-CC
      C2=G(I)-CC
      IF (C2.GT.0.) NVC1=NVC1+1
      IF (C1.GT.CV1) CV1=C1
      IF (C2.GT.CV2) CV2=C2
160   CONTINUE
      IF (CV1.GT.0.) IGOOD1=1
      IF (CV2.GT.0.) IGOOD2=1
170   CONTINUE
      ALP=A2
      OBJ=F2
C     ------------------------------------------------------------------
C     IF F2 VIOLATES FEWER CONSTRAINTS THAN F1 BUT STILL HAS CONSTRAINT
C     VIOLATIONS RETURN
C     ------------------------------------------------------------------
      IF (NVC1.LT.NVC.AND.NVC1.GT.0) GO TO 710
C     ------------------------------------------------------------------
C                    IDENTIFY BEST OF DESIGNS F1 ANF F2
C     ------------------------------------------------------------------
C     IBEST CORRESPONDS TO MINIMUM VALUE DESIGN.
C     IF CONSTRAINTS ARE VIOLATED, IBEST CORRESPONDS TO MINIMUM
C     CONSTRAINT VIOLATION.
      IF (IGOOD1.EQ.0.AND.IGOOD2.EQ.0) GO TO 180
C     VIOLATED CONSTRAINTS.  PICK MINIMUM VIOLATION.
      IBEST=1
      IF (CV1.GE.CV2) IBEST=2
      GO TO 190
180   CONTINUE
C     NO CONSTRAINT VIOLATION.  PICK MINIMUM F.
      IBEST=1
      IF (F2.LE.F1) IBEST=2
190   CONTINUE
      II=1
      IF (NCON.EQ.0) GO TO 230
C     ------------------------------------------------------------------
C     *****               2 - POINT INTERPOLATION                  *****
C     ------------------------------------------------------------------
      III=0
200   III=III+1
      C1=G1(III)
      C2=G(III)
      IF (ISC(III).EQ.0) GO TO 210
C     ------------------------------------------------------------------
C                            LINEAR CONSTRAINT
C     ------------------------------------------------------------------
      IF (C1.GE.1.0E-5.AND.C1.LE.CTBM) GO TO 220
      CALL CNMN07 (II,ALP,ZRO,ZRO,C1,A2,C2,ZRO,ZRO)
      IF (ALP.LE.0.) GO TO 220
      IF (C1.GT.CTBM.AND.ALP.GT.ALPFES) ALPFES=ALP
      IF (C1.LT.CTL.AND.ALP.LT.ALPLN) ALPLN=ALP
      GO TO 220
210   CONTINUE
C     ------------------------------------------------------------------
C                          NON-LINEAR CONSTRAINT
C     ------------------------------------------------------------------
      IF (C1.GE.1.0E-5.AND.C1.LE.CTAM) GO TO 220
      CALL CNMN07 (II,ALP,ZRO,ZRO,C1,A2,C2,ZRO,ZRO)
      IF (ALP.LE.0.) GO TO 220
      IF (C1.GT.CTAM.AND.ALP.GT.ALPFES) ALPFES=ALP
      IF (C1.LT.CT.AND.ALP.LT.ALPNC) ALPNC=ALP
220   CONTINUE
      IF (III.LT.NCON) GO TO 200
230   CONTINUE
      IF (LINOBJ.GT.0.OR.SLOPE.GE.0.) GO TO 240
C     CALCULATE ALPHA TO MINIMIZE FUNCTION.
      CALL CNMN04 (II,ALPMIN,ZRO,ZRO,F1,SLOPE,A2,F2,ZRO,ZRO,ZRO,ZRO)
240   CONTINUE
C     ------------------------------------------------------------------
C                             PROPOSED MOVE
C     ------------------------------------------------------------------
C     MOVE AT LEAST FAR ENOUGH TO OVERCOME CONSTRAINT VIOLATIONS.
      A3=ALPFES
C     MOVE TO MINIMIZE FUNCTION.
      IF (ALPMIN.GT.A3) A3=ALPMIN
C     IF A3.LE.0, SET A3 = ALPSID.
      IF (A3.LE.0.) A3=ALPSID
C     LIMIT MOVE TO NEW CONSTRAINT ENCOUNTER.
      IF (A3.GT.ALPNC) A3=ALPNC
      IF (A3.GT.ALPLN) A3=ALPLN
C     MAKE A3 NON-ZERO.
      IF (A3.LE.1.0E-20) A3=1.0E-20
C     IF A3=A2=ALPSID AND F2 IS BEST, GO INVOKE SIDE CONSTRAINT
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C     MODIFICATION.                                                     CONM1802
      ALPB=1.-A2/A3                                                     CONM1803
      ALPA=1.-ALPSID/A3                                                 CONM1804
      JBEST=0                                                           CONM1805
      IF (ABS(ALPB).LT.1.0E-10.AND.ABS(ALPA).LT.1.0E-10) JBEST=1        CONM1806
      IF (JBEST.EQ.1.AND.IBEST.EQ.2) GO TO 20                           CONM1807
C     SIDE CONSTRAINT CHECK NOT SATISFIED.                              CONM1808
      IF (NCON.EQ.0) GO TO 260                                          CONM1809
C     STORE CONSTRAINT VALUES IN G2.                                    CONM1810
      DO 250 I=1,NCON                                                   CONM1811
      G2(I)=G(I)                                                        CONM1812
250   CONTINUE                                                          CONM1813
260   CONTINUE                                                          CONM1814
C     IF A3=A2, SET A3=.9*A2.                                           CONM1815
      IF (ABS(ALPB).LT.1.0E-10) A3=.9*A2                                CONM1816
C     MOVE AT LEAST .01*A2.                                             CONM1817
      IF (A3.LT.(.01*A2)) A3=.01*A2                                     CONM1818
C     LIMIT MOVE TO 5.*A2.                                              CONM1819
      IF (A3.GT.(5.*A2)) A3=5.*A2                                       CONM1820
C     LIMIT MOVE TO ALPSID.                                             CONM1821
      IF (A3.GT.ALPSID) A3=ALPSID                                       CONM1822
C     MOVE A DISTANCE A3*S.                                             CONM1823
      ALP=A3-A2                                                         CONM1824
      ALPTOT=ALPTOT+ALP                                                 CONM1825
      DO 270 I=1,NDV                                                    CONM1826
      X(I)=X(I)+ALP*S(I)                                                CONM1827
270   CONTINUE                                                          CONM1828
      IF (IPRINT.LT.5) GO TO 300                                        CONM1829
      WRITE (6,780)                                                     CONM1830
      WRITE (6,740) A3                                                  CONM1831
      IF (NSCAL.EQ.0) GO TO 290                                         CONM1832
      DO 280 I=1,NDV                                                    CONM1833
280   G(I)=SCAL(I)*X(I)                                                 CONM1834.
      WRITE (6,750) (G(I),I=1,NDV)                                      CONM1835
      GO TO 300                                                         CONM1836
290   WRITE (6,750) (X(I),I=1,NDV)                                      CONM1837
300   CONTINUE                                                          CONM1838
C     ------------------------------------------------------------------CONM1839
C              UPDATE FUNCTION AND CONSTRAINT VALUES                    CONM1840
C     ------------------------------------------------------------------CONM1841
      NCAL(1)=NCAL(1)+1                                                 CONM1842
      JGOTO=2                                                           CONM1843
      RETURN                                                            CONM1844
310   CONTINUE                                                          CONM1845
      F3=OBJ                                                            CONM1846
      IF (IPRINT.GE.5) WRITE (6,760) F3                                 CONM1847
      IF (IPRINT.LT.5.OR.NCON.EQ.0) GO TO 320                           CONM1848
      WRITE (6,770)                                                     CONM1849
      WRITE (6,750) (G(I),I=1,NCON)                                     CONM1850
320   CONTINUE                                                          CONM1851
C     ------------------------------------------------------------------CONM1852
C       CALCULATE MAXIMUM CONSTRAINT VIOLATION AND PICK BEST DESIGN     CONM1853
C     ------------------------------------------------------------------CONM1854
      CV3=0.                                                            CONM1855
      IGOOD3=0                                                          CONM1856
      NVC1=0                                                            CONM1857
      IF (NCON.EQ.0) GO TO 340                                          CONM1858
      DO 330 I=1,NCON                                                   CONM1859
      CC=CTAM                                                           CONM1860
      IF (ISC(I).GT.0) CC=CTBM                                          CONM1861
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      C1=G(I)-CC                                                        CONM1862
      IF (C1.GT.CV3) CV3=C1                                             CONM1863
      IF (C1.GT.0.) NVC1=NVC1+1                                         CONM1864
330   CONTINUE                                                          CONM1865
      IF (CV3.GT.0.) IGOOD3=1                                           CONM1866
340   CONTINUE                                                          CONM1867
C     DETERMINE BEST DESIGN.                                            CONM1868
      IF (IBEST.EQ.2) GO TO 360                                         CONM1869
C     CHOOSE BETWEEN F1 AND F3.                                         CONM1870
      IF (IGOOD1.EQ.0.AND.IGOOD3.EQ.0) GO TO 350                        CONM1871
      IF (CV1.GE.CV3) IBEST=3                                           CONM1872
      GO TO 380                                                         CONM1873
350   IF (F3.LE.F1) IBEST=3                                             CONM1874
      GO TO 380                                                         CONM1875
360   CONTINUE                                                          CONM1876
C     CHOOSE BETWEEN F2 AND F3.                                         CONM1877
      IF (IGOOD2.EQ.0.AND.IGOOD3.EQ.0) GO TO 370                        CONM1878
      IF (CV2.GE.CV3) IBEST=3                                           CONM1879
      GO TO 380                                                         CONM1880
370   IF (F3.LE.F2) IBEST=3                                             CONM1881
380   CONTINUE                                                          CONM1882
      ALP=A3                                                            CONM1883
      OBJ=F3                                                            CONM1884
C     IF F3 VIOLATES FEWER CONSTRAINTS THAN F1 RETURN.                  CONM1885
      IF (NVC1.LT.NVC) GO TO 710                                        CONM1886
C     IF OBJECTIVE AND ALL CONSTRAINTS ARE LINEAR, RETURN.              CONM1887
      IF (LINOBJ.NE.0.AND.NLNC.EQ.NCON) GO TO 710                       CONM1888
C     IF A3 = ALPLN AND F3 IS BOTH GOOD AND BEST RETURN.                CONM1889
      ALPB=1.-ALPLN/A3                                                  CONM1890
      IF ((ABS(ALPB).LT.1.0E-20.AND.IBEST.EQ.3).AND.(IGOOD3.EQ.0)) GO TOCONM1891
     1 710                                                              CONM1892
C     IF A3 = ALPSID AND F3 IS BEST, GO INVOKE SIDE CONSTRAINT          CONM1893
C     MODIFICATION.                                                     CONM1894
      ALPA=1.-ALPSID/A3                                                 CONM1895
      IF (ABS(ALPA).LT.1.0E-20.AND.IBEST.EQ.3) GO TO 20                 CONM1896
C     ------------------------------------------------------------------CONM1897
C     **********               3 - POINT INTERPOLATION         *********CONM1898
C     ------------------------------------------------------------------CONM1899
      ALPNC=ALPSID                                                      CONM1900
      ALPCA=ALPSID                                                      CONM1901
      ALPFES=-1.                                                        CONM1902
      ALPMIN=-1.                                                        CONM1903
      IF (NCON.EQ.0) GO TO 440                                          CONM1904
      III=0                                                             CONM1905
390   III=III+1                                                         CONM1906
      C1=G1(III)                                                        CONM1907
      C2=G2(III)                                                        CONM1908
      C3=G(III)                                                         CONM1909
      IF (ISC(III).EQ.0) GO TO 400                                      CONM1910
C     ------------------------------------------------------------------CONM1911
C     LINEAR CONSTRAINT.  FIND ALPFES ONLY.  ALPLN SAME AS BEFORE.      CONM1912
C     ------------------------------------------------------------------CONM1913
      IF (C1.LE.CTBM) GO TO 430                                         CONM1914
      II=1                                                              CONM1915
      CALL CNMN07 (II,ALP,ZRO,ZRO,C1,A3,C3,ZRO,ZRO)                     CONM1916
      IF (ALP.GT.ALPFES) ALPFES=ALP                                     CONM1917
      GO TO 430                                                         CONM1918
400   CONTINUE                                                          CONM1919
C     ------------------------------------------------------------------CONM1920
C                        NON-LINEAR CONSTRAINT                          CONM1921
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C     ------------------------------------------------------------------CONM1922
      II=2                                                              CONM1923
      CALL CNMN07 (II,ALP,ZRO,ZRO,C1,A2,C2,A3,C3)                       CONM1924
      IF (ALP.LE.ZRO) GO TO 430                                         CONM1925
      IF (C1.GE.CT.AND.C1.LE.0.) GO TO 410                              CONM1926
      IF (C1.GT.CTAM.OR.C1.LT.0.) GO TO 420                             CONM1927
C     ALP IS MINIMUM MOVE.  UPDATE FOR NEXT CONSTRAINT ENCOUNTER.       CONM1928
410   ALPA=ALP                                                          CONM1929
      CALL CNMN07 (II,ALP,ALPA,ZRO,C1,A2,C2,A3,C3)                      CONM1930
      IF (ALP.LT.ALPCA.AND.ALP.GE.ALPA) ALPCA=ALP                       CONM1931
      GO TO 430                                                         CONM1932
420   CONTINUE                                                          CONM1933
      IF (ALP.GT.ALPFES.AND.C1.GT.CTAM) ALPFES=ALP                      CONM1934
      IF (ALP.LT.ALPNC.AND.C1.LT.0.) ALPNC=ALP                          CONM1935
430   CONTINUE                                                          CONM1936
      IF (III.LT.NCON) GO TO 390                                        CONM1937
440   CONTINUE                                                          CONM1938
      IF (LINOBJ.GT.0.OR.SLOPE.GT.0.) GO TO 450                         CONM1939
C     ------------------------------------------------------------------CONM1940
C              CALCULATE ALPHA TO MINIMIZE FUNCTION                     CONM1941
C     ------------------------------------------------------------------CONM1942
      II=3                                                              CONM1943
      IF (A2.GT.A3.AND.(IGOOD2.EQ.0.AND.IBEST.EQ.2)) II=2               CONM1944
      CALL CNMN04 (II,ALPMIN,ZRO,ZRO,F1,SLOPE,A2,F2,A3,F3,ZRO,ZRO)      CONM1945
450   CONTINUE                                                          CONM1946
C     ------------------------------------------------------------------CONM1947
C                       PROPOSED MOVE                                   CONM1948
C     ------------------------------------------------------------------CONM1949
C     MOVE AT LEAST ENOUGH TO OVERCOME CONSTRAINT VIOLATIONS.           CONM1950
      A4=ALPFES                                                         CONM1951
C     MOVE TO MINIMIZE FUNCTION.                                        CONM1952
      IF (ALPMIN.GT.A4) A4=ALPMIN                                       CONM1953
C     IF A4.LE.0, SET A4 = ALPSID.                                      CONM1954
      IF (A4.LE.0.) A4=ALPSID                                           CONM1955
C     LIMIT MOVE TO NEW CONSTRAINT ENCOUNTER.                           CONM1956
      IF (A4.GT.ALPLN) A4=ALPLN                                         CONM1957
      IF (A4.GT.ALPNC) A4=ALPNC                                         CONM1958
C     LIMIT MOVE TO RE-ENCOUNTER CURRENTLY ACTIVE CONSTRAINT.           CONM1959
      IF (A4.GT.ALPCA) A4=ALPCA                                         CONM1960
C     LIMIT A4 TO 5.*A3.                                                CONM1961
      IF (A4.GT.(5.*A3)) A4=5.*A3                                       CONM1962
C     UPDATE DESIGN.                                                    CONM1963
      IF (IBEST.NE.3.OR.NCON.EQ.0) GO TO 470                            CONM1964
C     STORE CONSTRAINT VALUES IN G2.  F3 IS BEST.  F2 IS NOT.           CONM1965
      DO 460 I=1,NCON                                                   CONM1966
      G2(I)=G(I)                                                        CONM1967
460   CONTINUE                                                          CONM1968
470   CONTINUE                                                          CONM1969
C     IF A4=A3 AND IGOOD1=0 AND IGOOD3=1, SET A4=.9*A3.                 CONM1970
      ALP=A4-A3                                                         CONM1971
      IF ((IGOOD1.EQ.0.AND.IGOOD3.EQ.1).AND.ABS(ALP).LT.1.0E-20) A4=.9*ACONM1972
     13                                                                 CONM1973
C     ------------------------------------------------------------------CONM1974
C                   MOVE A DISTANCE A4*S                                CONM1975
C     ------------------------------------------------------------------CONM1976
      ALP=A4-A3                                                         CONM1977
      ALPTOT=ALPTOT+ALP                                                 CONM1978
      DO 480 I=1,NDV                                                    CONM1979
      X(I)=X(I)+ALP*S(I)                                                CONM1980
48C   CONTINUE                                                          CONM1981
      IF (IPRINT.LT.5) GO TO 510                                        CONM1982
      WRITE (6,720)                                                     CONM1983
      WRITE (6,740) A4                                                  CONM1984
      IF (NSCAL.EQ.0) GO TO 500                                         CONM1985
      DO 490 I=1,NDV                                                    CONM1986
490   G(I)=SCAL(I)*X(I)                                                 CONM1987
      WRITE (6,750) (G(I),I=1,NDV)                                      CONM1988
      GO TO 510                                                         CONM1989
500   WRITE (6,750) (X(I),I=1,NDV)                                      CONM1990
510   CONTINUE                                                          CONM1991
C     ------------------------------------------------------------------CONM1992
C              UPDATE FUNCTION AND CONSTRAINT VALUES                    CONM1993
C     ------------------------------------------------------------------CONM1994
      NCAL(1)=NCAL(1)+1                                                 CONM1995
      JGOTO=3                                                           CONM1996
      RETURN                                                            CONM1997
520   CONTINUE                                                          CONM1998
      F4=OBJ                                                            CONM1999
      IF (IPRINT.GE.5) WRITE (6,760) F4                                 CONM2000
      IF (IPRINT.LT.5.OR.NCON.EQ.0) GO TO 530                           CONM2001
      WRITE (6,770)                                                     CONM2002
      WRITE (6,750) (G(I),I=1,NCON)                                     CONM2003
530   CONTINUE                                                          CONM2004
C     DETERMINE ACCAPTABILITY OF F4.                                    CONM2005
      IGOOD4=0                                                          CONM2006
      CV4=0.                                                            CONM2007
      IF (NCON.EQ.0) GO TO 550                                          CONM2008
      DO 540 I=1,NCON                                                   CONM2009
      CC=CTAM                                                           CONM2010
      IF (ISC(I).GT.0) CC=CTBM                                          CONM2011
      C1=G(I)-CC                                                        CONM2012
      IF (C1.GT.CV4) CV4=C1                                             CONM2013
540   CONTINUE                                                          CONM2014
      IF (CV4.GT.0.) IGOOD4=1                                           CONM2015
550   CONTINUE                                                          CONM2016
      ALP=A4                                                            CONM2017
      OBJ=F4                                                            CONM2018
C     ------------------------------------------------------------------CONM2019
C                     DETERMINE BEST DESIGN                             CONM2020
C     ------------------------------------------------------------------CONM2021
      GO TO (560,610,660),IBEST                                         CONM2022
560   CONTINUE                                                          CONM2023
C     CHOOSE BETWEEN F1 AND F4.                                         CONM2024
      IF (IGOOD1.EQ.0.AND.IGOOD4.EQ.0) GO TO 570                        CONM2025
      IF (CV1.GT.CV4) GO TO 710                                         CONM2026
      GO TO 580                                                         CONM2027
570   CONTINUE                                                          CONM2028
      IF (F4.LE.F1) GO TO 710                                           CONM2029
580   CONTINUE                                                          CONM2030
C     F1 IS BEST.                                                       CONM2031
      ALPTOT=ALPTOT-A4                                                  CONM2032
      OBJ=F1                                                            CONM2033
      DO 590 I=1,NDV                                                    CONM2034
      X(I)=X(I)-A4*S(I)                                                 CONM2035
590   CONTINUE                                                          CONM2036
      IF (NCON.EQ.0) GO TO 710                                          CONM2037
      DO 600 I=1,NCON                                                   CONM2038
      G(I)=G1(I)                                                        CONM2039
600   CONTINUE                                                          CONM2040
      GO TO 710                                                         CONM2041
```

```
 610  CONTINUE                                                          CONM2042
C     CHOOSE BETWEEN F2 AND F4.                                         CONM2043
      IF (IGOOD2.EQ.0.AND.IGOOD4.EQ.0) GO TO 620                        CONM2044
      IF (CV2.GT.CV4) GO TO 710                                         CONM2045
      GO TO 630                                                         CONM2046
 620  CONTINUE                                                          CONM2047
      IF (F4.LE.F2) GO TO 710                                           CONM2048
 630  CONTINUE                                                          CONM2049
C     F2 IS BEST.                                                       CONM2050
      OBJ=F2                                                            CONM2051
      A2=A4-A2                                                          CONM2052
      ALPTOT=ALPTOT-A2                                                  CONM2053
      DO 640 I=1,NDV                                                    CONM2054
      X(I)=X(I)-A2*S(I)                                                 CONM2055
 640  CONTINUE                                                          CONM2056
      IF (NCON.EQ.0) GO TO 710                                          CONM2057
      DO 650 I=1,NCON                                                   CONM2058
      G(I)=G2(I)                                                        CONM2059
 650  CONTINUE                                                          CONM2060
      GO TO 710                                                         CONM2061
 660  CONTINUE                                                          CONM2062
C     CHOOSE BETWEEN F3 AND F4.                                         CONM2063
      IF (IGOOD3.EQ.0.AND.IGOOD4.EQ.0) GO TO 670                        CONM2064
      IF (CV3.GT.CV4) GO TO 710                                         CONM2065
      GO TO 680                                                         CONM2066
 670  CONTINUE                                                          CONM2067
      IF (F4.LE.F3) GO TO 710                                           CONM2068
 680  CONTINUE                                                          CONM2069
C     F3 IS BEST.                                                       CONM2070
      OBJ=F3                                                            CONM2071
      A3=A4-A3                                                          CONM2072
      ALPTOT=ALPTOT-A3                                                  CONM2073
      DO 690 I=1,NDV                                                    CONM2074
      X(I)=X(I)-A3*S(I)                                                 CONM2075
 690  CONTINUE                                                          CONM2076
      IF (NCON.EQ.0) GO TO 710                                          CONM2077
      DO 700 I=1,NCON                                                   CONM2078
      G(I)=G2(I)                                                        CONM2079
 700  CONTINUE                                                          CONM2080
 710  CONTINUE                                                          CONM2081
      ALP=ALPTOT                                                        CONM2082
      IF (IPRINT.GE.5) WRITE (6,790)                                    CONM2083
      JGOTO=0                                                           CONM2084
      RETURN                                                            CONM2085
C     ------------------------------------------------------------------CONM2086
C                                  FORMATS                              CONM2087
C     ------------------------------------------------------------------CONM2088
C                                                                       CONM2089
C                                                                       CONM2090
 720  FORMAT (/5X,25HTHREE-POINT INTERPOLATION)                         CONM2091
 730  FORMAT (/////58H* * * CONSTRAINED ONE-DIMENSIONAL SEARCH INFORMATICONM2092
     1ON * * *)                                                         CONM2093
 740  FORMAT (//5X,15HPROPOSED DESIGN/5X,7HALPHA =,E12.5/5X,8HX-VECTOR) CONM2094
 750  FORMAT (1X,8E12.4)                                                CONM2095
 760  FORMAT (/5X,5HOBJ =,E13.5)                                        CONM2096
 770  FORMAT (/5X,17HCONSTRAINT VALUES)                                 CONM2097
 780  FORMAT (/5X,23HTWO-POINT INTERPOLATION)                           CONM2098
 790  FORMAT (/5X,35H* * * END OF ONE-DIMENSIONAL SEARCH)               CONM2099
      END                                                               CONM2100
      SUBROUTINE CNMN07 (II,XBAR,EPS,X1,Y1,X2,Y2,X3,Y3)                 CONM2101
```

```
C     ROUTINE TO FIND FIRST XBAR.GE.EPS CORRESPONDING TO A REAL ZERO    CONM2102
C     OF A ONE-DIMENSIONAL FUNCTION BY POLYNOMIEL INTERPOLATION.        CONM2103
C     BY G. N. VANDERPLAATS                             APRIL, 1972.    CONM2104
C     NASA-AMES RESEARCH CENTER,  MOFFETT FIELD, CALIF.                 CONM2105
C     II = CALCULATION CONTROL.                                         CONM2106
C          1:  2-POINT LINEAR INTERPOLATION, GIVEN X1, Y1, X2 AND Y2.   CONM2107
C          2:  3-POINT QUADRATIC INTERPOLATION, GIVEN X1, Y1, X2, Y2,   CONM2108
C              X3 AND Y3.                                               CONM2109
C     EPS MAY BE NEGATIVE.                                              CONM2110
C     IF REQUIRED ZERO ON Y DOES NOT EXITS, OR THE FUNCTION IS          CONM2111
C     ILL-CONDITIONED, XBAR = EPS-1.0 WILL BE RETURNED AS AN ERROR      CONM2112
C     INDICATOR.                                                        CONM2113
C     IF DESIRED INTERPOLATION IS ILL-CONDITIONED, A LOWER ORDER        CONM2114
C     INTERPOLATION, CONSISTANT WITH INPUT DATA, WILL BE ATTEMPTED AND  CONM2115
C     II WILL BE CHANGED ACCORDINGLY.                                   CONM2116
      XBAR1=EPS-1.                                                      CONM2117
      XBAR=XBAR1                                                        CONM2118
      JJ=0                                                              CONM2119
      X21=X2-X1                                                         CONM2120
      IF (ABS(X21).LT.1.0E-20) RETURN                                   CONM2121
      IF (II.EQ.2) GO TO 30                                             CONM2122
C                                                                       CONM2123
10    CONTINUE                                                          CONM2124
C     ------------------------------------------------------------------CONM2125
C                     II=1: 2-POINT LINEAR INTERPOLATION                CONM2126
C     ------------------------------------------------------------------CONM2127
      II=1                                                              CONM2128
      YY=Y1*Y2                                                          CONM2129
      IF (JJ.EQ.0.OR.YY.LT.0.) GO TO 20                                 CONM2130
C     INTERPOLATE BETWEEN X2 AND X3.                                    CONM2131
      DY=Y3-Y2                                                          CONM2132
      IF (ABS(DY).LT.1.0E-20) GO TO 20                                  CONM2133
      XBAR=X2+Y2*(X2-X3)/DY                                             CONM2134
      IF (XBAR.LT.EPS) XBAR=XBAR1                                       CONM2135
      RETURN                                                            CONM2136
20    DY=Y2-Y1                                                          CONM2137
C     INTERPOLATE BETWEEN X1 AND X2.                                    CONM2138
      IF (ABS(DY).LT.1.0E-20) RETURN                                    CONM2139
      XBAR=X1+Y1*(X1-X2)/DY                                             CONM2140
      IF (XBAR.LT.EPS) XBAR=XBAR1                                       CONM2141
      RETURN                                                            CONM2142
30    CONTINUE                                                          CONM2143
C     ------------------------------------------------------------------CONM2144
C                    II=2: 3-POINT QUADRATIC INTERPOLATION              CONM2145
C     ------------------------------------------------------------------CONM2146
      JJ=1                                                              CONM2147
      X31=X3-X1                                                         CONM2148
      X32=X3-X2                                                         CONM2149
      QQ=X21*X31*X32                                                    CONM2150
      IF (ABS(QQ).LT.1.0E-20) RETURN                                    CONM2151
      AA=(Y1*X32-Y2*X31+Y3*X21)/QQ                                      CONM2152
      IF (ABS(AA).LT.1.0E-20) GO TO 10                                  CONM2153
      BB=(Y2-Y1)/X21-AA*(X1+X2)                                         CONM2154
      CC=Y1-X1*(AA*X1+BB)                                               CONM2155
      BAC=BB*BB-4.*AA*CC                                                CONM2156
      IF (BAC.LT.0.) GO TO 10                                           CONM2157
      BAC=SQRT(BAC)                                                     CONM2158
      AA=.5/AA                                                          CONM2159
      XBAR=AA*(BAC-BB)                                                  CONM2160
      XB2=-AA*(BAC+BB)                                                  CONM2161
      IF (XBAR.LT.EPS) XBAR=XB2                                         CONM2162
      IF (XB2.LT.XBAR.AND.XB2.GT.EPS) XBAR=XB2                          CONM2163
      IF (XBAR.LT.EPS) XBAR=XBAR1                                       CONM2164
      RETURN                                                            CONM2165
      END                                                               CONM2166
      SUBROUTINE CNMN08 (NDB,NER,C,MS1,B,N3,N4,N5)                      CONM2167
      DIMENSION C(N4), B(N3,N3), MS1(N5)                                CONM2168
C     ROUTINE TO SOLVE SPECIAL LINEAR PROBLEM FOR IMPOSING S-TRANSPOSE  CONM2169
C     TIMES S.LE.1 BOUNDS IN THE MODIFIED METHOD OF FEASIBLE DIRECTIONS.CONM2170
C     BY G. N. VANDERPLAATS                             APRIL, 1972.    CONM2171
C     NASA-AMES RESEARCH CENTER,  MOFFETT FIELD, CALIF.                 CONM2172
C     REF.  'STRUCTURAL OPTIMIZATION BY METHODS OF FEASIBLE DIRECTIONS',CONM2173
C     G. N. VANDERPLAATS AND F. MOSES, JOURNAL OF COMPUTERS             CONM2174
C     AND STRUCTURES, VOL 3, PP 739-755, 1973.                          CONM2175
C     FORM OF L. P. IS BX=C WHERE 1ST NDB COMPONENTS OF X CONTAIN VECTORCONM2176
C     U AND LAST NDB COMPONENTS CONTAIN VECTOR V.  CONSTRAINTS ARE      CONM2177
C     U.GE.0, V.GE.0, AND U-TRANSPOSE TIMES V = 0.                      CONM2178
C     NER = ERROR FLAG.  IF NER.NE.0 ON RETURN, PROCESS HAS NOT         CONM2179
C     CONVERGED IN 5*NDB ITERATIONS.                                    CONM2180
C     VECTOR MS1 IDENTIFIES THE SET OF BASIC VARIABLES.                 CONM2181
C     ------------------------------------------------------------------CONM2182
C     CHOOSE INITIAL BASIC VARIABLES AS V, AND INITIALIZE VECTOR MS1    CONM2183
C     ------------------------------------------------------------------CONM2184
      NER=1                                                             CONM2185
      M2=2*NDB                                                          CONM2186
C     CALCULATE CBMIN AND EPS AND INITIALIZE MS1.                       CONM2187
      EPS=-1.0E+10                                                      CONM2188
      CBMIN=0.                                                          CONM2189
      DO 10 I=1,NDB                                                     CONM2190
      BI=B(I,I)                                                         CONM2191
      CBMAX=0.                                                          CONM2192
      IF (BI.LT.-1.0E-6) CBMAX=C(I)/BI                                  CONM2193
      IF (BI.GT.EPS) EPS=BI                                             CONM2194
      IF (CBMAX.GT.CBMIN) CBMIN=CBMAX                                   CONM2195
10    MS1(I)=0                                                          CONM2196
      EPS=.0001*EPS                                                     CONM2197
      IF (EPS.LT.-1.0E-10) EPS=-1.0E-10                                 CONM2198
      IF (EPS.GT.-.0001) EPS=-.0001                                     CONM2199
      CBMIN=CBMIN*1.0E-6                                                CONM2200
      IF (CBMIN.LT.1.0E-10) CBMIN=1.0E-10                               CONM2201
      ITER1=0                                                           CONM2202
      NMAX=5*NDB                                                        CONM2203
C     ------------------------------------------------------------------CONM2204
C     **********                BEGIN NEW ITERATION           **********CONM2205
C     ------------------------------------------------------------------CONM2206
20    ITER1=ITER1+1                                                     CONM2207
      IF (ITER1.GT.NMAX) RETURN                                         CONM2208
C     FIND MAX. C(I)/B(I,I) FOR I=1,NDB.                                CONM2209
      CBMAX=.9*CBMIN                                                    CONM2210
      ICHK=0                                                            CONM2211
      DO 30 I=1,NDB                                                     CONM2212
      C1=C(I)                                                           CONM2213
      BI=B(I,I)                                                         CONM2214
      IF (BI.GT.EPS.OR.C1.GT.0.) GO TO 30                               CONM2215
      CB=C1/BI                                                          CONM2216
      IF (CB.LE.CBMAX) GO TO 30                                         CONM2217
      ICHK=I                                                            CONM2218
      CBMAX=CB                                                          CONM2219
30    CONTINUE                                                          CONM2220
      IF (CBMAX.LT.CBMIN) GO TO 70                                      CONM2221
```

```
      IF (ICHK.EQ.0) GO TO 70                                           CONM2222
C     UPDATE VECTOR MS1.                                                CONM2223
      JJ=ICHK                                                           CONM2224
      IF (MS1(JJ).EQ.0) JJ=ICHK+NDB                                     CONM2225
      KK=JJ+NDB                                                         CONM2226
      IF (KK.GT.M2) KK=JJ-NDB                                           CONM2227
      MS1(KK)=ICHK                                                      CONM2228
      MS1(JJ)=0                                                         CONM2229
C     ------------------------------------------------------------------CONM2230
C                         PIVOT OF B(ICHK,ICHK)                         CONM2231
C     ------------------------------------------------------------------CONM2232
      BB=1./B(ICHK,ICHK)                                                CONM2233
      DO 40 J=1,NDB                                                     CONM2234
40    B(ICHK,J)=BB*B(ICHK,J)                                            CONM2235
      C(ICHK)=CBMAX                                                     CONM2236
      B(ICHK,ICHK)=BB                                                   CONM2237
C     ELIMINATE COEFICIENTS ON VARIABLE ENTERING BASIS AND STORE        CONM2238
C     COEFICIENTS ON VARIABLE LEAVING BASIS IN THEIR PLACE.             CONM2239
      DO 60 I=1,NDB                                                     CONM2240
      IF (I.EQ.ICHK) GO TO 60                                           CONM2241
      BB1=B(I,ICHK)                                                     CONM2242
      B(I,ICHK)=0.                                                      CONM2243
      DO 50 J=1,NDB                                                     CONM2244
50    B(I,J)=B(I,J)-BB1*B(ICHK,J)                                       CONM2245
      C(I)=C(I)-BB1*CBMAX                                               CONM2246
60    CONTINUE                                                          CONM2247
      GO TO 20                                                          CONM2248
70    CONTINUE                                                          CONM2249
      NER=0                                                             CONM2250
C     ------------------------------------------------------------------CONM2251
C     STORE ONLY COMPONENTS OF U-VECTOR IN 'C'.  USE B(I,1) FOR         CONM2252
C     TEMPORARY STORAGE                                                 CONM2253
C     ------------------------------------------------------------------CONM2254
      DO 80 I=1,NDB                                                     CONM2255
      B(I,1)=C(I)                                                       CONM2256
80    CONTINUE                                                          CONM2257
      DO 90 I=1,NDB                                                     CONM2258
      C(I)=0.                                                           CONM2259
      J=MS1(I)                                                          CONM2260
      IF (J.GT.0) C(I)=B(J,1)                                           CONM2261
      IF (C(I).LT.0.) C(I)=0.                                           CONM2262
90    CONTINUE                                                          CONM2263
      RETURN                                                            CONM2264
      END                                                               CONM2265
 00
 00
```

## APPENDIX C

## LIST OF SYMBOLS

$A_i$ design variable coefficient of profile shape function; Equation (14)

C blade chord, meters

i invariant point index; Equation (5); also, index for surface shape functions; Equation (14)

k dummy index; Equation (11)

M number of independent flow or geometrical variables to be perturbed; Equation (1)

n total number of shock points and high-gradient maxima points; Equation (13)

N total number of invariant points, equal to n + 2; Equation (5)

$q_j$ j*th* arbitrary geometric or flow parameter to be perturbed; Equation (8)

$q_{c_j}$ calibration flow value of $q_j$; Equation (7)

$q_{o_j}$ base flow value of $q_j$; Equation (7)

Q approximate flow solution for arbitrary flow quantity; Equation (1)

$Q_{c_j}$ calibration flow solution for value $q_{c_j}$ of arbitrary parameter; Equation (3)

$Q_o$ base flow solution for values $q_{o_j}$ of arbitrary parameters; Equation (1)

$Q_{1_j}$ j*th* perturbation solution per unit change of perturbed parameter $q_j$; Equation (3)

s strained x coordinate; Equation (2)

x nondimensional blade-fixed orthogonal coordinate; Equation (1), normalized by C

$\bar{x}_j$ nondimensional blade-fixed orthogonal coordinate related to j*th* calibration solution; Equation (3)

$x_1$ straining function associated with x coordinate; Equation (2)

$x_{1_i}$ straining function associated with *ith* invariant point; Equation (5)

$\delta x_o$ unit displacement in x direction associated with *ith* invariant point; Equations (6) and (10)

$\varepsilon_j$ desired perturbaiton change of *jth* geometric or flow parameter; Equation (8)

$\bar{\varepsilon}_j$ perturbation change of *jth* geometric or flow parameter between base and calibration flows; Equation (7)

### Subscripts

i denotes quantities associated with *ith* invariant point

j denotes perturbation quantities

### Superscripts

o denotes base flow quantities

c denotes quantities associated with calibration flows

# REFERENCES

1. Stahara, S. S., Chaussee, D. S., and Spreiter, J. R.: Perturbation Solutions for Transonic Flow on the Blade-to-Blade Surface of Compressor Blade Rows. NASA CR-2941, Jan. 1978.

2. Stahara, S. S., Elliott, J. P., and Spreiter, J. R.: A Rapid Perturbation Procedure for Determining Nonlinear Flow Solutions: Application to Transonic Turbomachinery Flows. NASA CR-3425, May 1981.

3. Stahara, S. S., Elliott, J. P., and Spreiter, J. R.: Development of a Multiple-Parameter Nonlinear Perturbation Procedure for Transonic Turbomachinery Flows: Preliminary Application to Design/Optimization Problems. NASA CR-3657, Jan. 1983.

4. Van Dyke, M.: Perturbation Methods in Fluid Mechanics. The Parabolic Press, California, 1975.

5. Nixon, D.: Perturbations in Two- and Three-Dimensional Transonic Flows. AIAA J., Vol. 16, Jul. 1978, pp. 699-709.

6. Nixon, D.: Design of Transonic Airfoil Sections Using a Similarity Theory. NASA TM 78521, Oct. 1978.

7. Stahara, S. S., Crisalli, A. J., and Spreiter, J. R.: Evaluation of a Strained Coordinate Perturbation Procedure: Nonlinear Subsonic and Transonic Flows. AIAA Paper No. 80-0339, Jan. 1980.

8. Nixon, D.: Perturbation Methods in Transonic Flow. AIAA Paper No. 80-1367, Jul. 1980.

9. Stahara, S. S., Elliott, J. P., and Spreiter, J. R.: A Rapid Method for the Approximate Determination of Nonlinear Solutions: Application to Aerodynamic Flows. ICAS Paper No. 80-7.5, Oct. 1980.

10. Nixon, D. and McIntosh, S. C., Jr.: Further Observations on the Strained Coordinate Method for Transonic Flows. AIAA J., Vol. 18, Dec. 1980, pp. 1540-1541.

11. Stahara, S. S.: The Rapid Approximate Determination of Nonlinear Solutions: Application to Aerodynamic Flows and Design/Optimization Problems. Transonic Aerodynamics. (Ed. D. Nixon) Vol. 81, Progress in Astronautics and Aeronautics. AIAA, N.Y., 1982, pp. 637-659.

12. Vanderplaats, G. N.: CONMIN — A Fortran Program for Constrained Function Minimization, User's Manual. NASA TMX-62,282, Aug. 1973.

13. Madsen, L. E. and Vanderplaats, G. N.: COPES — A Fortran Control Program for Engineering Synthesis. NPS 69-81-003, Mar. 1982.

14. Hicks, R. M. and Vanderplaats, G. N.: Application of Numerical Optimization to the Design of Supercritical Airfoils Without Drag-Creep. SAE Paper 770440, 1977.

15. Katsanis, T.: Fortran Program for Calculating Transonic Velocities on a Blade-to-Blade Stream Surface of a Turbomachine. NASA TN D-5427, Sep. 1969.

16. Crouse, J. E.: Computer Program for Definition of Transonic Axial-Flow Compressor Blade Rows. NASA TN D-7345, Feb. 1974.

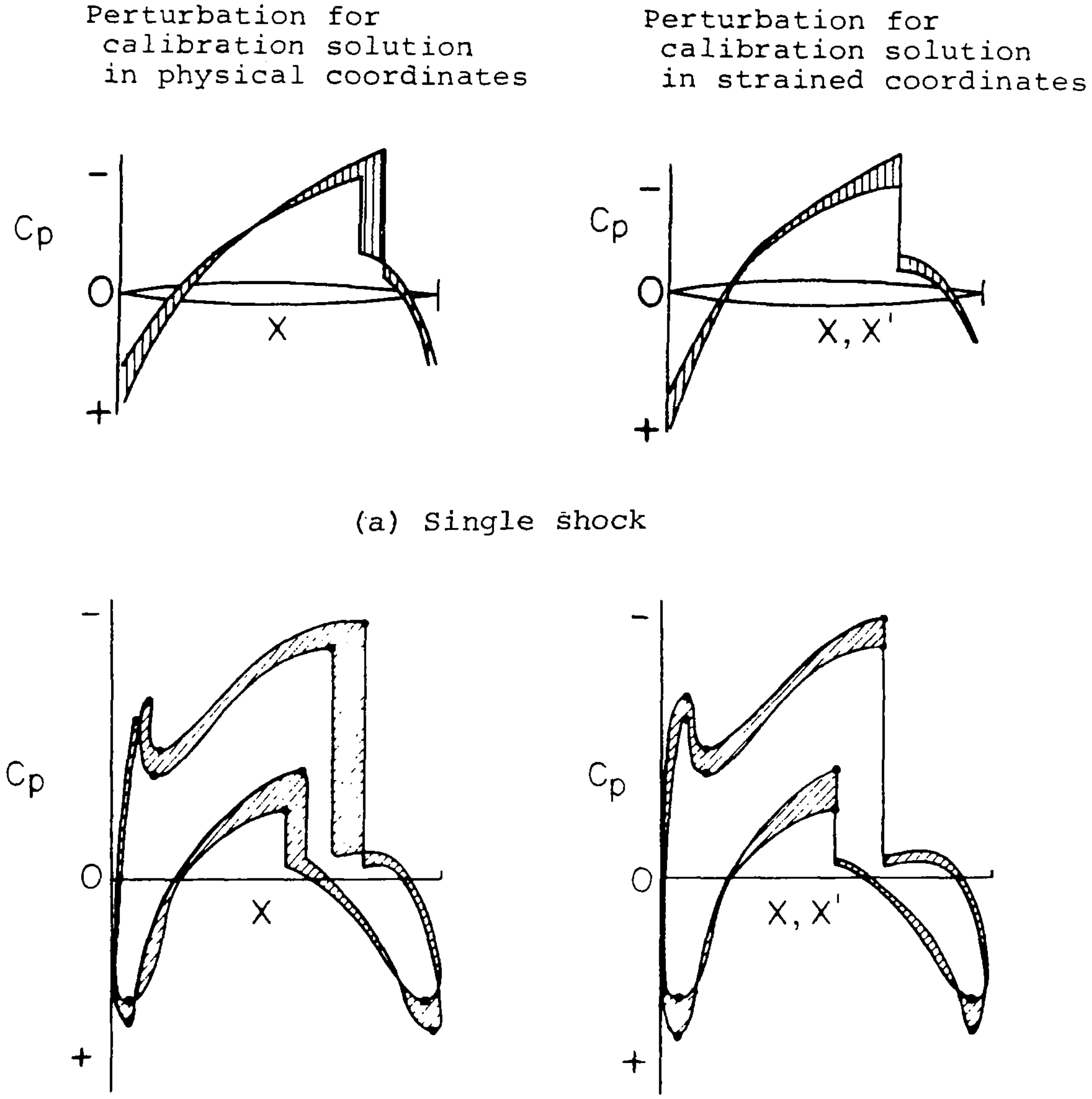
17. Katsanis, T. and McNally, W. D.: Fortran Program for Calculating Velocities and Streamlines on a Blade-to-Blade Stream Surface of a Tandem Blade Turbomachine. NASA TND-5044, 1969.

18. Kennelly, R. T., Jr.: Improved Method for Transonic Airfoil Design-by-Optimization. AIAA Paper No. 83-1864, July 1983.

TABLE 1

COMPARISON OF FINAL DESIGN VARIABLES AND OBJECTIVE FUNCTION WHEN EMPLOYING FULL NONLINEAR TSONIC SOLUTIONS OR PERTURBATION METHOD FOR DIFFERENT CHOICES OF CALIBRATION SOLUTION MATRIX FOR SIX DESIGN VARIABLE SUBCRITICAL OPTIMIZATION CASE STUDY USING MAXIMUM SUCTION SURFACE VELOCITY DIFFUSION OBJECTIVE

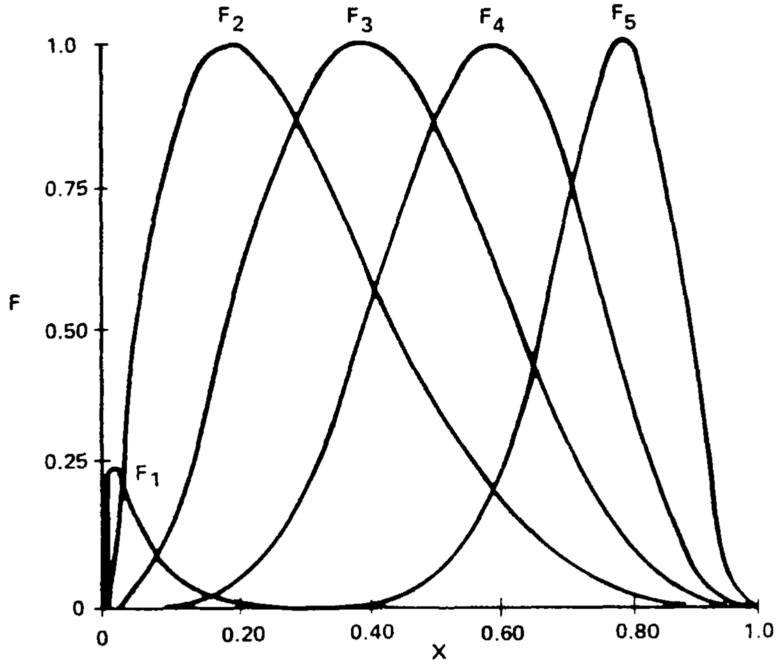
| Design Variables | KOCR | T | ZM | P | TMX | THLE | Objective Function |
|---|---|---|---|---|---|---|---|
| INITIAL | | | | | | | |
| Baseline | -10.0000 | 0.2500 | 0.4500 | 1.50000 | 0.0500 | 0.0050 | 1.8400 |
| Upper Bound | 0.0000 | 0.6000 | 0.5500 | 4.0000 | 0.1000 | 0.0120 | |
| Lower Bound | -15.0000 | 0.2000 | 0.2000 | 0.5000 | 0.0300 | 0.0030 | |
| FINAL<br>TSONIC SOLUTIONS ONLY RESULTS<br>IOPT=1 | | | | | | | |
| Final | -7.3854 | 0.2000 | 0.5500 | 0.9220 | 0.0300 | 0.0060 | 1:6764 |
| PERTURBATION SOLUTION RESULTS<br>IOPT=2 | | | | | | | |
| CASE 1 | | | | | | | |
| Calibration | -7.0000 | 0.2000 | 0.5500 | 0.9400 | 0.0300 | 0.0060 | |
| Final | -9.1904 | 0.2342 | 0.5555 | 0.9371 | 0.0358 | 0.0052 | 1.6918 |
| CASE 2 | | | | | | | |
| Calibration | -9.0000 | 0.2350 | 0.4950 | 1.6500 | 0.0550 | 0.0055 | |
| Final | -8.8994 | 0.3098 | 0.5500 | 0.7463 | 0.0300 | 0.0050 | 1.6829 |
| CASE 3 | | | | | | | |
| Calibration | -11.0000 | 0.2250 | 0.4050 | 1.3500 | 0.0450 | 0.0045 | |
| Final | -9.7099 | 0.3162 | 0.5500 | 1.1332 | 0.0323 | 0.0055 | 1.7304 |
| CASE 4 | | | | | | | |
| Calibration | -8.0000 | 0.2300 | 0.5000 | 1.0000 | 0.0350 | 0.0058 | |
| Final | -8.8860 | 0.2814 | 0.5500 | 0.9023 | 0.0370 | 0.0051 | 1.6986 |
| CASE 5 | | | | | | | |
| Calibration | -7.0000 | 0.2000 | 0.5500 | 0.9000 | 0.0300 | 0.0070 | |
| Final | -9.1846 | 0.2314 | 0.5500 | 0.9397 | 0.0363 | 0.0053 | 1.6909 |
| CASE 6 | | | | | | | |
| Calibration | -11.0000 | 0.6000 | 0.2000 | 4.0000 | 0.1000 | 0.0120 | |
| Final | -7.1492 | 0.3166 | 0.5500 | 1.2202 | 0.0300 | 0.0046 | 1.7332 |
| IOPT=3 | | | | | | | |
| Final | -8.0297 | 0.2000 | 0.5500 | 0.7356 | 0.0363 | 0.0039 | 1.6989 |


Perturbation for calibration solution in physical coordinates
Perturbation for calibration solution in strained coordinates
Cp
-
O
+
X
Cp
-
O
+
X, X'
Cp
-
O
+
X
Cp
-
O
+
X, X'

(a) Single shock

(b) Multiple shock and high-gradient locations.

Figure 1.- Illustration of perturbation solution for calibration solution in physical and strained coordinates



$$Z = Z_{BASE} + \sum_i a_i F_i$$

$$F_1 = X^{1/4}(1-X)/E^{20X}$$

$$F_2 = SIN(\pi X^{0.431})^3$$

$$F_3 = SIN(\pi X^{0.757})^3$$

$$F_4 = SIN(\pi X^{1.357})^3$$

$$F_5 = SIN(\pi X^{3.106})^3$$

DESIGN VARIABLES:

$a_1, a_2, a_3, a_4, a_5$

Figure 2.- Illustration of typical ordinate shape functions $F_i$ employed in blade contour alteration optimization problems.

OBJECTIVE IS TO MINIMIZE:

$$\Sigma(C_{p_{Predicted}} - C_{p_{Desired}})^2$$

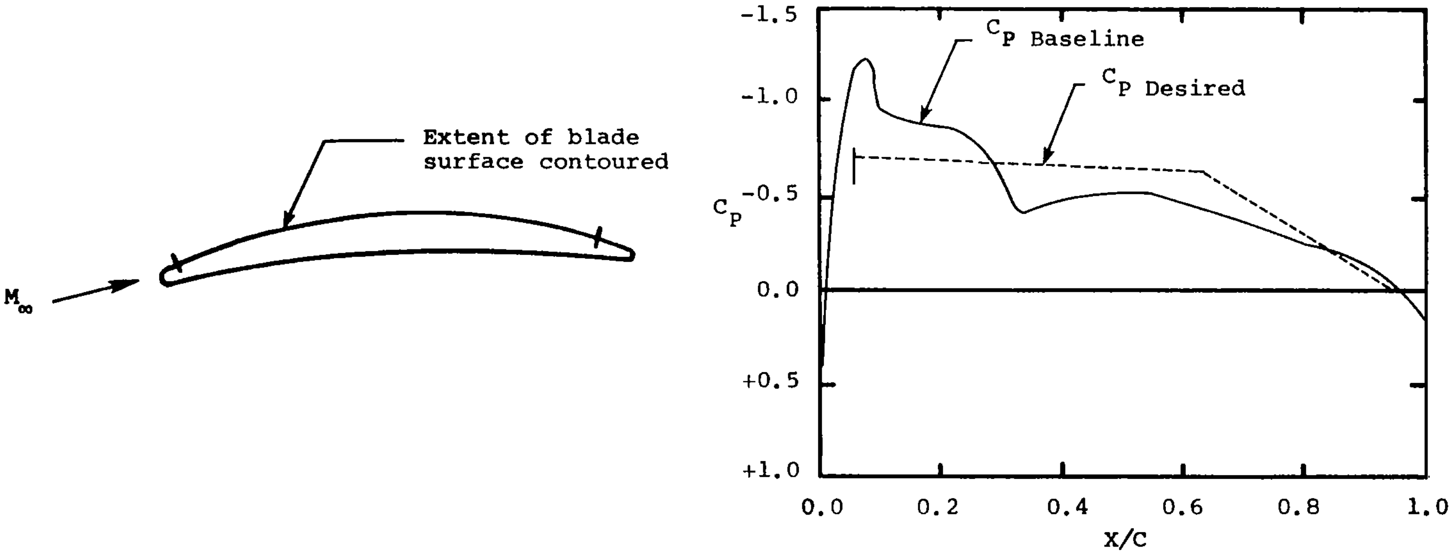


Figure 3.- Illustration of physical basis of optimization problem involving blade surface contouring to tailor the surface pressure distribution to a desired distribution.

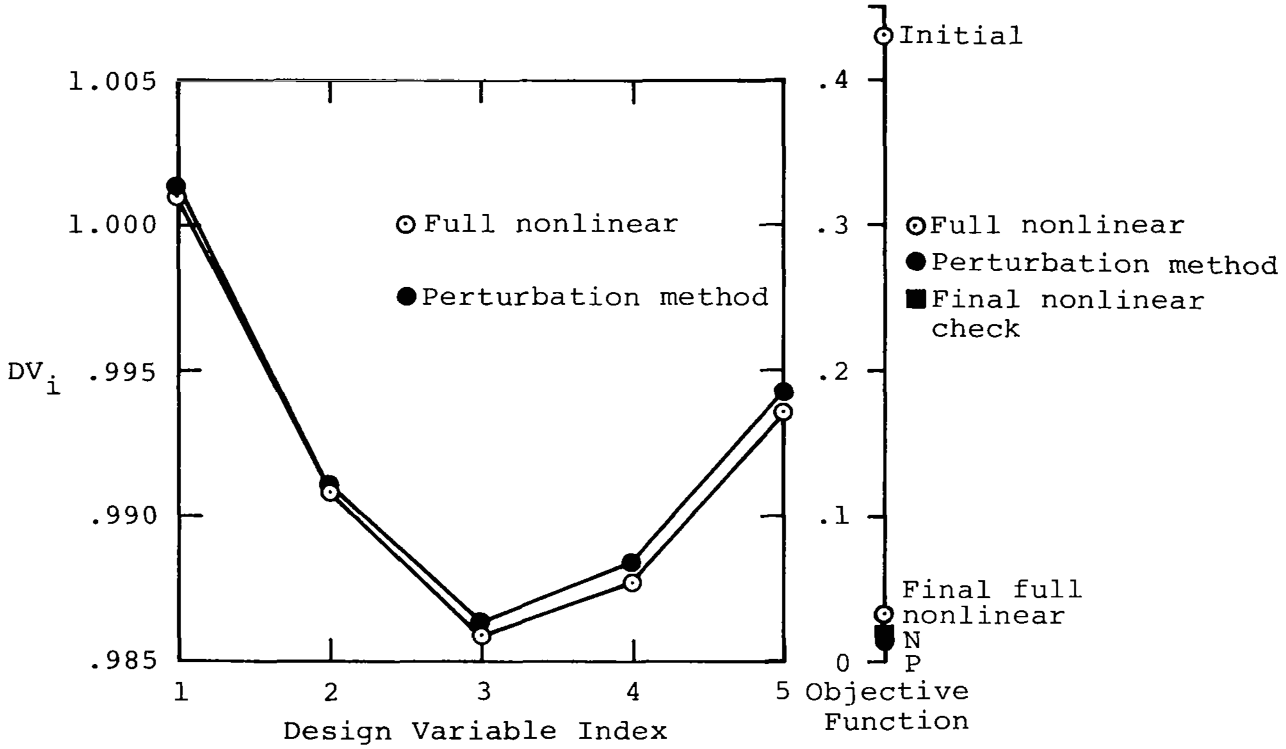


Figure 4.- Comparison of perturbation predicted and full nonlinear results for final design variables and objective function for 5 design variable supercritical case study with surface pressure tailoring objective.

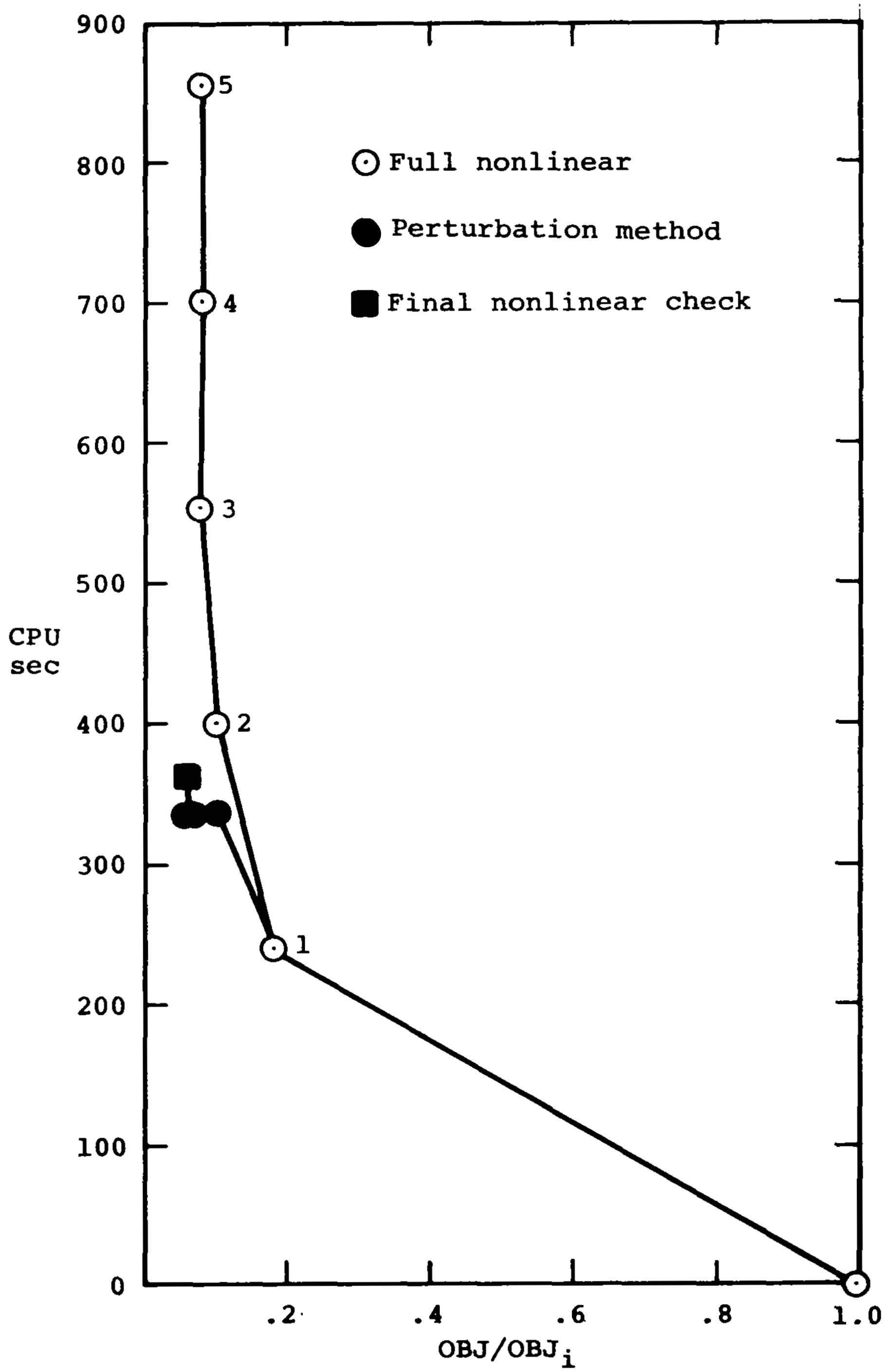


Figure 5.- Comparison of computational work and objective function reduction per optimization search cycle when employing perturbation method after first search cycle (●) or when using full nonlinear solutions (⊙) for a 5 design variable supercritical case study with surface pressure tailoring objective.

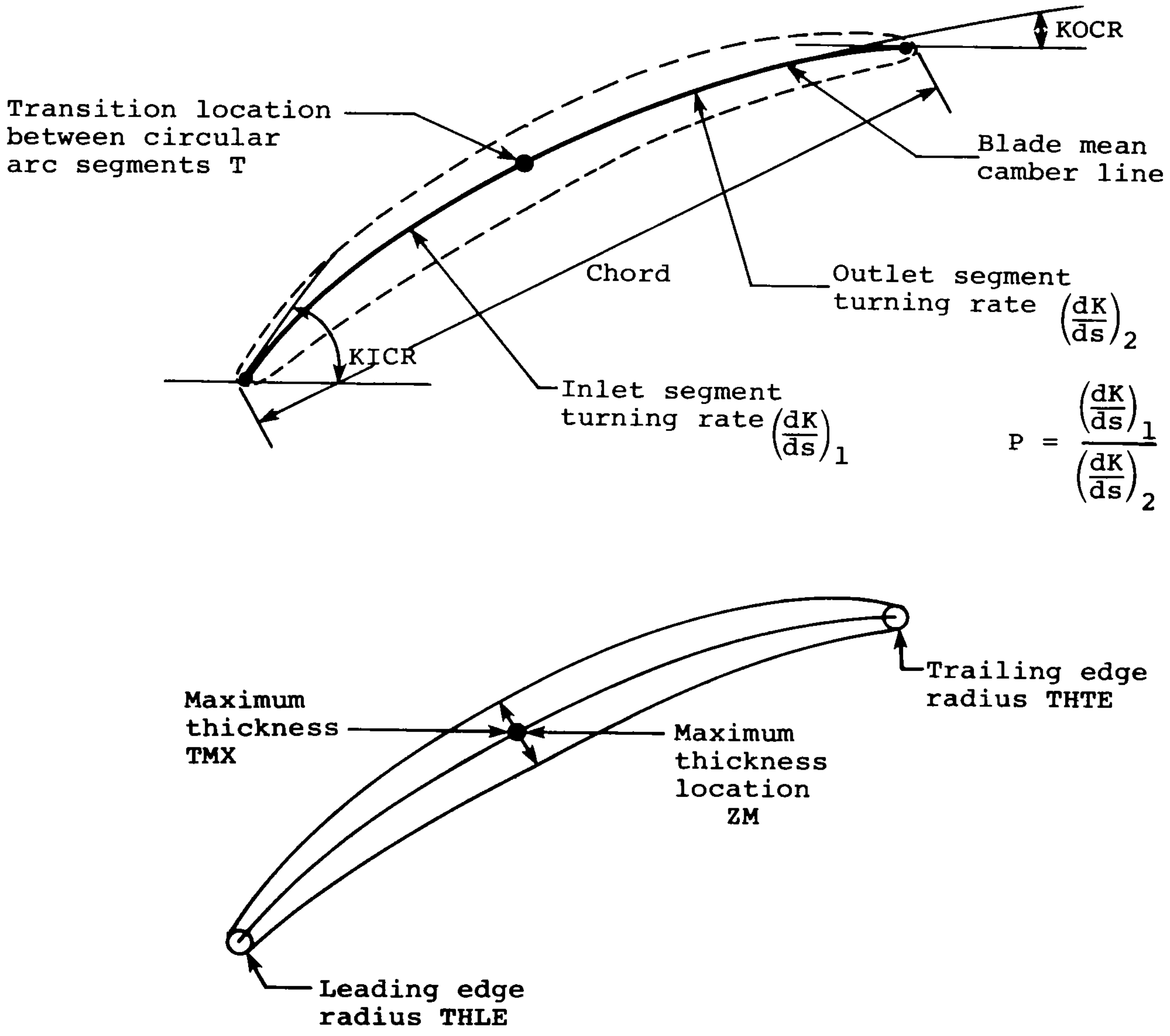

KOCR
Transition location between circular arc segments T
Blade mean camber line
Chord
Outlet segment turning rate $\left(\frac{dK}{ds}\right)_2$
KICR
Inlet segment turning rate $\left(\frac{dK}{ds}\right)_1$
$P = \frac{\left(\frac{dK}{ds}\right)_1}{\left(\frac{dK}{ds}\right)_2}$
Trailing edge radius THTE
Maximum thickness TMX
Maximum thickness location ZM
Leading edge radius THLE

Figure 6.- NASA circular arc blade element layout parameters.

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16. Abstract

An investigation was carried out to complete the preliminary development of a combined perturbation/optimization procedure and associated computational code for designing optimized blade-to-blade profiles of turbomachinery blades. The overall purpose of the procedures developed in this study is to provide demonstration of a rapid nonlinear perturbation method for minimizing the computational requirements associated with parametric design studies of turbomachinery flows. The method reported here combines the multiple-parameter nonlinear perturbation method, successfully developed in previous phases of this study, with the NASA TSONIC blade-to-blade turbomachinery flow solver, and the COPES-CONMIN optimization procedure into a user's code for designing optimized blade-to-blade surface profiles of turbomachinery blades. Results of several design applications and a documented version of the code together with a user's manual are provided.

17. Key Words (Suggested by Author(s))

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