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METHODS FOR COMPARATIVE EVALUATION OF PROPULSION SYSTEM DESIGNS FOR SUPERSONIC AIRCRAFT

Prepared By:

RAY M. TYSON
RONALD Y. MAIRS
FLOYD D. HALFERTY, JR.
BRUCE E. MOORE
DAVID CHALOFF
ARNOLD W. KNUDSEN

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16. Abstract

The propulsion system comparative evaluation study had two objectives: (1) to define a rapid, approximate method for evaluating the effects of propulsion system changes for an advanced supersonic cruise airplane, and (2) verification of the approximate method by comparing its mission performance results with those from a more detailed analysis.

A table look-up computer program was developed to determine nacelle drag increments for a range of parametric nacelle shapes and sizes. Aircraft sensitivities to propulsion parameters were defined. Nacelle shapes, installed weights, and installed performance were determined for four study engines selected from the NASA Supersonic Cruise Aircraft Research (SCAR) engine studies program. Both rapid evaluation method (using sensitivities) and traditional preliminary design methods were then used to assess the four engines. The method was found to compare well with the more detailed analyses.

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FOREWORD

This document presents results of the study "Methods for Comparative Evaluation of Propulsion System Designs for Supersonic Aircraft." The NASA technical representative was Dr. Edward A. Willis. In addition to the authors noted, significant contributions to this study and report were made by Ellwood Bonner, aerodynamics; Henry K. Chin and Louis C. Young, propulsion.

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SUPERSONIC AIRCRAFT

By Ray M. Tyson, Ronald Y. Mairs, Floyd D. Halferty, Jr.,
Bruce E. Moore, David Chaloff, and Arnold W. Knudsen

Los Angeles Aircraft Division, Rockwell International

INTRODUCTION

The National Aeronautics and Space Administration is conducting a continuing program of advanced supersonic technology studies with the objective of developing an adequate technology base to support development of future supersonic cruising aircraft. It is recognized in this program that one of the more sensitive problems in the synthesis of a successful supersonic cruising aircraft is that of airframe/engine integration. This process must investigate and properly manage the interactions between the technical disciplines of external aerodynamics, internal aerodynamics, engine cycle design, acoustics, mass properties, and structural design; and, it must be responsive to the practical considerations of fabrication, maintenance, and operation.

The results of a recently completed study, reference 1, of the effects of nacelle size and nacelle shape on the drag, weight, and wing camber plane warping of a supersonic transport illustrated the sensitivity of these parameters to relatively small changes in nacelle shape. The resultant shape of a nacelle is dependent on the geometry of the engine (inlet area, mounting provisions, accessory location, nozzle area, etc.) since this establishes certain control points in the design of the nacelle. It is important, therefore, that the engine designer be aware of this sensitivity to engine geometry, and be provided with some guidelines for favorable geometry relationships. It is probable that some engine geometry control can be achieved by the designer with no penalty in engine performance, although on a total system basis some engine performance degradation could be accepted in trade for reduced drag.

Although considerable effort has been expended on the problem of airframe/engine integration, it has been mostly in the nature of point designs. The study of reference 1 produced results for two specific nacelle shapes which resulted from installation of a dry turbojet engine and a duct heating turbofan engine. A comparison of these results shows the superiority of one nacelle shape over the other, but gives no information directly applicable to other installations having differing nacelle shapes. This report therefore treats nacelle shape and size in a parametric fashion so that a range of propulsion systems can be readily compared on a consistent basis. To meet the user's needs, it was clear that methodology faster and more convenient than the traditional aircraft-preliminary-design process would be required--even at some cost in terms of accuracy. Therefore, the approach was taken of organizing a relevant, existing set of nacelle drag data (reference 2), together with supplementary data points as required to cover the parametric range, into a computer table-lookup program. The program then yields supersonic wave and friction drag increments as function of size and shape parameters for a representative supersonic cruise airplane configuration (reference 3). The drag code, combined with linear sensitivity factors (derived from perturbation studies of the reference 2 airplane), provides the desired rapid approximate methodology for comparing alternative propulsion system designs.

The methods of analysis and major results of this study are described herein in the "STUDY PROCEDURE" section. User's information for the code, program listings and mathematical details are presented in the Appendix.

SUMMARY OF RESULTS

The present work is an extension of a previous study performed for NASA Langley Research Center (contract NAS1-13906) and documented in reference 2. In that program, a baseline airplane was defined. Under the current contract, the baseline was revised slightly as described on page 71 for consistency in validating the approximate method; the revised baseline is used when perturbating and comparing airplanes with other engines. The baseline and revised baseline airplanes are described in Table 1. The baseline airplane was based on the NASA modified SCAT 15F vehicle described in reference 3. Parametric data were generated showing the effects of variations of nacelle shape on cruise drag for a range of shapes that reasonably cover engine designs applicable to supersonic cruising aircraft. Generally, it was found that nacelles shaped such that the maximum cross-sectional area occurred at or near the nozzle exit and having little or no boattail resulted in the lowest wave drag. In fact, nacelle shapes were found that produce favorable interference effects (drag reduction) of such magnitude as to nearly offset the friction drag of the nacelle. These results are valid only for vehicles of this general configuration and nacelle location. Different vehicle configurations or nacelle locations could results in different "best" shapes. In considering possible trades of reduced drag through design changes in the engine for some penalty in engine weight and specific fuel consumption (SFC), it is necessary to have visibility of the net impact of all three effects on the total airplane in order to make a comparative evaluation. Therefore, sensitivity data were developed for the effects of changes in drag, propulsion system weight, takeoff thrust, and SFC on the takeoff gross weight as a figure of merit. Results of the weight sensitivity trades showed that the airplane gross weight is highly

TABLE 1.- BASELINE AIRPLANES

	NASA Langley Study		REVISED BASELINE	
Design Mission Range, km (n mi)	7 408	(4 000)	7 408	(4 000)
Design Cruise Mach Number	2.4	2.4	2.4	2.4
Payload (292 passengers), kg (lb)	27 682	(61 028)	27 682	(61 028)
Balanced Field Length, m (ft)	3 190	(10 500)	3 190	(10 500)
Engines (4)	VSCE 502B	VSCE 502B	VSCE 502B	VSCE 502B
Takeoff Gross Weight, kg (lb)	322 046	(712 188)	316 783	(698 375)

sensitive to both drag and engine SFC at supersonic cruise. A one-drag-count change (approximately 1 percent of airplane drag) results in a 1-percent takeoff gross weight change; a 1-percent change is SFC also results in a 1-percent change in takeoff gross weight. Changes in drag or SFC at other flight conditions and changes in propulsion system weight had relatively small effects on takeoff gross weight.

The follow-on program, described in this report, was intended to render the above-mentioned parametric data into a convenient, useable form. The objective was to develop a reasonably accurate method for the rapid, preliminary evaluation of the effects of variations in propulsion system design parameters on the total system performance of an integrated engine/airframe system. The figure of merit used was the airplane takeoff gross weight to perform a design reference mission. The effort was organized around the following five tasks:

(1) Estimation of supersonic cruise drag increments reflecting nacelle shape and size (in the form of a computer table look-up program)

(2) Estimation of propulsion system installation weight

(3) Estimation of airplane takeoff gross weight

(4) Validation of the approximate method

(5) Reporting

Estimation of Supersonic Cruise Drag

A computer table look-up program was developed (see appendix) which yields the incremental wave and friction drags of nacelles as functions of five nacelle geometry variables and airplane mach number. The drag increments are for the total vehicle relative to the vehicle with nacelles removed. The five nacelle shape parameters used as inputs to the program are:

A_c	Inlet capture area
A_{MAX}	Nacelle maximum cross-sectional area
A_n	Nozzle exit area (supersonic cruise position)
X_{MAX}	Distance from inlet cowl leading edge to maximum cross-sectional area
L	Nacelle total length
S_{REF}	Reference wing area

It has been found that the table look-up results correlate best with more detailed analyses when the maximum cross-sectional area and its position are based on the area that occurs at the intersection of straight lines originating from the inlet and nozzle and whose slopes nearly match the slopes of the actual nacelle. A sample output from the computer program is shown in table 2.

TABLE 2. - SAMPLE OUTPUT

```
NACELLE GEOMETRY

      CAPTURE AREA          2.79  SQ M   (      30.00  SQ FT)
      MAXIMUM AREA          4.18  SQ M   (      45.00  SQ FT)
      NOZZLE AREA           3.48  SQ M   (      37.50  SQ FT)
      LOC. OF MAX. AREA     6.22    M    (      20.40    FT )
      TOTAL LENGTH         10.36    M    (      33.99    FT )

WING REFERENCE AREA       929.03  SQ M   (  10000.00  SQ FT)

INCREMENTAL NACELLE DRAG COEFFICIENTS
      MACH 1.2     CDF=  0.00053   CDW=  0.00040    CDO=  0.00093
      MACH 2.32    CDF=  0.00047   CDW=  0.00007    CDO=  0.00054
      MACH 1.20                                     CDO=  0.00093

XMAX/L=    0.600    AN/AC=    1.250    AMAX/AC=    1.500    L/DC=    5.500


INCREMENTAL NACELLE DRAG COEFFICIENTS - LTV REFERENCE VEHICLE
      MACH 1.2     CDF=  0.00072   CDW= -0.00041    CDO=  0.00031
      MACH 2.32    CDF=  0.00058   CDW= -0.00016    CDO=  0.00042
      MACH 1.25                                     CDO=  0.00032
```

This task also included preparation of design guidelines for the installation of the engine in the nacelle so that consistency in definition of design control points for external nacelle shaping is achieved. Guidelines for establishing inlet and inlet cowl shape, engine envelope definition (including provisions for wiring, plumbing, power takeoff, engine accessories, aircraft accessories, fluid reservoirs, air bleed ducts, and engine mounts), structural allowances, and engine cowl and nozzle fairing shapes were defined. A sample of the nacelle shape buildup is shown in figure 1.

Estimation of Propulsion System Installation Weight

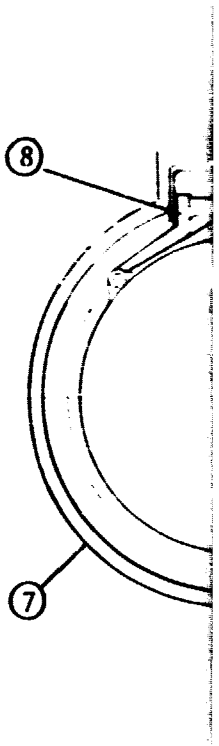
A simplified procedure was developed for the prediction of nacelle structure weight. Weight estimation of aircraft structure is a complex process and requires more design detail than will ordinarily be performed in the type of preliminary studies being considered here; therefore, the procedure was keyed to gross elements of the propulsion system installation and yields only approximate weights. The important aspect of having a well-defined procedure, even though considerable tolerance in the results must be accepted, is that consistency is achieved in making comparative analyses.

Estimation of Airplane Takeoff Gross Weight

A method has been defined for the determination of the impact of the propulsion system installation (cruise drag, SFC, weight) on the total system performance utilizing takeoff gross weight as the figure of merit. This method was based on results of sensitivity studies performed for Langley Research Center. Utilizing these sensitivity values, the drag and weight increments from tasks 1 and 2, and SFC's from engine performance estimates, this procedure yields the airplane takeoff weight required to accomplish the design mission. The baseline vehicle is the vehicle defined in reference 2 with the VSCE 502B engine. The total change in vehicle takeoff gross weight due to propulsion changes may be determined from the equation:

$$\mathrm{TOGW}_{\mathrm{new}} = \mathrm{TOGW}_{\mathrm{baseline}} \times R_{\mathrm{SFC}} \times R_{C_D} \times R_{\mathrm{WT}} \times R_{\mathrm{FNE}_{\mathrm{TO}}}$$

where "R" factors are the relative takeoff gross weight factors for each of the propulsion changes obtained from a linear sensitivity analysis of the baseline system. The drag factor is based on a supersonic cruise increment.



Legend

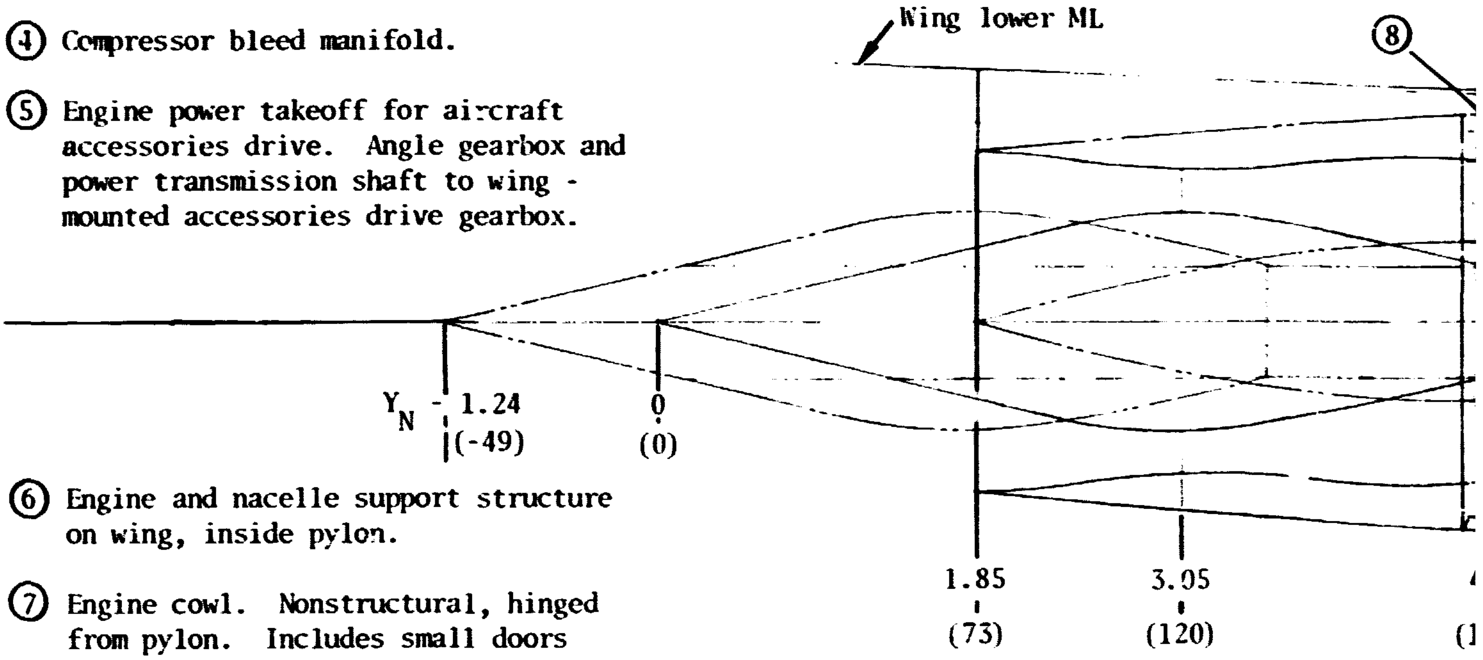
① Engine accessories. Encapsulated for cooling. Includes all temperature - limited components.

② Engine lube reservoir

③ Engine peripheral hardware.
Includes: engine fluid lines (anti-ice air, fuel, lube oil, hydraulic, drains, etc),
variable geometry mechanisms,
electrical harnesses,
instrumentation.
Local protrusions will occur beyond this envelope.

④ Compressor bleed manifold.

⑤ Engine power takeoff for aircraft accessories drive. Angle gearbox and power transmission shaft to wing - mounted accessories drive gearbox.



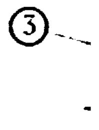
⑥ Engine and nacelle support structure on wing, inside pylon.

⑦ Engine cowl. Nonstructural, hinged from pylon. Includes small doors for local access.

⑧ Main mount (front)

⑨ Stabilizer mount (rear)

Dimension in meters (inches)



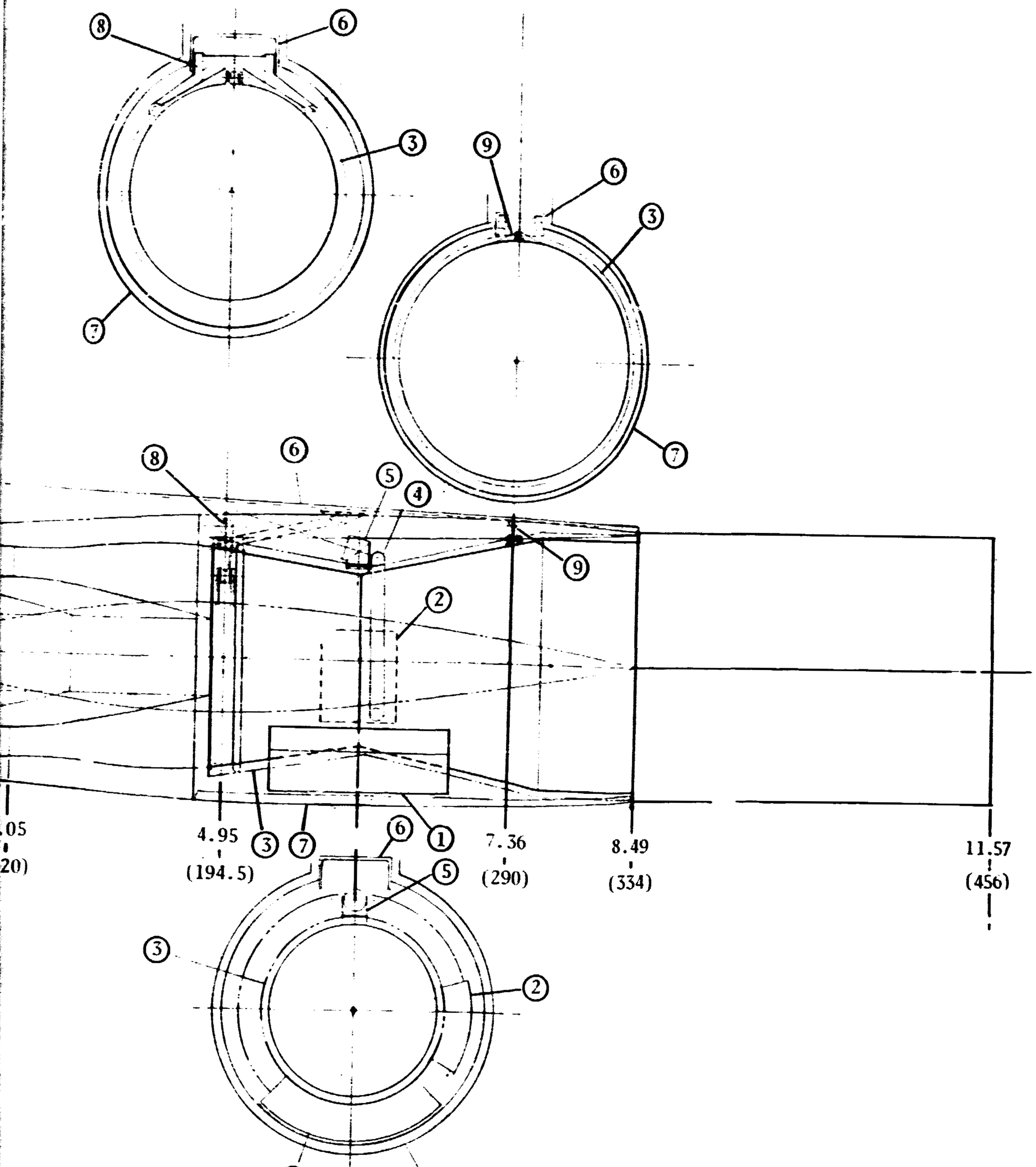


Figure 1. - Nacelle layout

Validation of the Approximate Method

Standard preliminary design procedures were applied in the installation of four representative engines selected from the NASA Supersonic Cruise Aircraft Research (SCAR) program engine studies, in the baseline supersonic transport airplane. Drag and weight estimates were made utilizing conventional procedures. The airplanes were then sized to the design mission utilizing an automated reiterative process. The results of this task provide a more exact evaluation of the selected engines than is obtainable with the approximate method and thus serve as a reference for its evaluation.

The four engines considered were the refined (January 1976) Pratt and Whitney Aircraft (PWA) VSCE 502B and VCE 112C, and the General Electric Company (GE) GE21/J10 B1 and GE21/J11 B3. These engines were chosen as representative examples which would exercise the approximate method over a sizeable range, in order to determine its limits of validity. This can be done in a consistent fashion by comparing the approximate and detailed results shown in Table 3 for each engine. (On the other hand, meaningful engine-to-engine comparisons cannot be made on the basis of table 3 because the example engines do not necessarily reflect a consistent set of basic technology assumptions, noise characteristics, or state of evolution within the SCAR program. Hence, these and similar results discussed later in this report should not be interpreted as being indicative of the final outcome of the ongoing SCAR engine studies.)

TABLE 3.- COMPARISON OF APPROXIMATE AND DETAILED VEHICLE TAKEOFF GROSS WEIGHTS

Engine	Weight Based on Detailed Analysis kg (lb)	Weight Based on Sensitivities kg (lb)
VSCE 502B	316 783 (698 375)	Revised Baseline
VSCE 502B (refined)	320 146 (705 790)	320 046 (705 568)
VCE 112C	402 625 (887 622)	401 092 (884 258)
GE21/J10 B1	514 450 (1 134 149)	463 708 (1 022 283)
GE21/J11 B3	629 306 (1 387 359)	510 136 (1 124 638)

By comparing detailed and sensitivity results for each engine in table 3, it is immediately clear that a good level of agreement has been reached. The relative error (normalized by the gross weight based on detailed results) is shown in Figure 2 as a function of the total incremental change in TOGW (normalized by the baseline value). As might be expected from theoretical considerations, the error is negligible for small perturbation; in fact, it does not exceed 2 percent of the takeoff gross weight until the increment itself is in excess of 30 percent. It is important to note also that the error is consistent, i.e. always of the same sign (the approximate method underpredicts). Thus, even among highly-dissimilar engines, the correct ranking is preserved. With these facts in mind, it is concluded that the approximate method is in fact a reliable and reasonably accurate tool for

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such purposes as engine evaluation and comparison, over a range of about ± 30 percent from the baseline TOGW. Considerably larger increments also could be accepted (temporarily) as intermediate steps in an optimization study, provided that the final case of interest is within the ± 30 percent band.

The user should nevertheless observe several cautions in applying these results. As a general practice, it is desirable to check the "final result" of a study by detailed methods. This is strongly recommended for cases approaching or passing beyond the accuracy band. The sensitivity values ("R" factors) are to some extent dependent upon the engines sizing criteria, the assumed mission profile and flight rules. The user should therefore review these items carefully before beginning a study and generate a more appropriate set of "R" factors if significant differences are noted. More fundamentally, it should be recognized that the wave drag data is strictly applicable only to the reference 3 airplane configuration and geometrically similar scaled versions thereof. Trend results with nacelle shape for different airplanes of the same general arrangement are believed to be representative, although detailed agreement would not be expected. The use of the present data for airplanes having significantly different shape, proportions or nacelle treatment is not indicated. Doubtful cases should be checked at several points to validate the data and/or establish corrections.

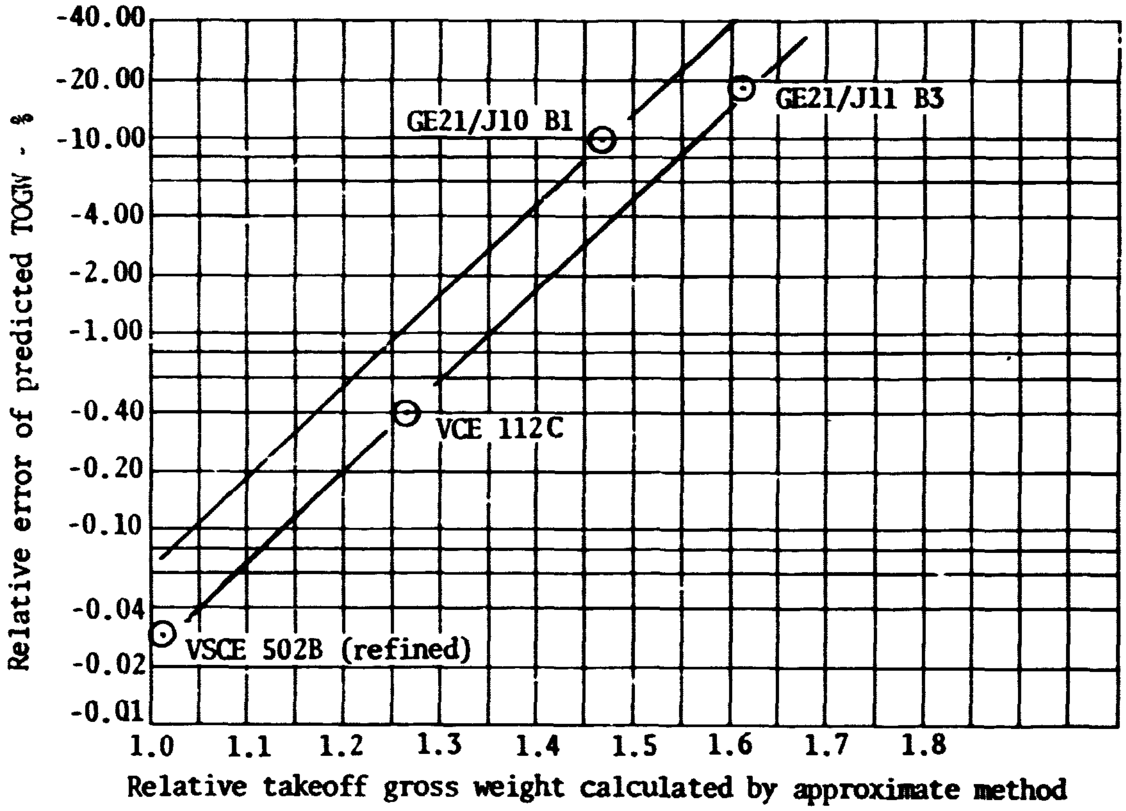


Figure 2.- Error characteristics of approximate method

Conclusions and Recommendations

Engine shape, airflow lapse rate with mach number, thrust lapse rate with mach number, SFC and noise characteristics have large impacts on vehicle takeoff gross weight. As an example of engine shape effects, a comparison of cross sectional area variation of nacelles with the VSCE 502B and VCE 112C engines is shown in figure 3. The only significant difference in shape is that the VCE 112C has a smaller nozzle exit area. This results in drag and takeoff gross weight changes as shown in table 4. Thus, a nozzle that is 0.043 m (1.7 in) smaller results in takeoff gross weight increment of 3 200 kg (7 100 lb) just due to the nacelle drag change.

Engine airflow lapse rate with mach number directly affects inlet capture area. For example, the GE21/J10 B1 has approximately 16-percent lower supersonic cruise airflow relative to takeoff airflow than does the VSCE 502B. The smaller capture area results in approximately 4-percent lower inlet recovery at static conditions and therefore reduced takeoff thrust. In addition, the smaller capture area results in a more rapid increase of nacelle cross-sectional area with nacelle length, and therefore higher drag.

Engine takeoff thrust and thrust lapse rate with mach number have significant effects on engine size required to meet takeoff distance requirements. For example, the VCE 112C has 6-percent lower takeoff thrust at static conditions and 20-percent lower thrust at mach 0.3 (at reduced power to meet noise requirements) than the VSCE 502B for a given static takeoff airflow. This resulted in an increase in engine size of approximately 15 percent to meet balanced field length requirements.

A change of 1 percent in SFC at supersonic cruise results in a 1-percent change in vehicle takeoff gross weight or about 3 200 kg (7 100 lb).

Engine exhaust noise characteristics have a significant impact on vehicle takeoff gross weight. All four engines were assumed to employ thrust cutback at the takeoff noise measurement point. However, all the engines did not take full advantage of the extra ground attenuation while the aircraft was still on the ground. For example, the GE21/J11 B3 has 26-percent lower thrust-per-unit airflow than the VSCE 502B. Thus, the GE21/J11 B3 yields approximately 6 db lower sideline noise at takeoff on the ground, but it must be sized larger to meet the takeoff distance requirement.

The sensitivity method has been shown to be a valid method for preliminary assessment of propulsion system modifications, and it is therefore recommended to be used for this purpose. Continued airframe/propulsion integration studies and coordination effort between engine and airframe manufacturers in the aforementioned high-sensitivity areas are also recommended.

Nacelle characteristics		
	PWA VSCE 502B	PWA VCE 112C
A_C	2.93 sq m (31.5 sq ft)	2.93 sq m (31.5 sq ft)
ℓ	10.3 m (33.25 ft)	11.2 m (36.86 ft)
A_B	0.17 sq m (0.57 sq ft)	0.15 sq m (0.50 sq ft)

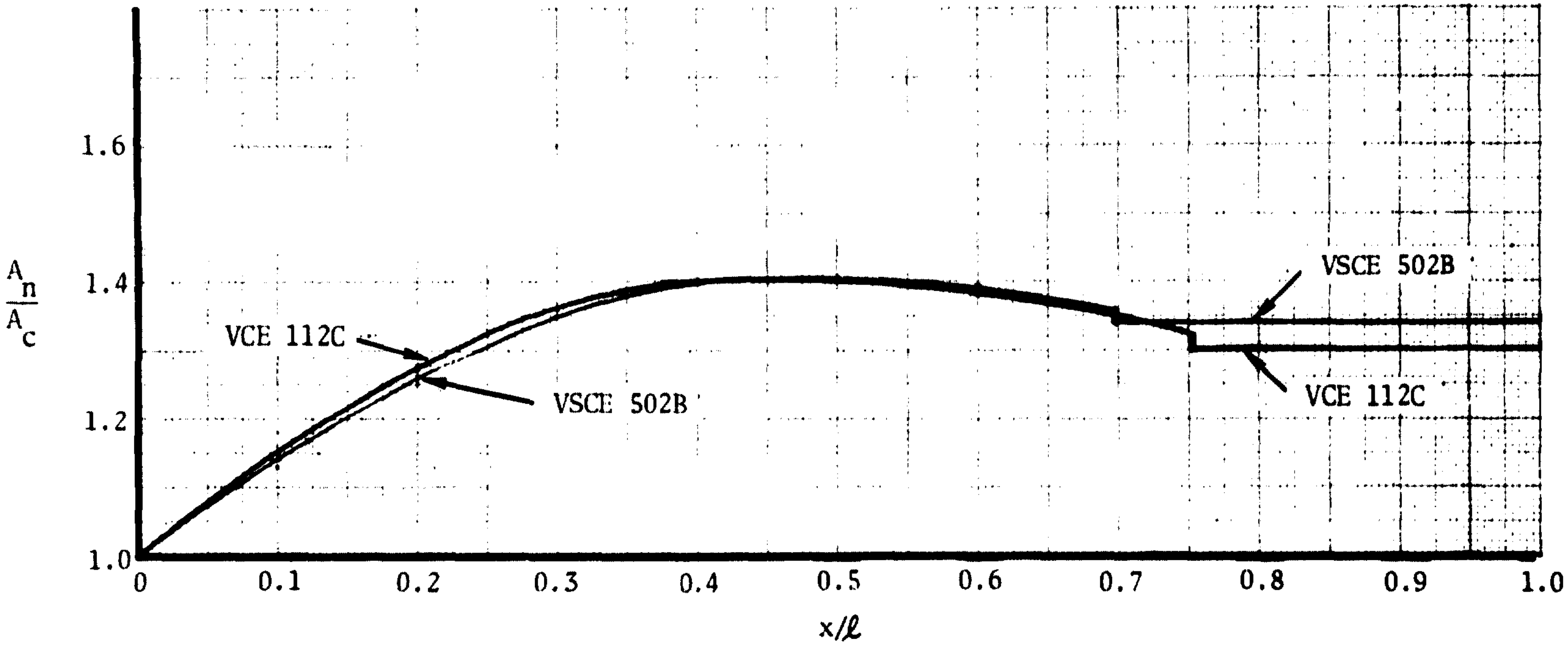


Figure 3. - Normalized nacelle cross-sectional area variation for VSCE 502B and VCE 112C.

TABLE 4. - DRAG AND TAKEOFF GROSS WEIGHT INCREMENTS DUE TO CHANGES IN ENGINE SHAPE

Engine	ΔC_D, Supersonic Cruise Nacelle Drag Increment Relative to Nacelles Off	Takeoff Gross Weight Increment Relative to VSCE 502B kg (lb)
VSCE 502B	0.00046	Base
VCE 112C	0.00055	3200 (7100)

SYMBOLS

A	Area, sq m (sq ft or sq in)
BLB	Boundary layer bleed
BLC	Boundary layer control
BP	Basepoint
C	Coefficient or Chord, m (ft or in)
d	Diameter, m (ft or in)
D	Drag, daN (lb)
db	Decibel
F	Thrust, kg (lb)
K	Drag-due-to-lift factor
ℓ	Length, m (ft or in)
L	Lift, N (lb)
M	Mach number
R	Relative TOGW factor
S	Area, sq m (sq ft or sq in)
SFC	Specific fuel consumption, kg/hr/N (lb/hr/lb)
T	Thrust, N (lb)
TOGW	Takeoff gross weight, kg (lb)
V	Velocity, m/sec (ft/sec)
W	Weight, kg (lb)
X	Nacelle station, m (ft or in)
Δ	Increment

Subscripts

AMAX	Maximum cross-sectional area
B	Base

c	Capture
CD	Drag coefficient
D	Drag
F	Friction
f	Fuel
i	Inlet throat
K	Indicates lift coefficient at minimum drag
L	Lift
LO	Loftoff
MAX	Maximum
n	Nozzle exit
ne	Net effort
P	Profile
REF	Reference
R	Root
SFC	Specific fuel consumption
SUB	Subsonic
SUPER	Supersonic
TO	Takeoff
W	Wave
WT	Weight
0	Freestream
1	Critical engine failure

STUDY PROCEDURE

Approach

The general approach of this study included using the baseline airplane, parametric nacelle drag results, and takeoff gross weight sensitivities developed in the NASA Langley Research Center contract of reference 2. A nacelle drag table look-up computer program and guidelines for determining nacelle shape were developed to allow estimation of supersonic cruise drag. A method to assess the propulsion system installation weight was defined. A method of determining vehicle takeoff gross weight using vehicle sensitivities to propulsion changes was developed. The method was verified by analyzing in detail four selected propulsion systems.

Because of the dependence of this study on the baseline airplane and ground rules of the study of reference 2, the definition of the baseline airplane is included. In this report, descriptions of the airplane configurations used are as follows:

(1) The <u>reference</u> airplane is the NASA-modified SCAT 15F arrow wing supersonic transport (defined in reference 3),

(2) The basepoint vehicle is the reference modified only as required to install the Pratt and Whitney Aircraft (PWA) VSCE 502B engine,

(3) The baseline airplane is the basepoint resized to the design requirements on a standard-plus-8° C day.

The structure design and operational empty weight of the reference airplane were assumed to meet all design criteria. Weight and aerodynamic characteristics of the study airplanes were derived by increments from the reference configuration.

Baseline Airplane Definition

Basepoint airplane.- The "basepoint" airplane for this study is based on the NASA modified SCAT 15F arrow wing reference configuration as described in reference 3. The propulsion system of this airplane has been replaced with PWA variable stream control engines (VSCE 502B) having 408 kg/sec (900 lb/sec) airflow each and witn axisymmetric variable geometry inlets designed for mach 2.4 cruise conditions. The resulting basepoint vehicle is shown in figure 4. This airplane has a gross weight of 336 973 kg (742 890 lb), a range of 7471 km, (4034 n.mi.), and a balanced field length of 3017 m (9898 ft).

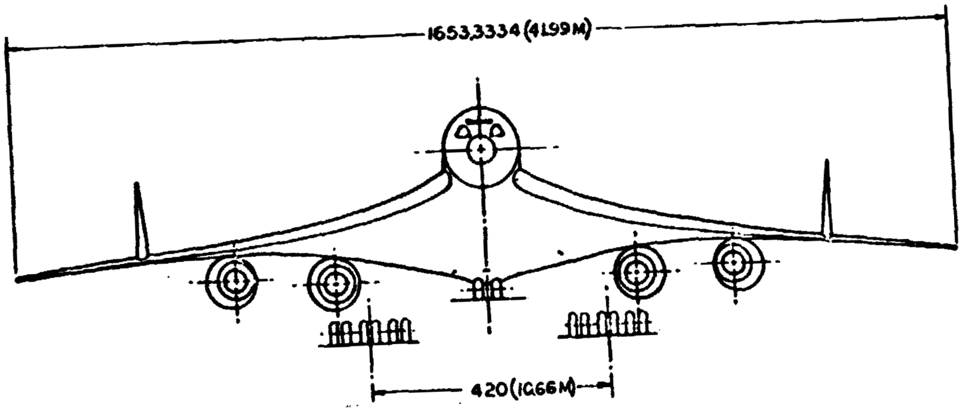
All performance and sizing calculations were made using the Rockwell Vehicle Sizing and Performance Evaluation Program (VSPEP). This computer program is a design tool capable of scaling a known basepoint vehicle according to specified values of several different design parameters. These include vehicle gross weight (or fuel weight), thrust-to-weight ratio (or engine size), wing-loading (or wing area), and payload or fixed equipment weight and volume. Performance may be determined at specified gross weight, or alternatively, a search routine permits automatic sizing of the vehicle gross weight such that a specified radius or range of the design mission is satisfied. Vehicle performance is calculated internally from a set of subroutines programmed according to a detailed performance analysis model. The subroutines are general in nature and permit calculation of a wide variety of mission profiles. Several mission profiles may be calculated simultaneously. Takeoff and landing distances and maneuvering capability may also be determined. Figure 5 illustrates the evaluation process.

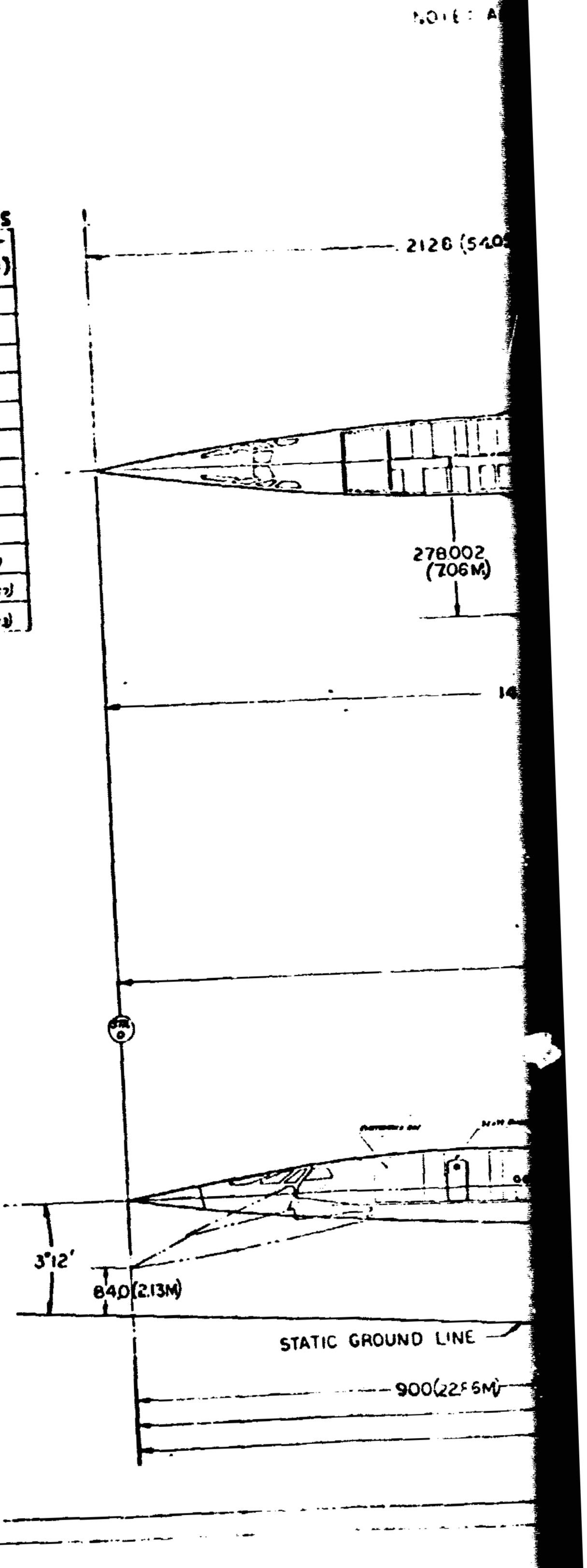
Typical mission legs which may be calculated include warmup, taxi, takeoff, climb, descent, cruise, and loiter operations. Climb and descent performance are determined by numerical integration of the equations of motion along a specified flight schedule. Internally generated schedules are also available, including minimum time and minimum fuel flight paths as defined by the energy method. Constraints on the allowable flight regime are included. Cruises and loiters may be determined at fixed or optimum speeds and altitudes. Numerical

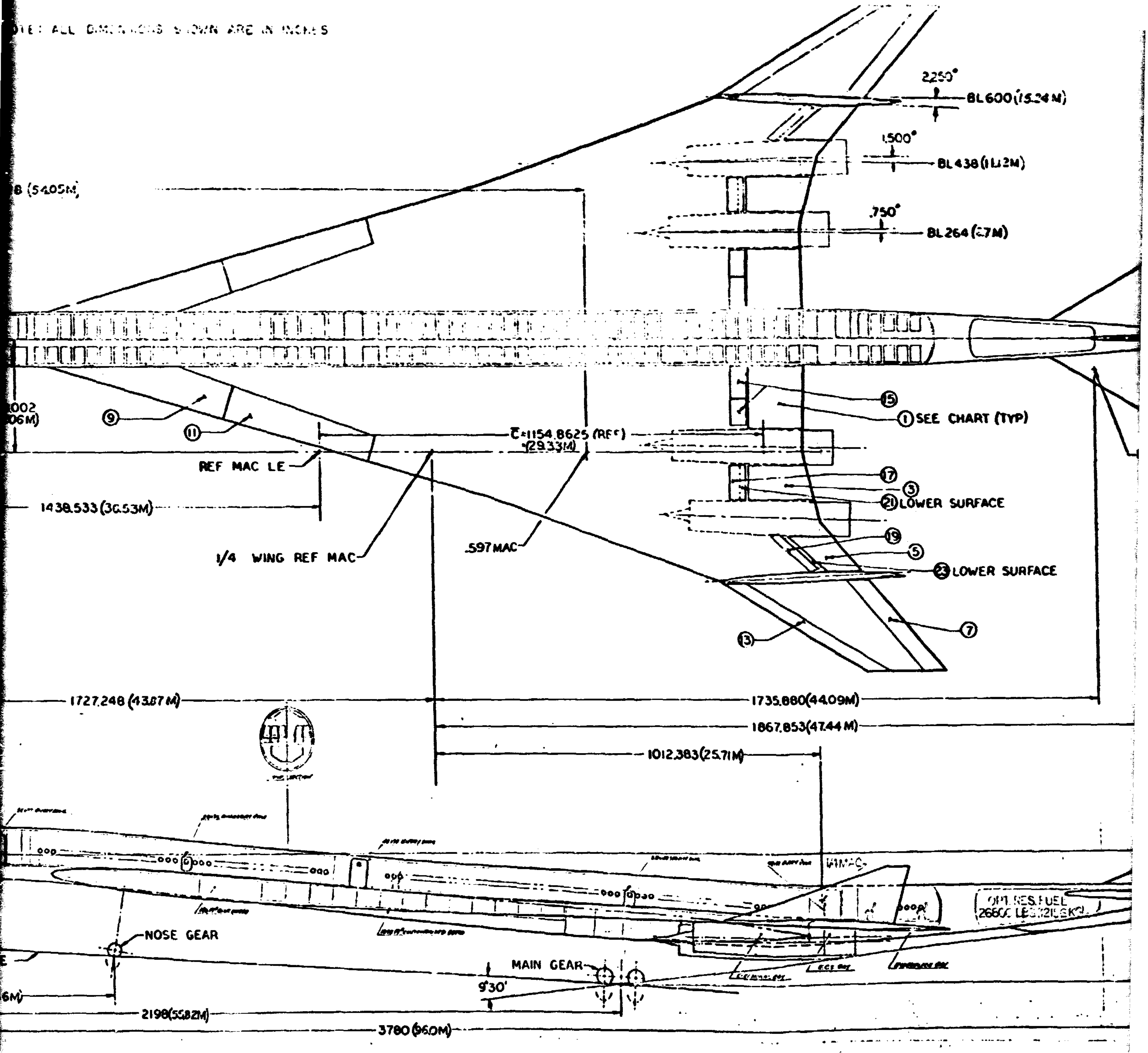
GEOMETRY	WING	HORIZ	VERT	VERT FIN ON WING
AREA (GROSS) S FT²	10996.365	600.000	109.000	233.275 EA
MAC (GROSS) $\bar{c}$ IN	1343.0684	254.964	194.128	310.550
AREA (REF) S FT²	9969.000	—	—	—
MAC (REF) $\bar{c}$ IN	1154.5525	—	—	—
AREA (EXPOSED) S FT²	—	441.0 ([illegible])	—	—
SPAN b FT	137.7778	32.0 ([illegible])	7.6 ([illegible])	10.75 (3.27)
ASPECT RATIO (GROSS)	1.72627	1.707	.527	.495
ASPECT RATIO (REF)	1.90417	—	—	—
SWEEP Λ_{LE} DEG	74.0 ; 70.84 ; 60.0	60.64	68.20	73.42
ROOT CHORD IN	2196.935	367.200	278.400	458.400
TIP CHORD IN	211.6667	82.80 ([illegible])	66.00 ([illegible])	62.40 (1.58)
ROOT T/C %	SEE FIG V-7	3.0	2.996	2.996
TIP T/C %	SEE FIG V-7	3.0	2.996	2.996
TAPER RATIO	—	.257	.237	.136
INCIDENCE DEG	—	—	—	—
DIHEDRAL DEG	—	-15.0	—	—
VOL COEFF (GROSS) $\bar{V}$	—	.070	.011	.026
VOL COEFF (REF) $\bar{V}$	—	.090	.012	.029

WING CONTROL SURFACES

[illegible] DATA	NUMBER [illegible]	AREA FT² EACH (m²)
t_1	1/2	145 ([illegible])
t_2	3/4	100 ([illegible])
t_3	5/6	60 ([illegible])
t_4	7/8	91 (8.45)
L_1	9/10	198 (18.39)
L_2	11/12	165 ([illegible])
L_6	13/14	92 (8.54)
	15/16	40 (3.71)
	17/18	26 (2.41)
	19/20	18 (1.67)
	21/22	6 (0.557)
	23/24	8 (0.743)







FOLDOUT FRAME 2

Fi

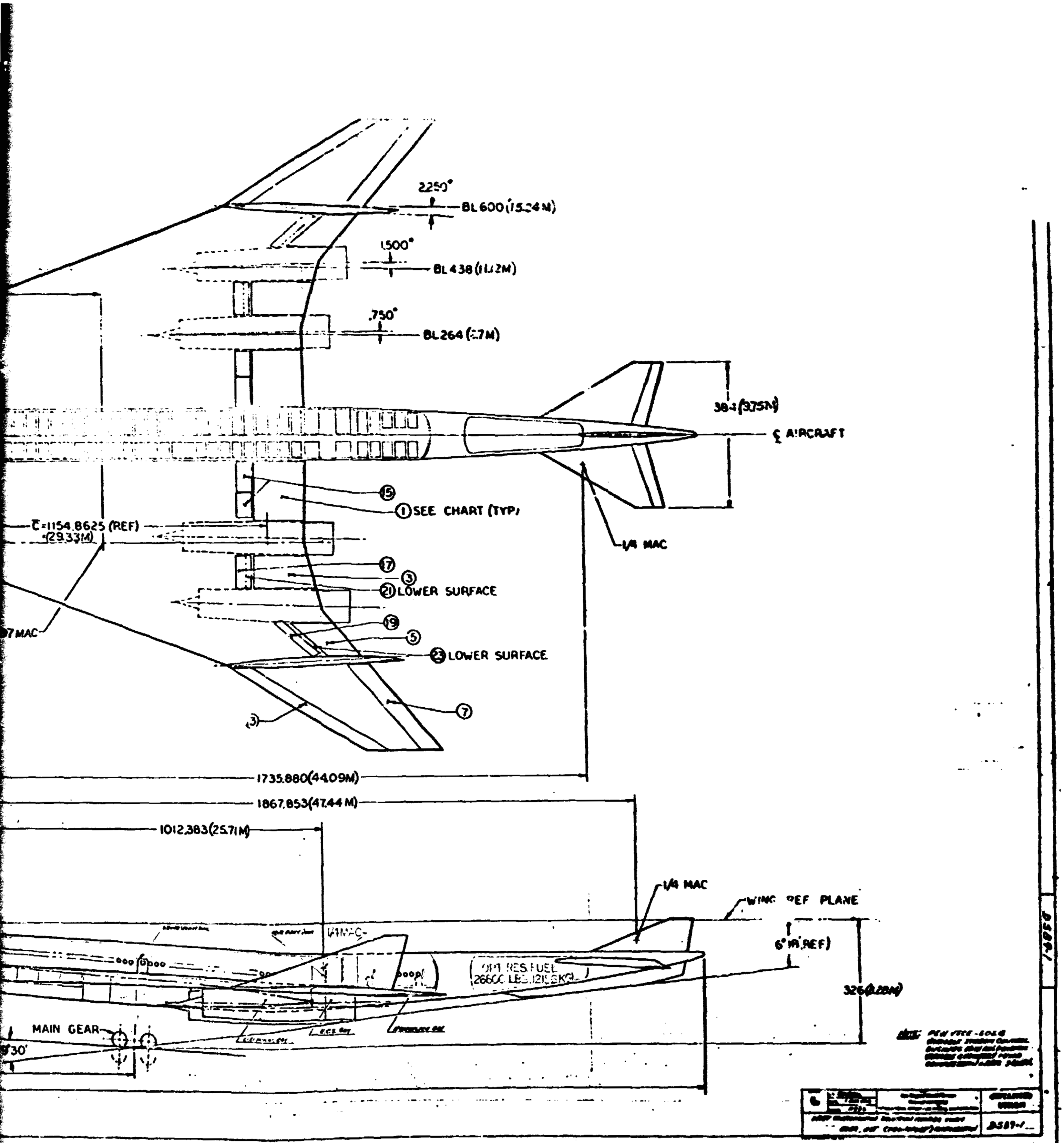


Figure 4. - Basepoint airplane

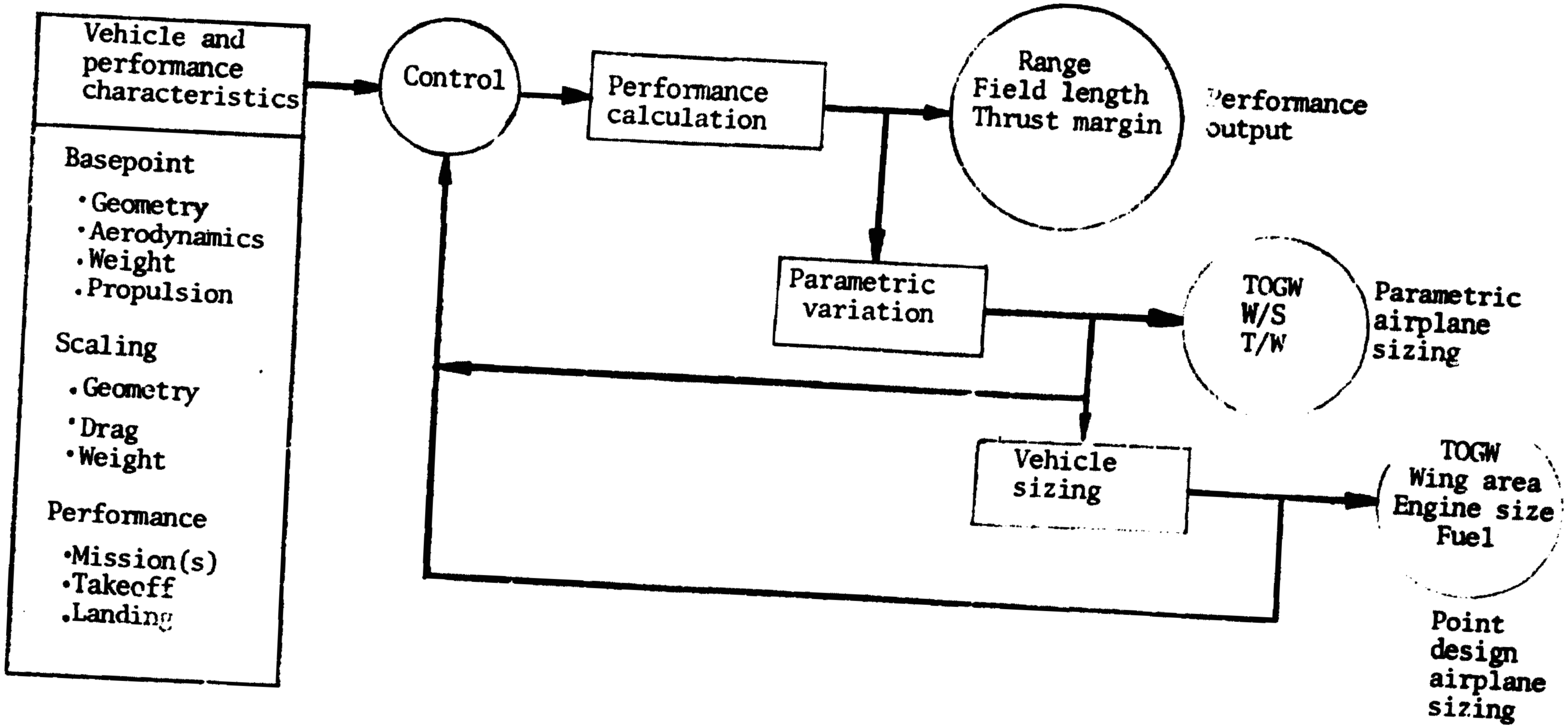


Figure 5.-Vehicle sizing and performance evaluation program.

searches are used to determine optimum speeds and altitudes at the beginning and end of each of these legs.

Data input to the VSPEP for the AST basepoint vehicle include:

- Weights broken down by major component, along with scaling information on the wing, tails, fuselage, and engines.
- Drags broken down by major component and by type (e.g., friction drag, wave drag, drag due to lift, base drag).
- Installed propulsion data, including thrust and fuel flow as functions of speed, altitude, and power setting.
- Dimensional data such as lengths, areas, and volumes for major components and the total vehicle.

Performance items calculated by the VSPEP on the basepoint and baseline vehicles for this study consist of the following:

(1) Design mission range

(2) Alternate mission range

(3) Takeoff distance with FAR 36 (Federal Aviation Regulation, part 36) noise requirements

(4) Balanced field takeoff distance

(5) Thrust-to-drag ratio at mach 2.32, 18 300 m (60 000 ft)

(6) Thrust-to-drag ratio at mach 1.2 during the climb leg

A description of each of these performance items is given in the following paragraphs. Because engine data were provided for a standard-plus-8°C (14.4°F) day, all airplane performance characteristics were computed for that atmospheric condition.

Design mission.- A profile of the design mission is shown in figure 6. This mission consists mainly of a mach 2.32 cruise. Fuel reserves as recommended in reference 4 are calculated for an alternate airport located 460 km (250 n.mi.) from the destination airport.

The design mission consists of:

(1) Warmup and takeoff - 10 minutes at idle power plus 1 minute at maximum power.

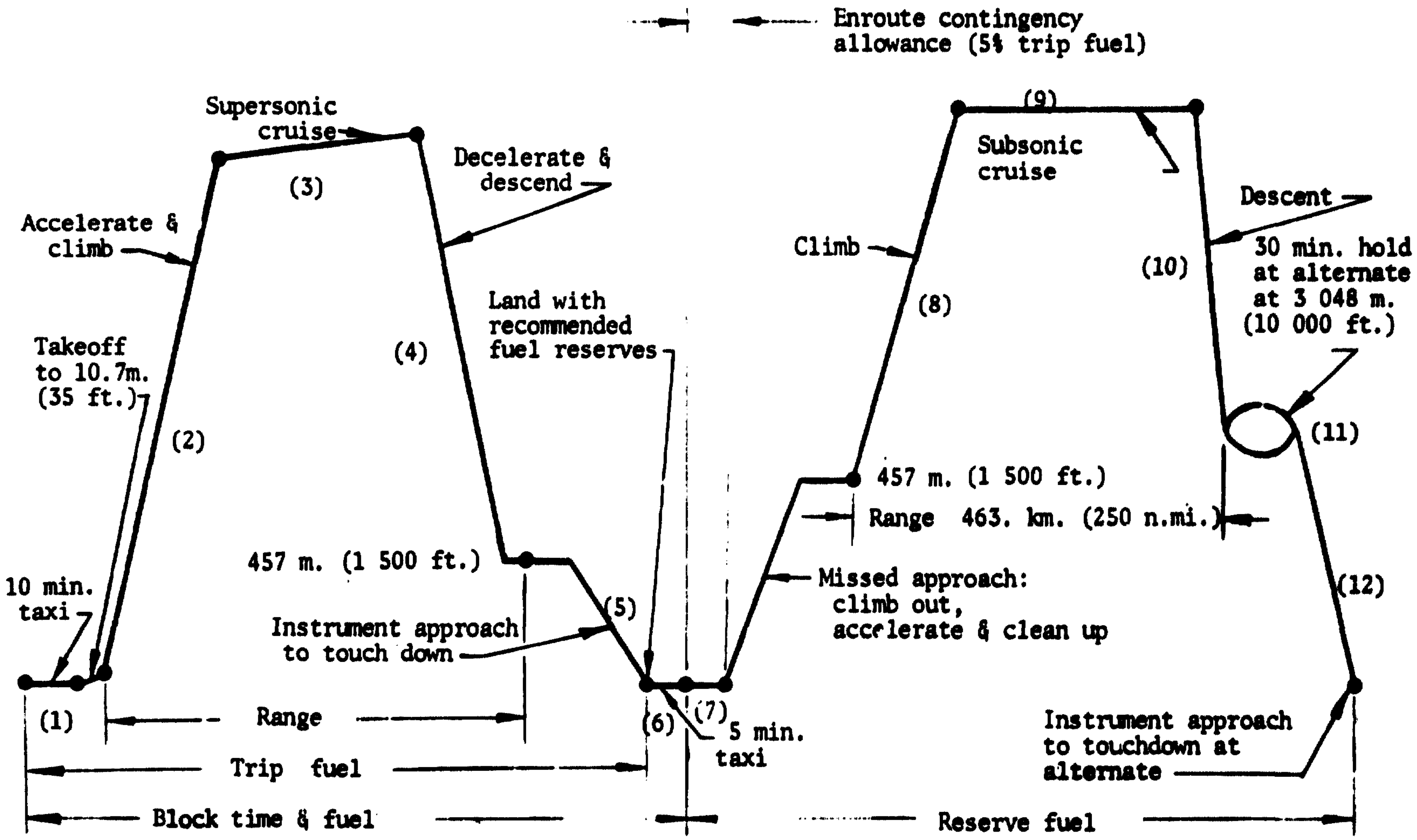


Figure 6.-Reference mission

(2) Climb - Maximum power climb and accelerate to cruise altitude and mach number.

(3) Cruise - Cruise at mach 2.32 at altitude for best cruise range.

(4) Descent - Descend and decelerate to mach 0.5 and 457 m (1500 ft) using idle power.

(5) Approach and land - Descend to mach 0.3 at sea level using idle power.

(6) Taxi - 5 minutes at idle power.

(7) Reserve allowance - 5-percent of total fuel used in all previous legs.

(8) Reserve climb - Climb to subsonic cruise conditions.

(9) Reserve cruise - Subsonic cruise at mach number and altitude for best range.

(10) Reserve descent - Descend and decelerate to holding altitude and mach number using idle power.

(11) Reserve hold - Loiter for 30 minutes at 3048 m (10 000 ft) at the mach number for best endurance.

(12) Reserve approach and land - Descend to sea level using idle power.

Alternate mission.- A profile of the alternate mission is shown in figure 7. The first half of the alternate is identical to the first half of the design mission. At the point corresponding to the midpoint of the design mission, a failure is assumed to occur in the most critical engine. At this point, the airplane descends and continues to cruise subsonically with one engine windmilling. The fuel reserve remaining at the end of this mission is equal to the reserve fuel as calculated for the design mission.

The alternate mission consists of:

(1) Warmup and takeoff - Same as design mission.

(2) Climb - Same as design mission.

(3) Cruise - Same as design mission.

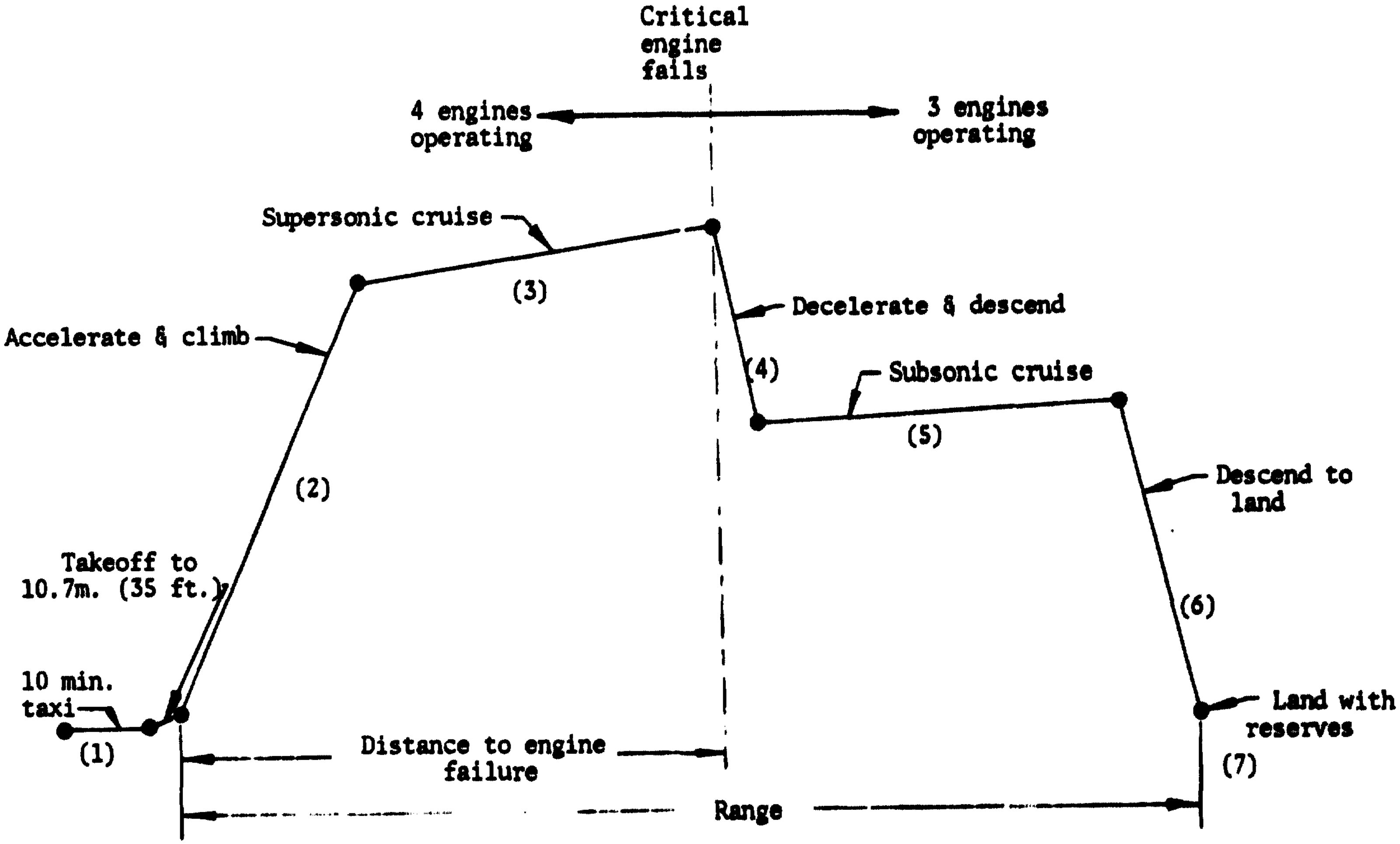


Figure 7.-Alternate mission

(4) Descent - Descend and decelerate to subsonic cruise conditions using idle power, following failure of most critical engine.

(5) Cruise - Subsonic cruise at mach number and altitude for best range with one engine inoperative.

(6) Descend and land - Descend to sea level using idle power.

(7) Reserve - Allow total reserve fuel equal to that calculated for design mission legs 7 through 12.

Balanced field takeoff.- Takeoff distance is calculated over a 10.7 m (35 ft) obstacle. It is assumed that a maximum usable lift coefficient of 0.555 is available for climbout. Balanced field length involves three requirements:

(1) Distance for a normal takeoff is calculated with all engines (throttled if necessary so that FAR 36 noise requirements are not exceeded) and this distance is multiplied by 1.15.

(2) Distance is calculated for a takeoff when an engine fails at the critical speed and the airplane continues the takeoff. In this instance, the throttles may be advanced after the engine failure if they are not already at maximum power (without regard to noise requirements).

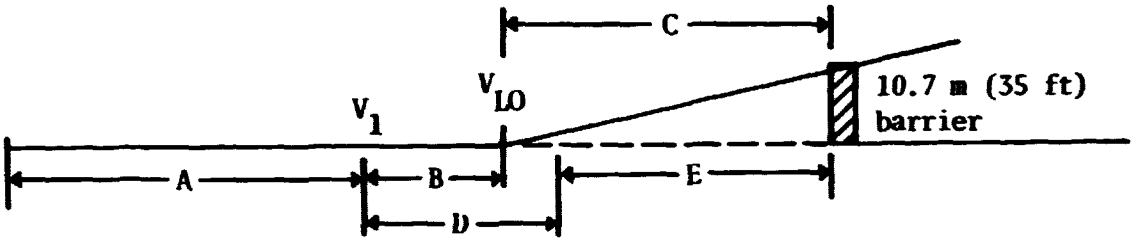
(3) Distance is calculated when an engine fails at the critical speed and the takeoff is aborted. The airplane is stopped by applying brakes and cutting the remaining engines to idle. The critical speed for engine failure is determined by varying the speed at which engine failure occurs (i.e., V_1) until the accelerate-continue distance is equal to the accelerate-stop distance (i.e., segments B + C = D + E as shown in figure 7). The balanced field length is then defined as the greatest of items (1), (2), and (3).

Thrust-to-drag ratio.- The thrust-to-drag (T/D) ratio is calculated using maximum available thrust at 2.32 mach, 18 300 m (60 000 ft). Drag is that for level flight at the same conditions. Airplane weight is that at the start of the supersonic cruise as calculated for the design mission. The thrust-to-drag ratio is also calculated for the point in the climb-accelerate leg at which mach 1.2 is reached. In this case the altitude and vehicle weight are the actual values during the climb at which the vehicle reaches mach 1.2.

Baseline airplane.- The "baseline" airplane for this study is a resized version of the aforementioned "basepoint." Resizing was accomplished by exercising the VSPEP for a matrix of thrust-to-weight and wing loading values, and allowing the program to search for the gross weight, in each case, that satisfies the design mission range requirement of 7408 km (4000 n.mi.). Plots of the results are shown in figures 9 through 11. The parameters shown include vehicle gross weight as well as those performance items for which requirements must be met.

The balanced field length requirement is plotted on the airplane gross weight plot in figure 9. This allows a "baseline" airplane to be chosen which is defined as the minimum gross weight vehicle that meets or exceeds the following performance requirements:

Design mission range	7408 km (4000 n. mi.) with 292 passengers
Balanced field length	3200 m (10 500 ft)
Minimum T/D during climb or cruise	1.2



A - Distance up to critical engine failure V_1

B - 3-engine acceleration distance from V_1 to V_{LO}

C - 3-engine lift-off to barrier distance

D - Distance gained after engine failure before full brake application

E - Stopping distance

V_1 - Critical engine failure speed

V_{LO} - Lift-off velocity

Figure 8. - Balanced field length definition

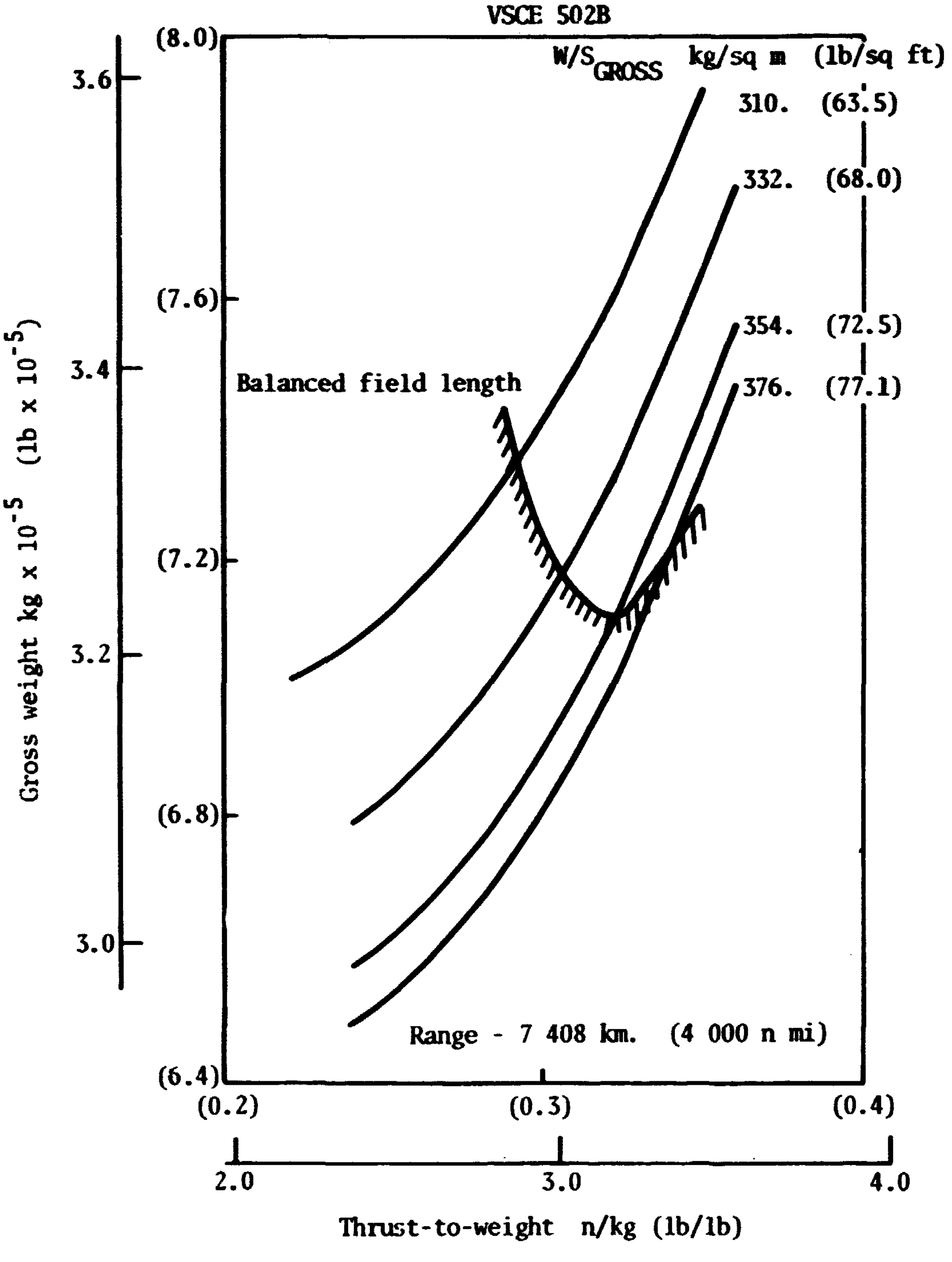


Figure 9. - Gross weight versus thrust-to-weight and wing loading.

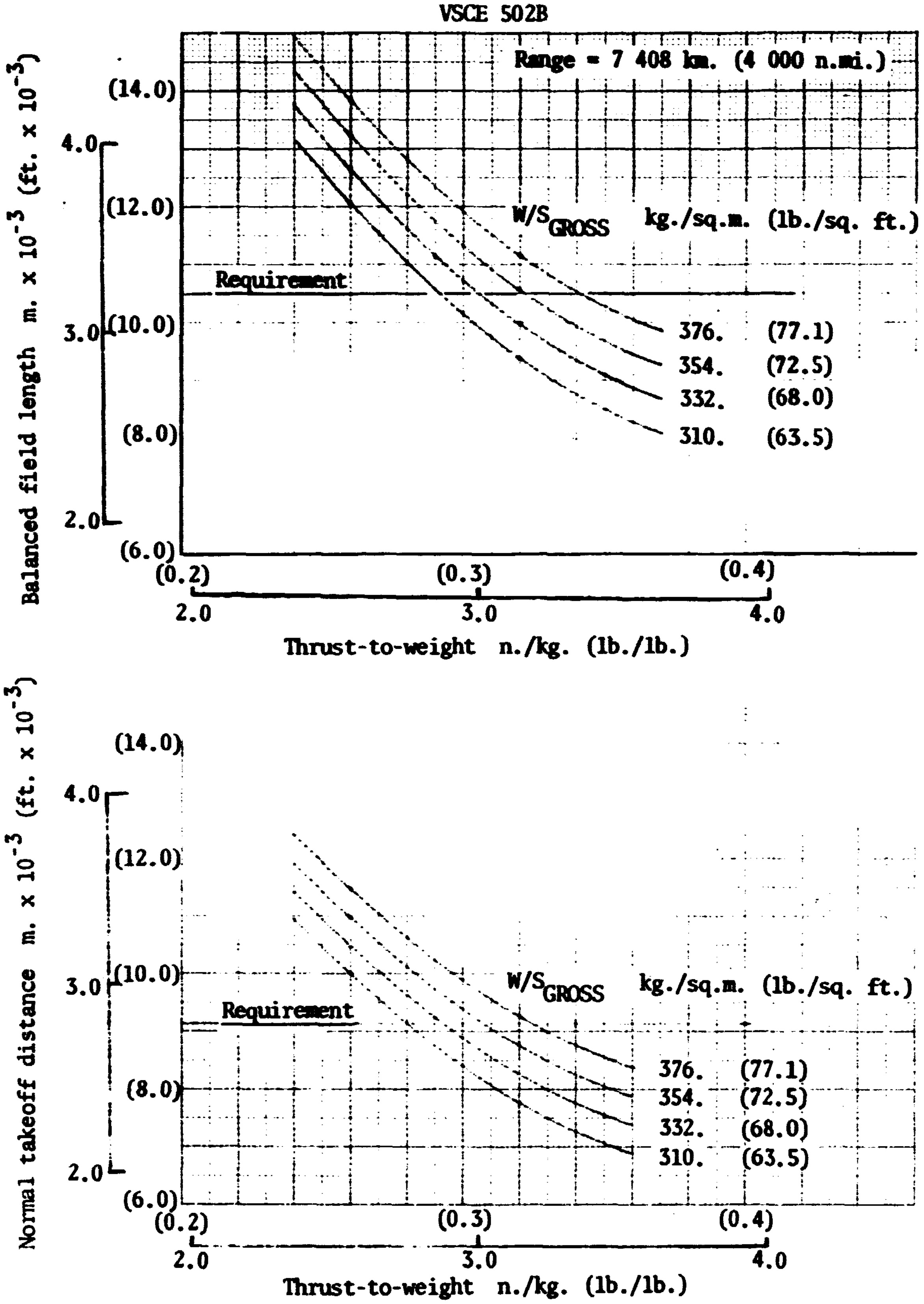


Figure 10. -Balanced field length versus thrust-to-weight and wing loading

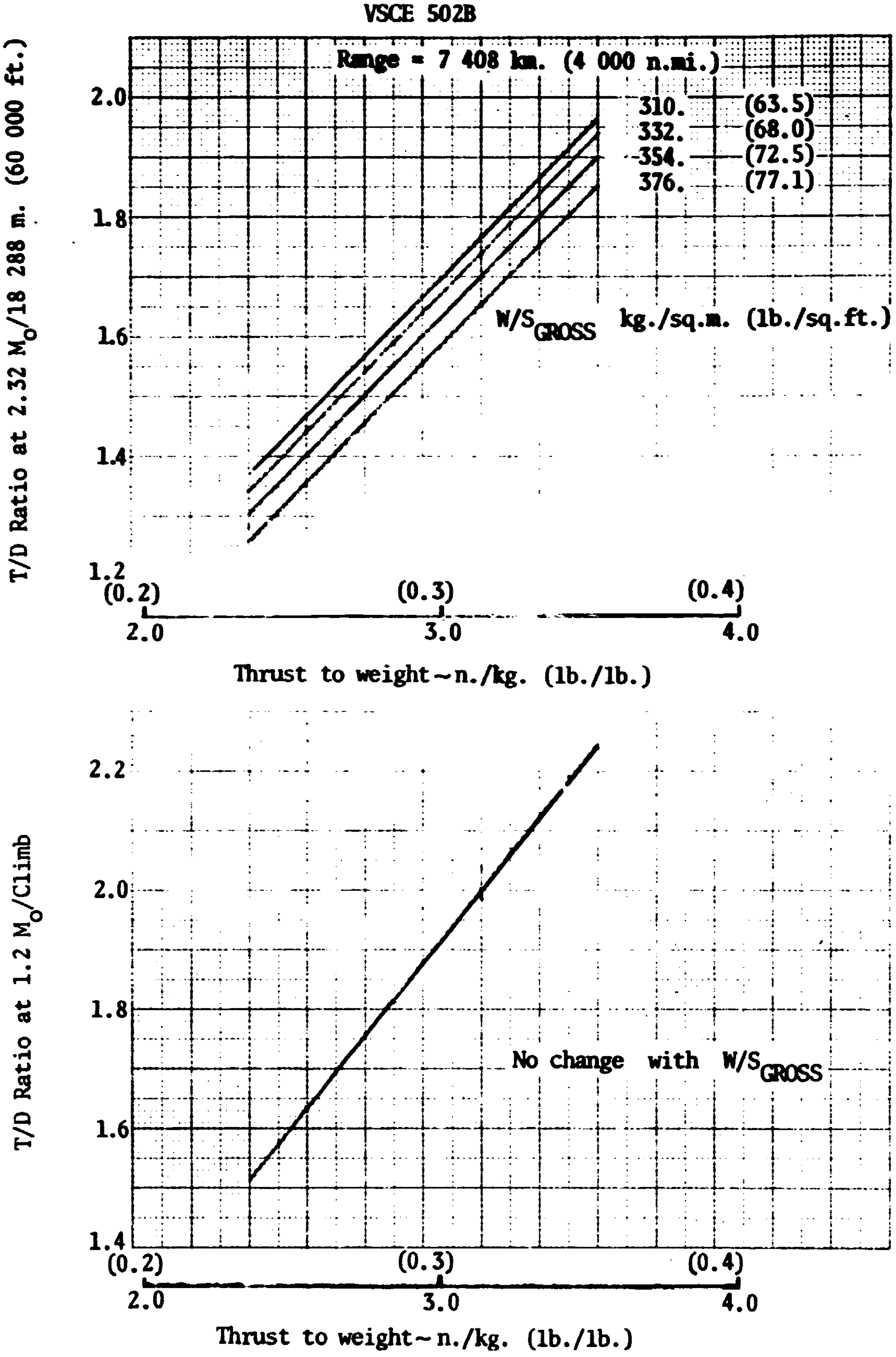


Figure 11.-Thrust/drag ratio versus thrust-to-weight and wing loading.

Since the thrust-to-drag requirements are exceeded for all cases, figure 10, only the balanced field length requirements are included in figure 9.

The resulting "baseline" airplane has a gross weight of 323 046 kg (712 188 lb); a thrust-to-weight ratio of 3.16 n/kg (0.323 lb/lb) based on installed, static takeoff thrust; and a wing loading of 354 kg/sq m (72.5 lb/sq ft) based on gross wing area. (As discussed on page 71, the baseline was revised slightly for consistency in validating the approximate methods, but the discussion presented here is for the NASA Langley study baseline.)

Further airplane design and performance characteristics for both the "basepoint" and "baseline" airplanes are shown in table 5. Design and alternate mission summaries are shown in tables 6 through 9 for the baseline airplane. In these tables, the first leg of the alternate mission includes the first four legs of the design mission while leg five of the alternate includes reserves for legs nine through 15 of the design mission. The path followed during the climb-accelerate leg is a minimum fuel path calculated internally by the VSPEP program. This path as calculated for the baseline airplane is shown in figure 12.

Propulsion.- Because many of the current and recently completed supersonic cruising aircraft studies have used axisymmetric inlets, a mixed-compression, axisymmetric inlet was defined for use in the basepoint aircraft for this study. The inlet diameter is 1.93 meters (76 inches), and capture area is 2.926 square meters (4 536 square inches). For takeoff, the basic centerbody is held in the transonic position, but the fore and aft conical segments are translated aft to create a centerbody auxiliary inlet. The auxiliary inlet opening in the centerbody is 10 percent of capture area. Inlet pressure recoveries and spillage, bypass, and BLC drags were estimated, and their effects were included in installed propulsion performance. Engine accessories were assumed to be located in the wing. The nacelle drawing is shown in figure 13.

The engine performance data available for the VSCE 502B engine included the effects of an inlet recovery schedule, nozzle external drags (base plus boattail), 0.45 kilogram-per-second (1.0 pound-per-second) high-pressure compressor air bleed, and 149 kilowatts (200 horsepower) power extraction. Installed performance data were computed by modifying the engine data to include the effects of changes in inlet pressure recovery and inlet drags (spillage, bypass, and boundary layer control). Because the amount of engine data available was not sufficient to compute aircraft mission performance, additional installed performance data were generated by calculating corrected thrust and fuel flow parameters and by extrapolating based on trends of engines with similar characteristics. Fortunately, these techniques were required only at flight conditions where the airplane flies for a short duration. Thus, any possible errors due to data extrapolation should have minimal effect on airplane performance. All data were for standard-plus-8°C day.

TABLE 5. - AIRPLANE CHARACTERISTICS

	Basepoint		Baseline	
Engine Airflow, kg./sec. (lb./sec.)	408	(900)	395	(869)
Thrust-to-weight, n./kg. (lb./lb.)	3.14	(0.3208)	3.16	(0.323)
Reference Wing Area, sq.m. (sq. ft.)	926	(9 969)	827	(8 902)
Gross Wing Area, sq.m. (sq. ft.)	1 022	(10 996)	912	(9 819)
Wing Loading (gross area), kg./sq.m. (lb./sq. ft.)	330	(67.56)	354	(72.53)
TOGW, kg. (lb.)	336 973	(742 890)	323 042	(712 188)
Fuel Weight, kg. (lb.)	158 475	(349 834)	151 643	(334 754)
Max. Wing Fuel, kg. (lb.)	207 950	(459 050)	175 484	(387 382)
Design Range, km. (n.mi.)	7 475	(4 034)	7 412	(4 000)
Eng. Out Range, km. (n.mi.)	6 285	(3 392)	6 259	(3 378)
FAR 36 T.O. Dist., m. (ft.)	2 498	(8 194)	2 648	(8 661)
Bal. Field T.O. Dist., m. (ft.)	3 017	(9 898)	3 190	(10 466)
Thrust-to-Drag @ 2.32 M/18 300 m. (60 000 ft.)		1.747		1.716
Thrust-to-Drag @ 1.2M/Climb		2.005		2.019
Initial Cruise L/D		9.649		9.541
Initial Cruise SFC (installed) kg./hr./daN. (lb./hr./lb.)	1.393	(1.366)	1.385	(1.358)

TABLE 6. - BASELINE DESIGN MISSION SUMMARY - INTERNATIONAL UNITS

LEG. NO.	OPERATION	WEIGHT, kg.	ALTITUDE, m.	MACH	FUEL USED, kg.	TIME, min.	TOTAL TIME min.	RANGE, km.	TOTAL RANGE, km.
	INITIAL WEIGHT	323 046							
1	WO & TO	319 171	0	0.305	3 871	10.0	10.0	0	0
2	CL TO 1500	317 071	457	0.500	2 100	1.3	11.3	10	10
3	CLB-ACC	292 535	16 746	2.320	24 535	12.8	24.1	288	299
4	CRUISE	239 921	17 910	2.320	52 614	82.9	107.0	3 405	3 704
5	CRUISE	196 262	19 168	2.320	43 659	82.6	189.7	3 395	7 100
6	DESCEND	194 735	457	0.500	1 526	17.3	207.0	296	7 396
7	DES-LAND	194 500	0	0.300	235	1.5	208.6	12	7 409
8	TAXI-ALL	193 853	0	0.0	646	5.0	213.6	0	7 409
9	5PCT ALL	187 394	0	0.0	6 459	0.0	213.6	0	7 409
10	CL 1500	186 826	457	0.500	567	0.7	214.3	5	7 414
11	CLB-ACC	181 460	12 337	0.950	5 366	10.2	224.5	158	7 573
12	CRUISE	179 067	12 427	0.950	2 393	10.8	235.3	181	7 754
13	DESCEND	178 195	3 048	0.470	871	9.5	244.9	123	7 877
14	LOITER	171 744	3 048	0.454	6 450	30.0	274.9	0	7 877
15	DES-LAND	171 207	0	0.300	537	3.7	278.6	33	7 911
TOTAL FUEL USED = 151 834									

TABLE 7. - BASELINE DESIGN MISSION SUMMARY - ENGLISH UNITS

LEG. NO.	OPERATION	WEIGHT, lbs.	ALTITUDE, ft.	MACH NO.	FUEL USED, lbs.	TIME min.	TOTAL TIME min.	RANGE n.m.	TOTAL RANGE n.m.
	INITIAL WEIGHT	712 188							
1	WO & TO	703 653	0	0.305	8 534	10.0	10.0	0	0
2	CL TO 1500	699 022	1 500	0.500	4 631	1.3	11.3	5	5
3	CLB-ACC	644 931	54 943	2.320	54 090	12.8	24.1	155	161
4	CRUISE	528 936	58 761	2.320	115 994	82.9	107.0	1 838	2 000
5	CRUISE	432 684	62 889	2.320	96 252	82.6	189.7	1 833	3 833
6	DESCEND	429 318	1 500	0.500	3 365	17.3	207.0	159	3 993
7	DES-LAND	428 800	0	0.300	518	1.5	208.6	7	4 000
8	TAXI-ALL	427 374	0	0.0	1 425	5.0	213.6	0	4 000
9	5PCT ALL	413 134	0	0.0	14 240	0.0	213.6	0	4 000
10	CL TO 1500	411 882	1 500	0.500	1 251	0.7	214.3	2	4 003
11	CLB-ACC	400 052	40 476	0.950	11 830	10.2	224.5	85	4 089
12	CRUISE	394 775	40 773	0.950	5 276	10.8	235.3	98	4 187
13	DESCEND	392 853	10 000	0.470	1 921	9.5	244.9	66	4 253
14	LOITER	378 632	10 000	0.454	14 221	30.0	274.9	0	4 253
15	DES-LAND	377 448	0	0.300	1 184	3.7	278.6	18	4 271
	TOTAL FUEL USED = 334 739								

TABLE 8. - BASELINE ALTERNATE MISSION SUMMARY - INTERNATIONAL UNITS

LEG. NO.	OPERATION	WEIGHT, kg.	ALTITUDE, m	MACH NO.	FUEL USED, kg.	TIME min.	TOTAL TIME min.	RANGE km.	TOTAL RANGE km.
	INITIAL WEIGHT	323 046							
1	DES LEGS 1-4	239 921	0	0.0	83 121	107.0	107.0	3 704	3 704
2	DES-DEC	239 539	8 212	0.900	381	7.9	115.0	189	3 894
3	CRUISE	194 718	9 461	0.900	44 821	136.7	251.7	2 248	6 142
4	DESCEND	193 850	0	0.300	868	10.2	262.0	113	6 256
5	RESERVE	171 204	0	0.0	22 646	65.0	327.0	502	6 758

Total Fuel Used = 151 838

TABLE 9. - BASELINE ALTERNATE MISSION SUMMARY - ENGLISH UNITS

LEG NO.	OPERATION	WEIGHT, lbs.	ALTITUDE, ft.	MACH NO.	FUEL USED lbs.	TIME min.	TOTAL TIME min.	RANGE n.m.	TOTAL RANGE n.m.
	INITIAL WEIGHT	712 188							
1	DES LEGS 1-4	528 936	0	0.0	183 251	107.0	107.0	2 000	2 000
2	DES-DEC	528 095	26 944	0.900	841	7.9	115.0	102	2 102
3	CRUISE	429 281	31 040	0.900	98 813	136.7	251.7	1 213	3 316
4	DESCEND	427 368	0	0.300	1 913	10.2	262.0	61	3 378
5	RESERVE	377 441	0	0.0	49 926	65.0	327.0	271	3 649

Total Fuel Used = 334 746

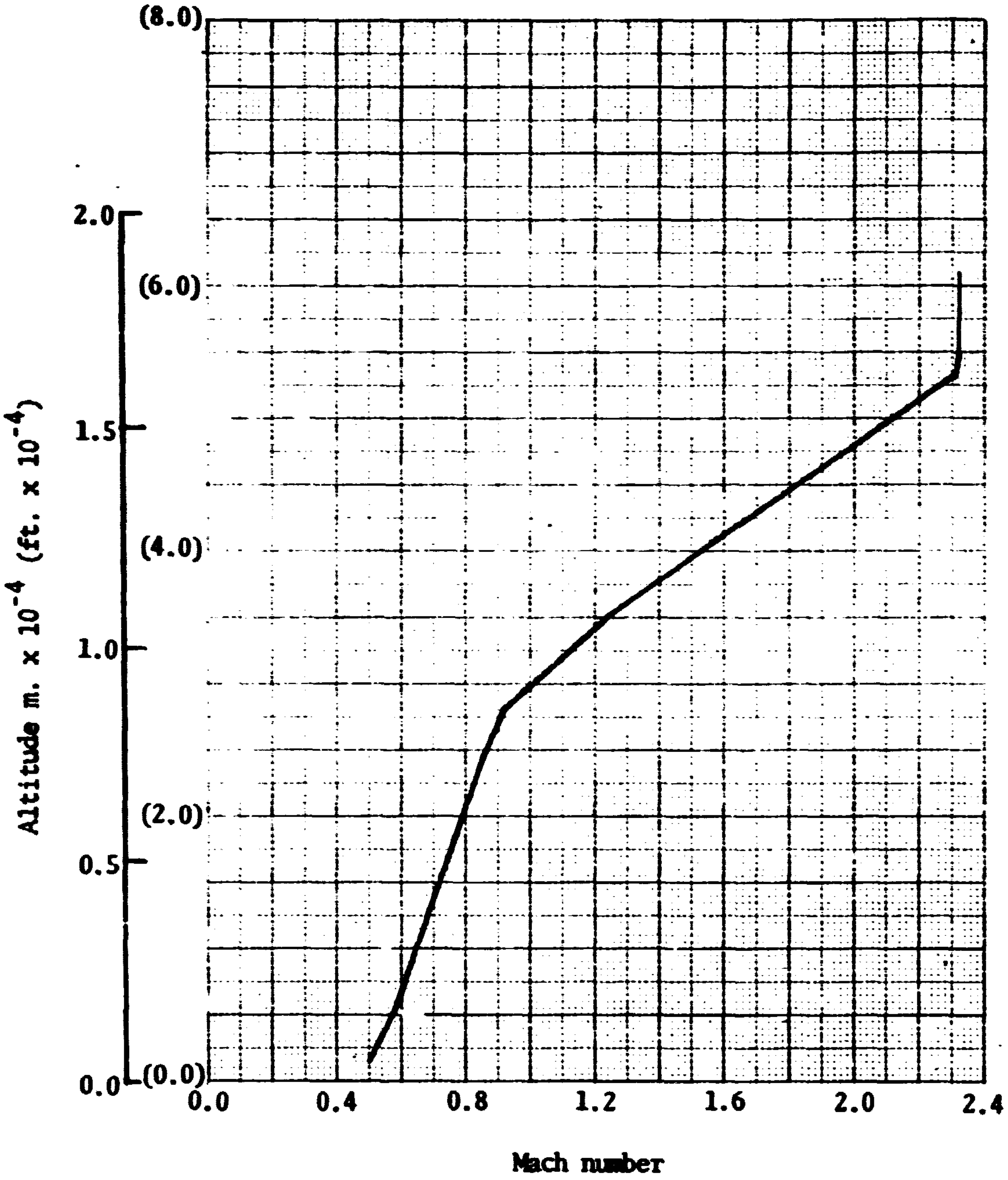


Figure 12.-Baseline airplane climb path

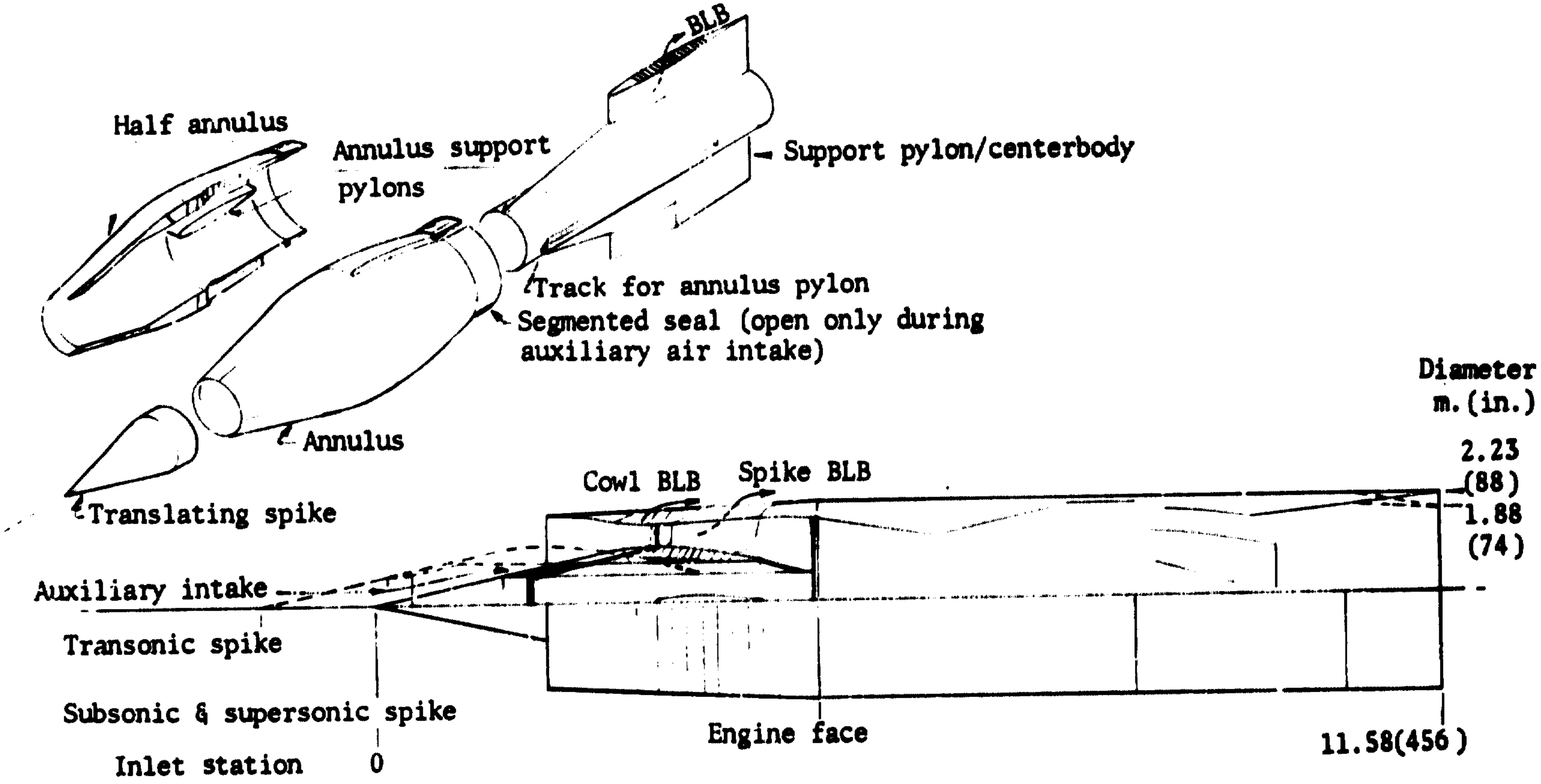


Figure 13. - Basepoint nacelle.

At takeoff, the engine power setting was scheduled so that the aircraft meets FAR 36-traded noise levels. The SAE exhaust jet noise prediction method was used with the modification to overall sound pressure level recommended by Bushell (reference 5). This modification has no effect on perceived noise level at static conditions, but it results in approximately 4 decibels (db) higher noise than the standard SAE method at mach 0.3. A 1.5 db reduction in sideline noise was assumed due to sideline shielding while the airplane is on the ground. An 8-decibel reduction in noise level due to the coannular nozzle effect was assumed for all flight conditions and power settings. Information from PWA indicates that coannular configurations reduce noise by 7 to 9 decibels when the difference between core velocity and bypass velocity is 152 meters per second (500 feet per second) or more, with the core stream having the lower velocity.

Mass properties.- The basepoint vehicle weight summary is given in table 10. The NASA reference vehicle weight summary (reference 3) from which the basepoint was derived is also shown. The differences between the weights of the two vehicles are in the engines and nacelles. The basepoint vehicle has VSCE 502B 408 kg/sec (900 lb/sec) airflow engines in lieu of the 363 kg/sec (800 lb/sec) engines in the NASA reference vehicle.

The VSCE 502B bare engine weight including nozzle and thrust reverser was supplied by PWA. Weight increments of 22.7 kg (50 lb) for residual fluids and 22.7 kg (50 lb) for miscellaneous engine/airframe interfacing provisions were added to the bare weight to obtain an installed weight. Table 11 shows the installed engine weight summary.

The basepoint nacelle weight estimate is based on the nacelle drawing, figure 13. For the weight evaluation, the nacelle was divided into three sections: forward of the engine front face (inlet cowl), aft of the front face (engine cowl), and inlet spike. The engine cowl weight was estimated at 34.2 kg/sq m (7 lb/sq ft) of wetted area. This weight includes all the nacelle structure that supports and surrounds the engine and was derived from prior Rockwell International studies of a similar type. The inlet cowl and spike weights were calculated using statistical weight estimating equations obtained from the technical report SEG-TR-67-1, Preliminary Design Methodology for Air-Induction Systems (reference 6). Engine mount weights were calculated statistically at 1.5-percent of the engine weight. The mount weights are included with the nacelle weight.

The weight summary of the basepoint nacelle is presented in table 12.

TABLE 10. - VEHICLE WEIGHT SUMMARY

ITEM	NASA REFERENCE VEHICLE		BASEPOINT	
	Kg	LB	Kg	LB
Wing	37 805	83 347	37 805	83 347
Horizontal Tail	2 391	5 271	2 391	5 271
Vertical Tail	2 148	4 735	2 148	4 735
Fuselage	24 636	54 314	24 636	54 314
Landing Gear	13 138	28 965	13 138	28 965
Nacelle	8 625	19 015	7 410	16 336
Structure Total	(88 743	(195 647	(87 528	(192 968
Engines	27 139	59 832	24 494	54 000
Thrust Reversers	4 809	10 601		
Miscellaneous Systems	807	1 780	807	1 780
Fuel System-Tanks and Plumbing	2 622	5 781	2 622	5 781
Propulsion Total	(35 377	(77 994	(27 923	(61 561
Surface Controls	4 527	9 981	4 527	9 981
Instruments	1 542	3 400	1 542	3 400
Hydraulics	2 540	5 600	2 540	5 600
Electrical	2 291	5 050	2 291	5 050
Avionics	1 220	2 690	1 220	2 690
Furnishings and Equipment	11 390	25 111	11 390	25 111
Air Conditioning	3 720	8 200	3 720	8 200
Anti-icing	95	210	95	210
Systems and Equipment Total	(27 325	(60 242	(27 325	(60 242
Weight Empty	151 445	333 883	142 776	314 771
Crew and Baggage-Flight,	306	675	306	675
-Cabin,	744	1 640	744	1640
Unusable Fuel	1 059	2 335	1 059	2 335
Engine Oil	361	795	361	795
Passenger Service	4 015	8 852	4 015	8 852
Cargo Containers	1 343	2 960	1 343	2 960
Operating Weight	159 273	351 140	150 604	332 028
Passengers, (292)	21 854	48 180	21 854	48 180
Passenger Baggage	5 828	12 848	5 828	12 848
Zero Fuel Weight	186 955	412 168	178 286	393 056
Mission Fuel	158 680	349 832	158 681	349 834
Design Gross Weight	345 635	762 000	336 973	742 890

TABLE 11. - BASEPOINT ENGINE WEIGHT

Item	Weight/Vehicle	
	kg	lb
Engines (including nozzle & thrust reverser) (4)	24 312	53 600
Residual Fluids	91	200
Miscellaneous Provisions	91	200
Engines as Installed	24 494	54 000

Aerodynamics.- Friction drag estimates were made for a fully turbulent, hydraulically smooth condition using the incompressible Von-Karman-Schoenherr method (reference 7) in conjunction with the adiabatic compressibility correction of Sommer and Short (reference 8). Component characteristic lengths (e.g., the distance from the inlet lip to the exhaust nozzle exit, the exposed mean aerodynamic chord of planar surfaces, etc.) and the altitude along the mission climb profile were used to evaluate length Reynolds numbers. Flat plate values were increased by 3-percent to account for form losses.

TABLE 12. - BASEPOINT NACELLE WEIGHT

Item	Weight/Vehicle	
	kg	lb
Nacelles		
Engine Cowl	2782	6132
Inlet Cowl	1299	2864
Spike	2961	6528
Engine Mounts	368	812
Total Nacelle	7410	16 336

The wave drag due to thickness was estimated as a function of mach number using supersonic area rule theory (references 9 and 10) in conjunction with a transparent wing simulation, an inlet mass flow ratio of one, and the nozzle exit area held fixed at its supersonic cruise position. The effect of inlet spillage and nozzle position is included in the installed thrust. All results reported here are based on the use of a 51-mach-plane ($\Delta X = 0.02\ L\ (\phi)$), 13-roll-angle ($\Delta\phi = 15°$) analysis. Basepoint configuration results for increased solution mesh density did not indicate any appreciable change.

Supersonic cruise trimmed drag-due-to-lift characteristics are assumed to be equal to the reference configuration of reference 3 and consequently independent of wing and engine size and nacelle shape. A different design wing twist and camber is required for each case to realize this performance. The lifting efficiency may be conservative for some of the more favorably shaped nacelles of the parametric drag study in that any increased benefit that may be realized from favorable nacelle thickness/wing lift interference over and above that of the reference configuration is neglected. Conversely, for the less favorably-shaped nacelles, the analysis may be somewhat optimistic. At off design conditions, the above assumption is necessary because the required analysis is beyond the scope of the contract effort.

A comparison of the VSCE 502B (408 kg/sec, 900 lb/sec airflow) nacelle of figure 13 to that of the reference configuration nonafterburning single spool turbojet with variable geometry turbine (363 kg/sec, 800 lb/sec airflow) of reference 3 is presented on figure 14. The basepoint nacelle is 1.95 meters (6.4 feet) shorter and has a 0.14 meter (0.46 feet) smaller maximum diameter. The relative cross-sectional shape of the two nacelles is presented in figure 15. The basepoint total configuration normal cross-sectional area distribution is shown in figure 16.

Estimated total and nacelle incremental skin friction and wave drag characteristics (relative to nacelles off) for the basepoint configuration are presented in table 13. The wave drag results are for the case in which the nozzle exit planes are the same as the reference configuration. A slightly higher drag results ($\Delta C_{D_W} = 0.00006$ at mach 2.7) if the inlet planes are matched.

The friction, wave, and total drag increments of the basepoint nacelle are compared to those of the reference nacelle in figure 17. The basepoint configuration has a slightly smaller installation drag in spite of 12.5-percent greater airflow because of the more favorable nacelle shape (no boattail) as shown in figure 14. It was subsequently determined that a further reduction of 0.5 count could be realized by meridial contour optimization.

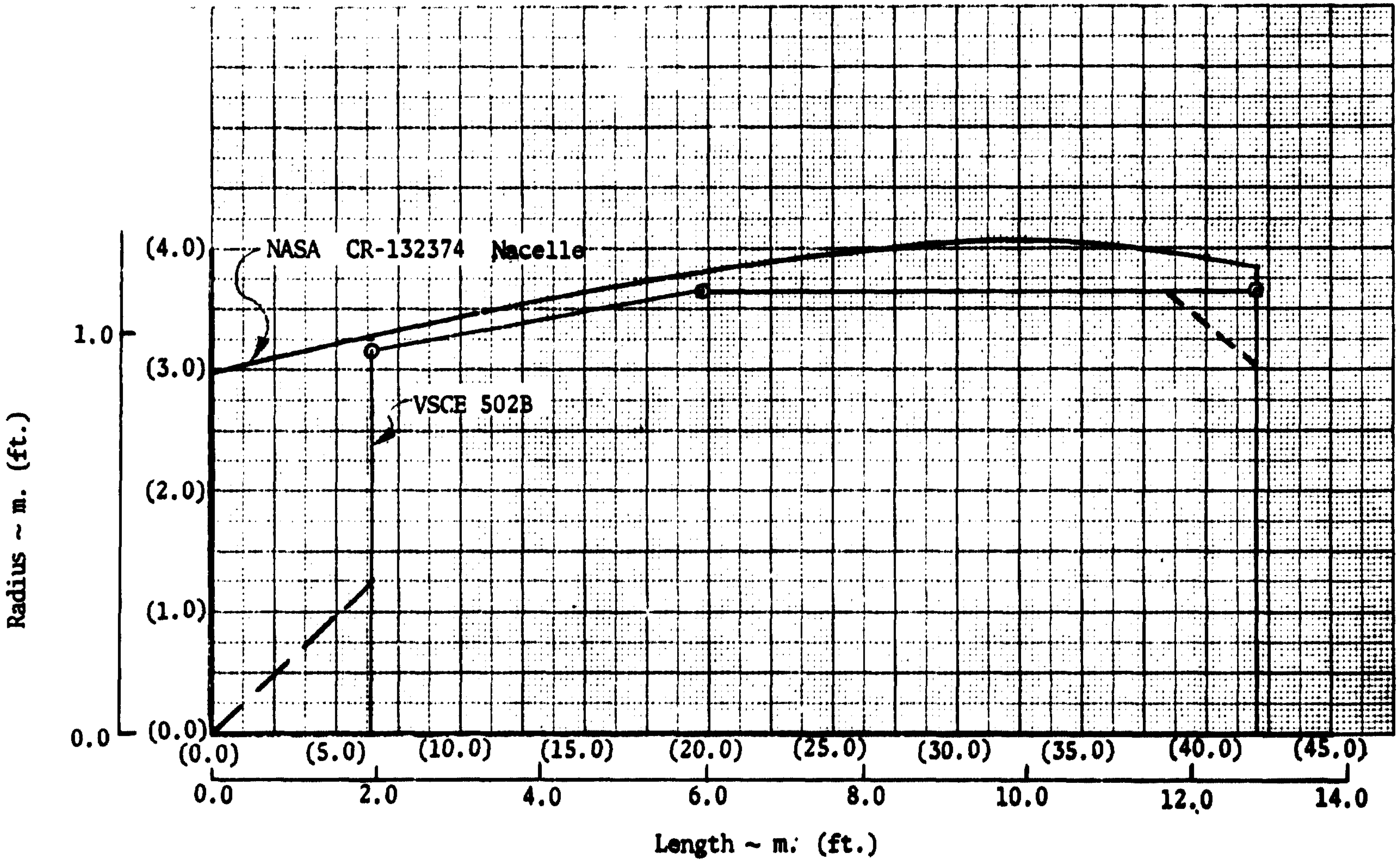
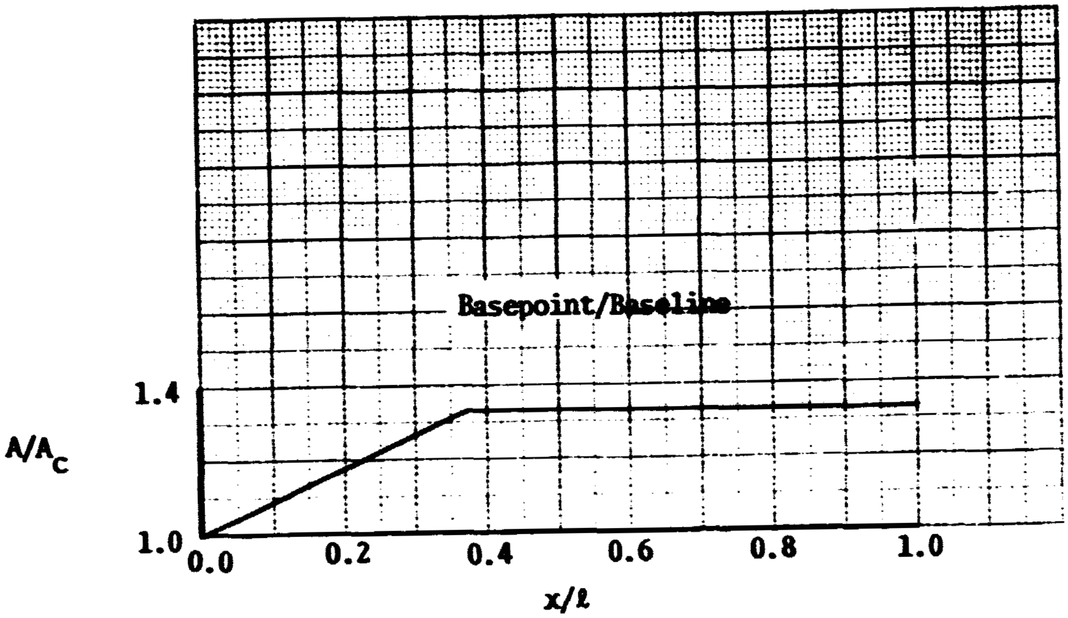


Figure 14. - Comparison of reference and basepoint nacelles.



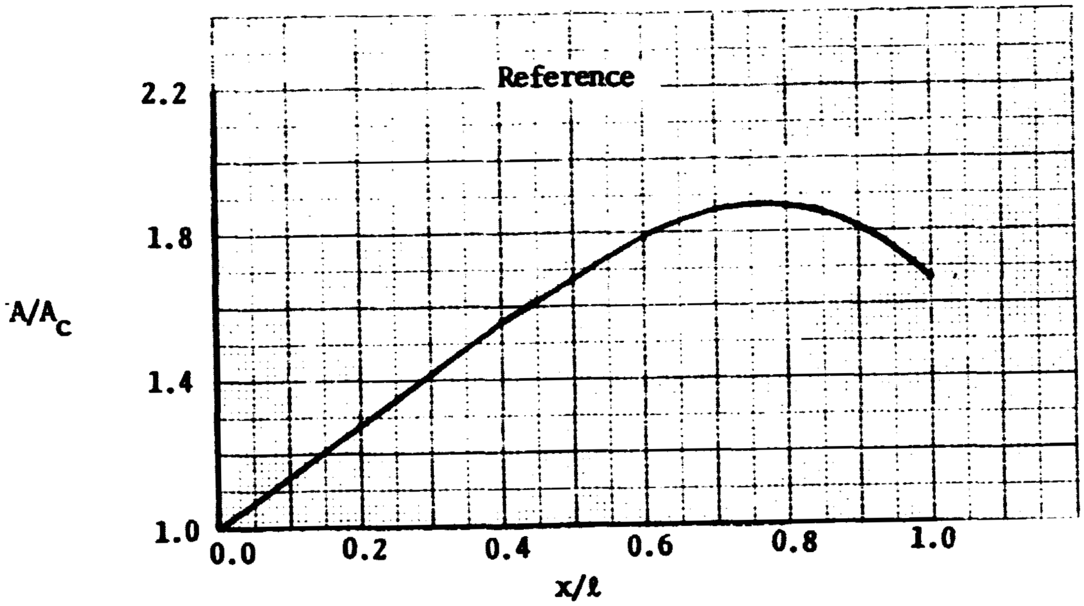


Figure 15. - Nacelle cross-sectional area variation.

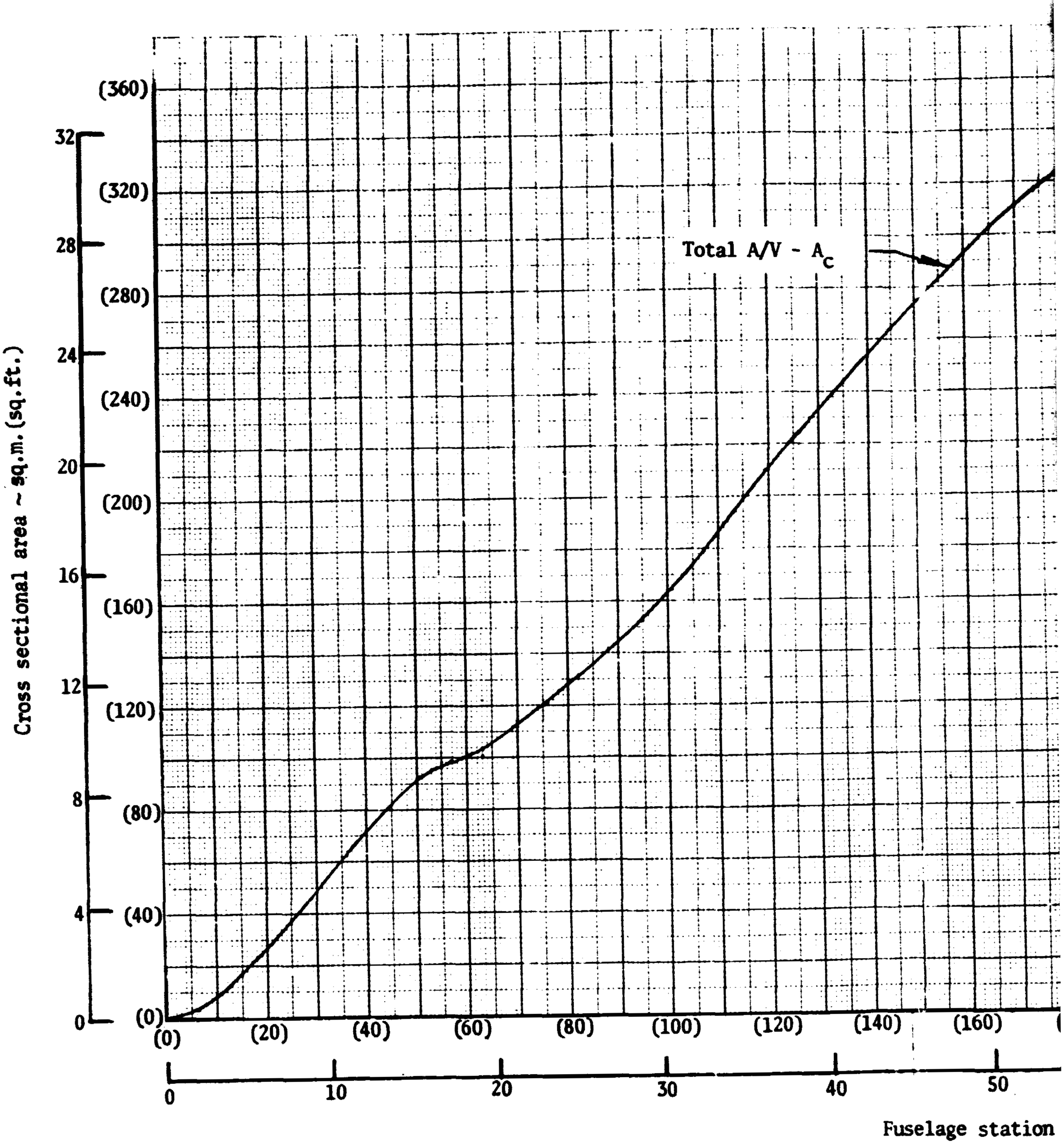


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Figure 16. - Basepoint vehicle cros

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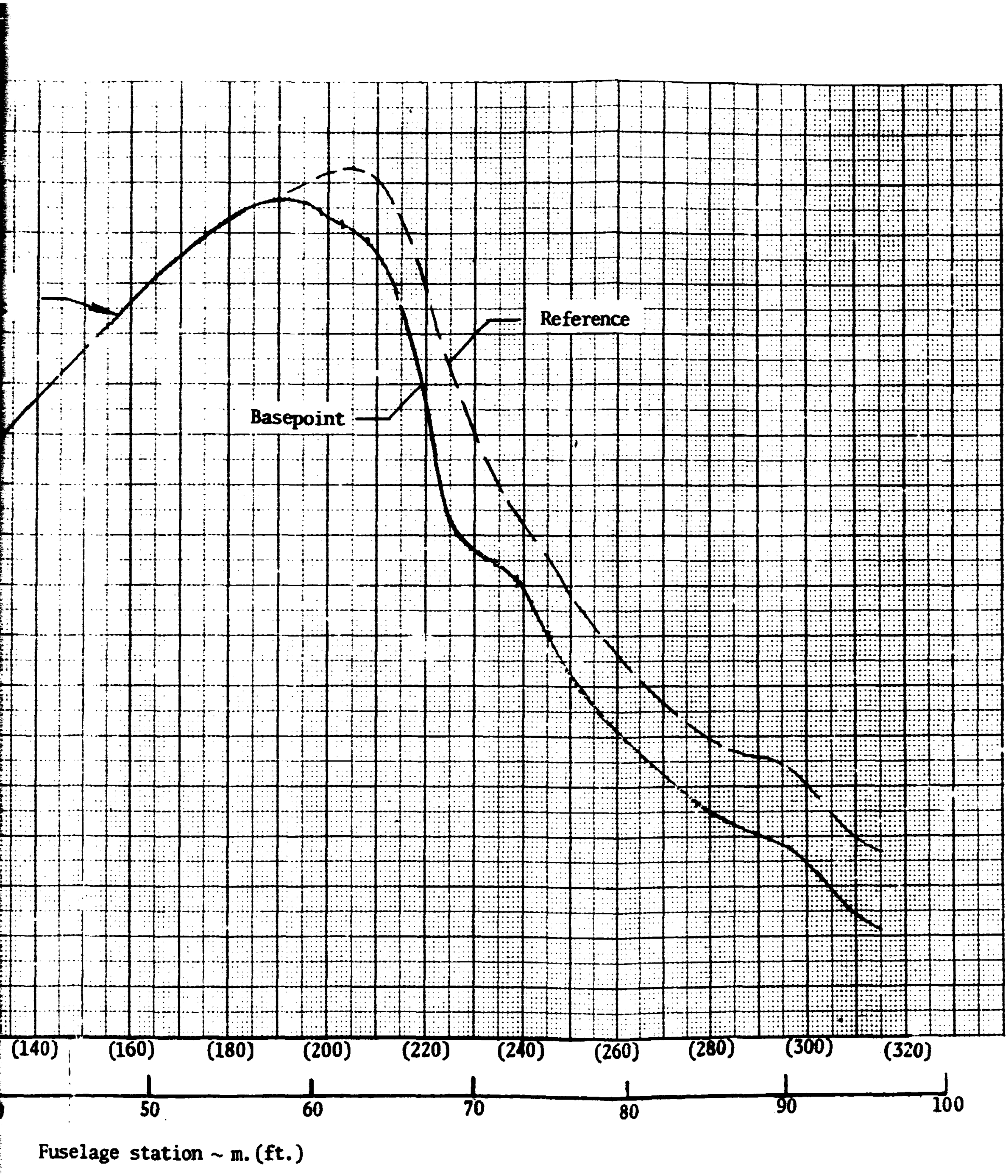

asepoint vehicle cross-sectional area variation.

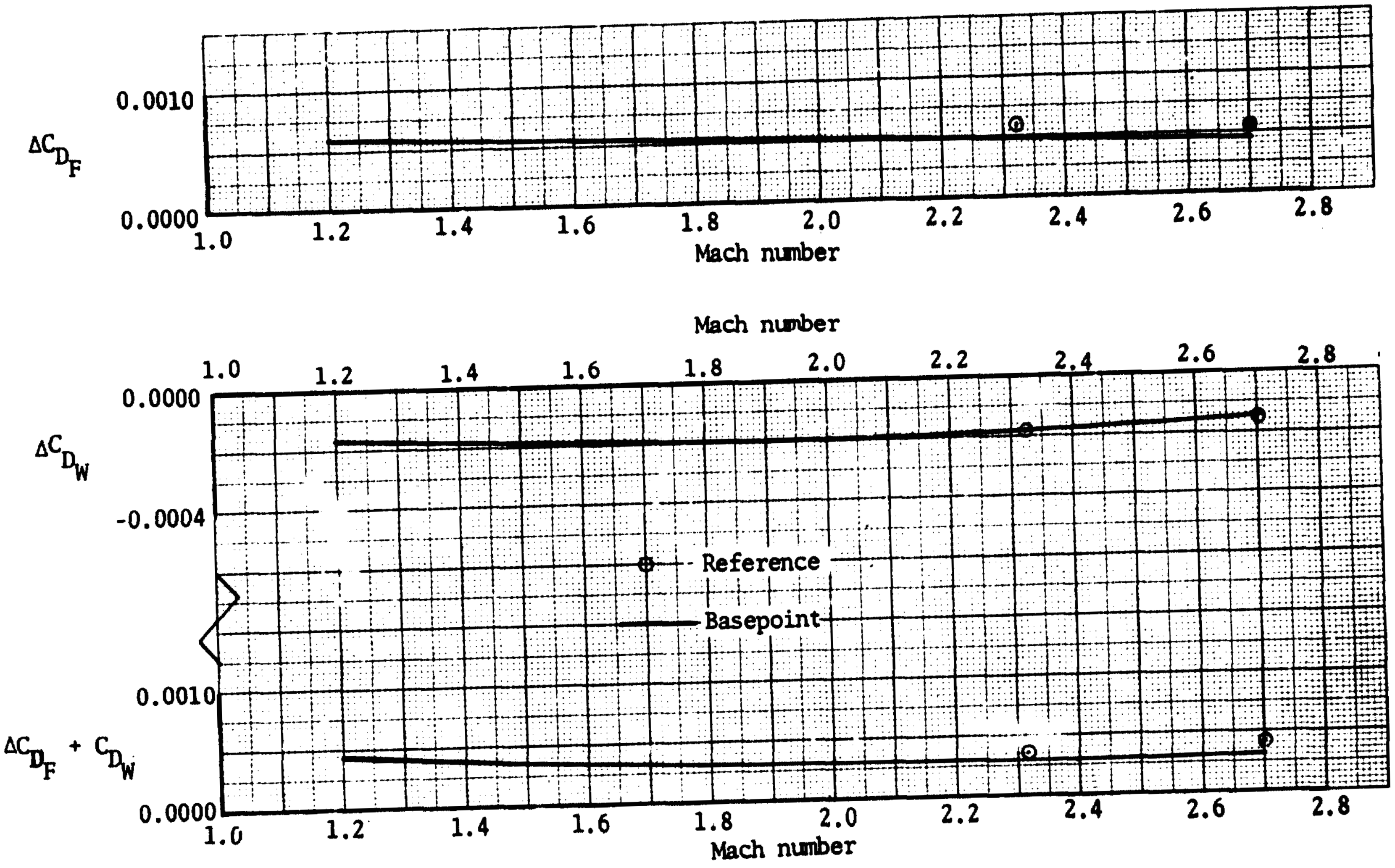

Figure 17. - Basepoint incremental nacelle drag versus Mach number

TABLE 13. - BASEPOINT CONFIGURATION ESTIMATED PROFILE AND WAVE
DRAG CHARACTERISTICS S_{REF} = 929 sq m (10 000 sq ft)

M_o	Altitude		Aircraft		Nacelle	
	m	ft	C_{D_P}	C_{D_W}	ΔC_{D_P}	ΔC_{D_W}
0.4	457	1 500	0.0061	----	0.00065	----
0.8	6 400	21 000	0.00572	----	0.00062	----
1.2	10 455	34 300	0.00545	0.00365	0.00060	-0.00017
1.4	11 521	37 800	0.00522	0.00316	0.00058	-0.00018
1.8	13 594	44 600	0.00490	0.00254	0.00055	-0.00019
2.32	16 764	55 000	0.00450	0.00222	0.00050	-0.00018
2.7	18 288	60 000	0.00418	0.00217	0.00046	-0.00014

The aerodynamic characteristics used in resizing the basepoint wing and engine size to produce the baseline configuration used for all parametric nacelle drag studies were established as follows.

Fully turbulent friction levels were adjusted for difference in surface area and length Reynolds number of the wing and nacelle. The wave drag variation of the basepoint configuration as a function of wing and engine size were parametrically evaluated for input to the sizing program. The results are presented in figure 18. The effect of engine size was essentially nil at this scale for the nacelle shape under consideration.

The trimmed drag due to lift characteristics were assumed to be independent of wing size and equal to the reference configuration. The specific levels used are presented in figures 19 through 21 and were taken directly from reference 3.

Sizing of the basepoint configuration produced the study baseline (table 5) which had a 12-percent smaller wing size and a 3.5-percent smaller engine size. The associated normal cross-sectional area distribution is presented in figure 22. A summary of the component surface areas and reference lengths is presented in table 14, and table 15 presents baseline drags.

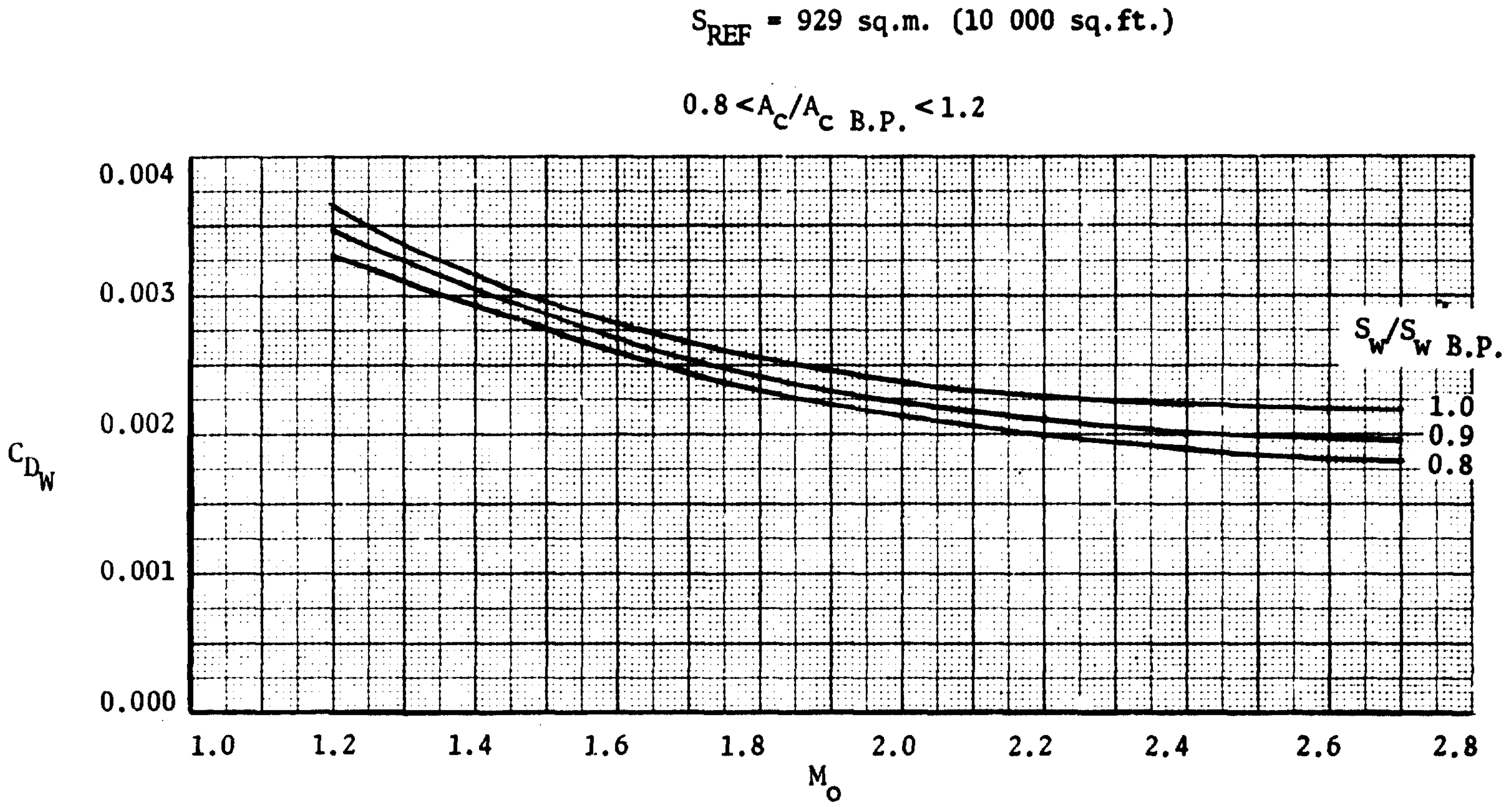

Figure 18. - Basepoint wave drag sizing data

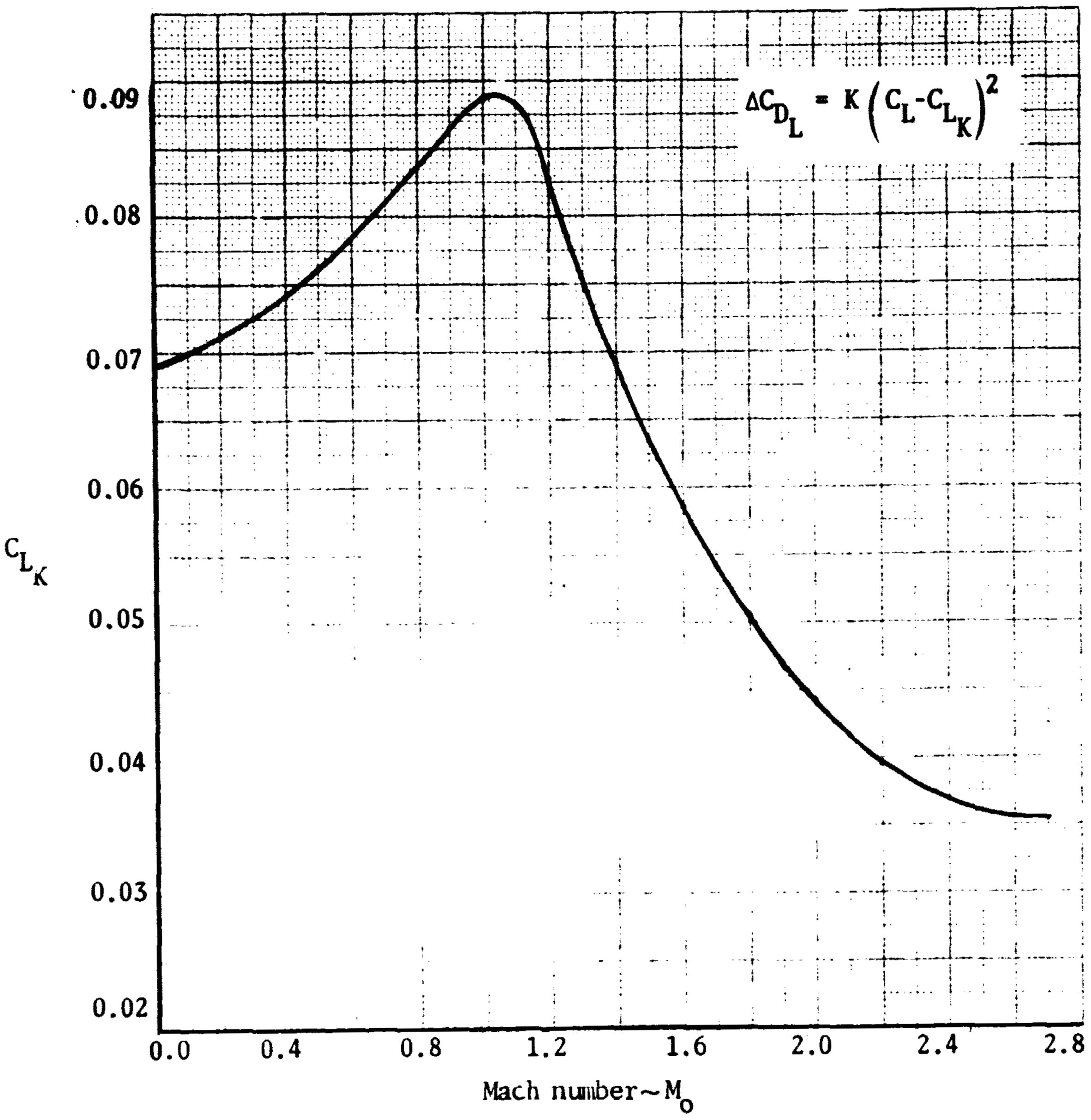

Figure 19. - C_{L_K} versus Mach number.

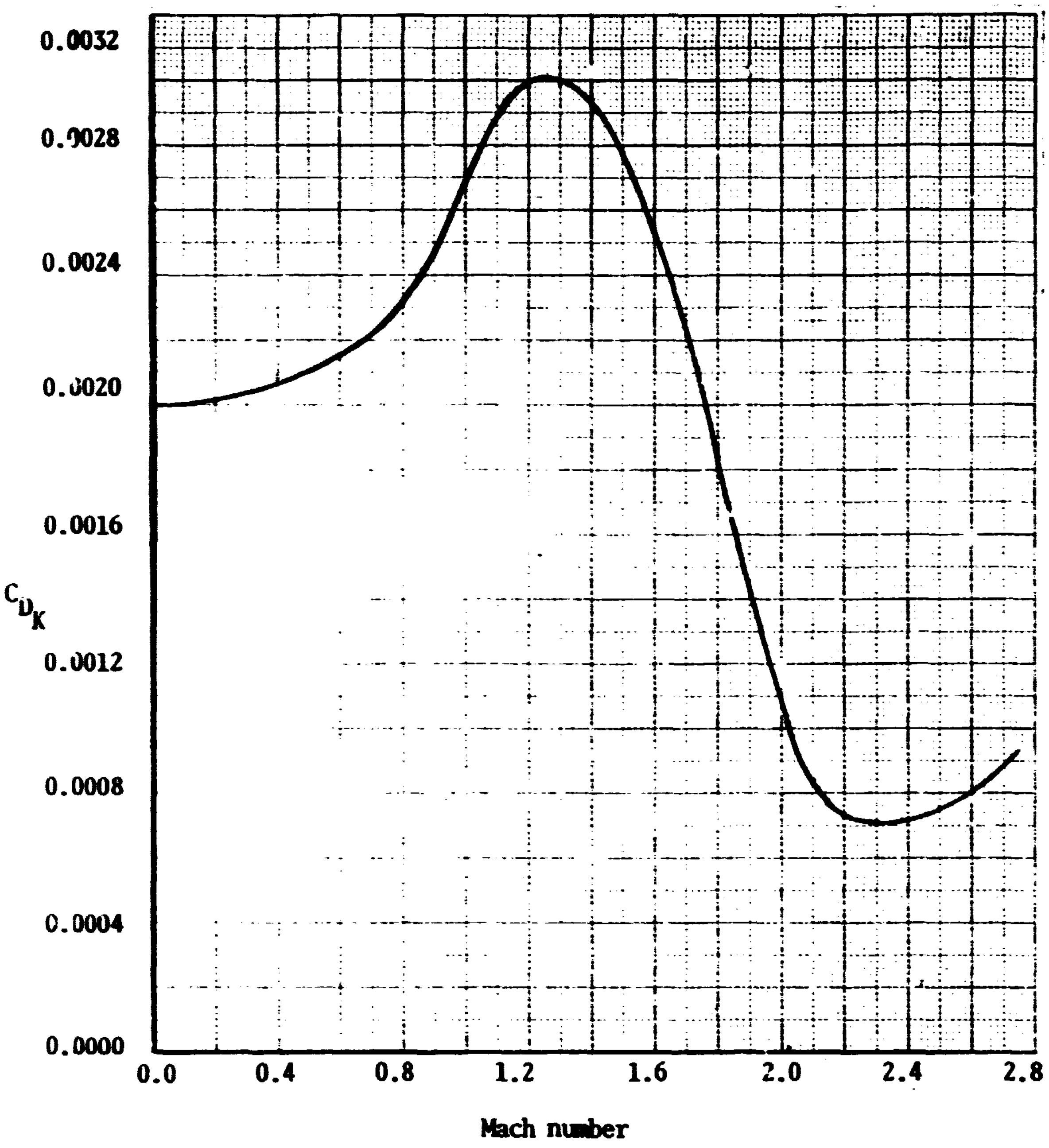

Figure 20. - C_{D_K} versus Mach number.

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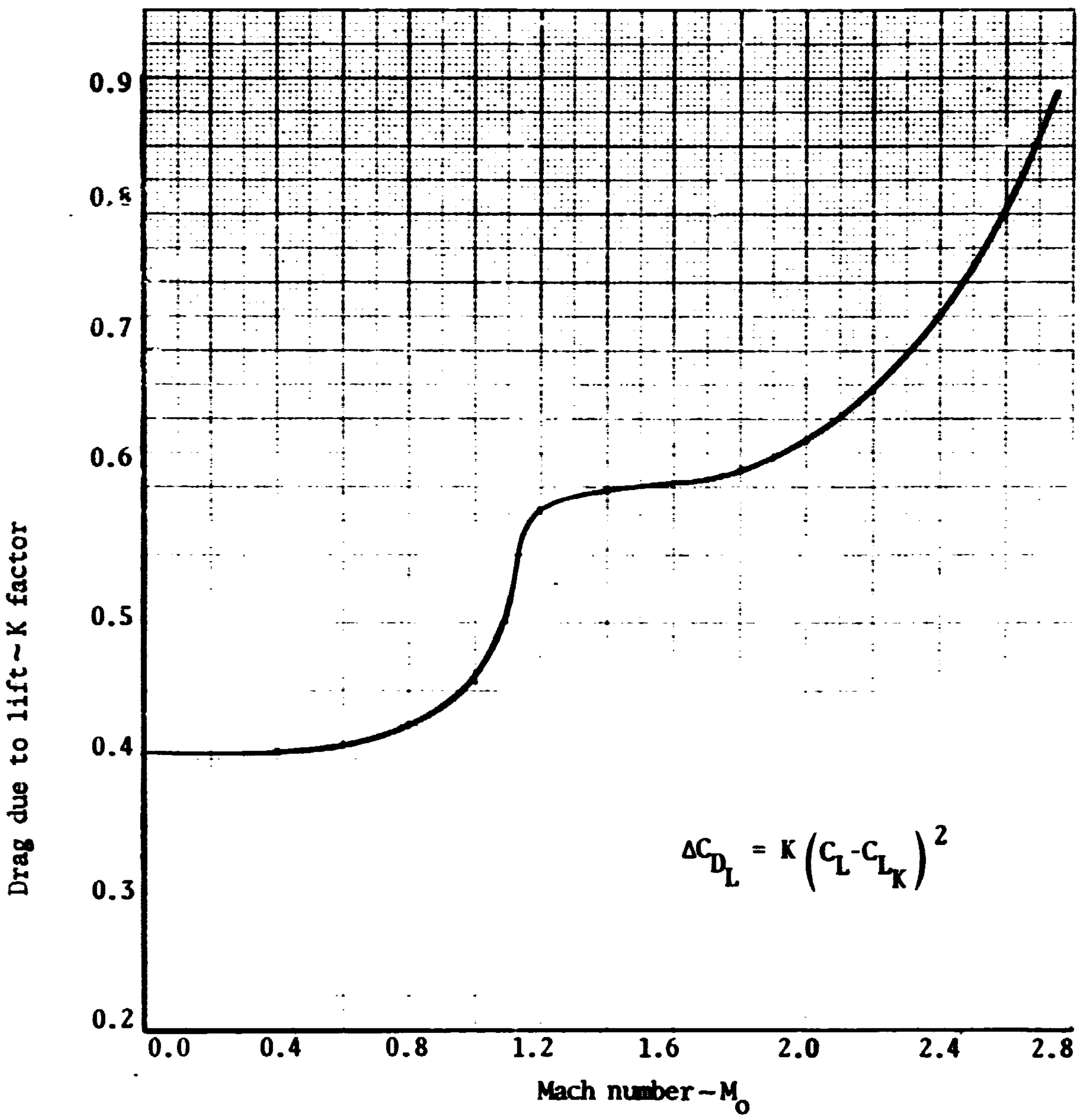
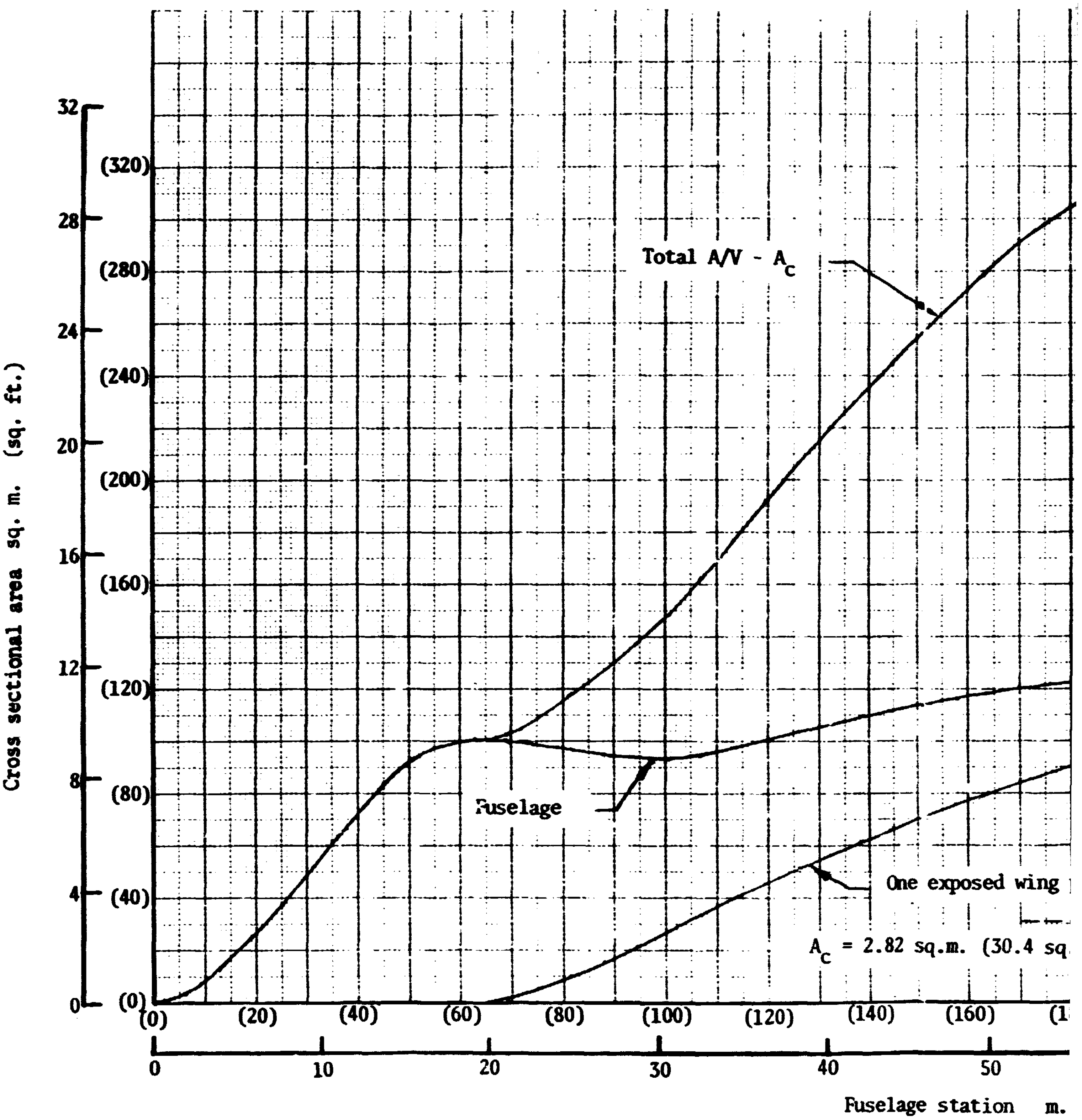


Figure 21. - 'K' factor versus Mach number.



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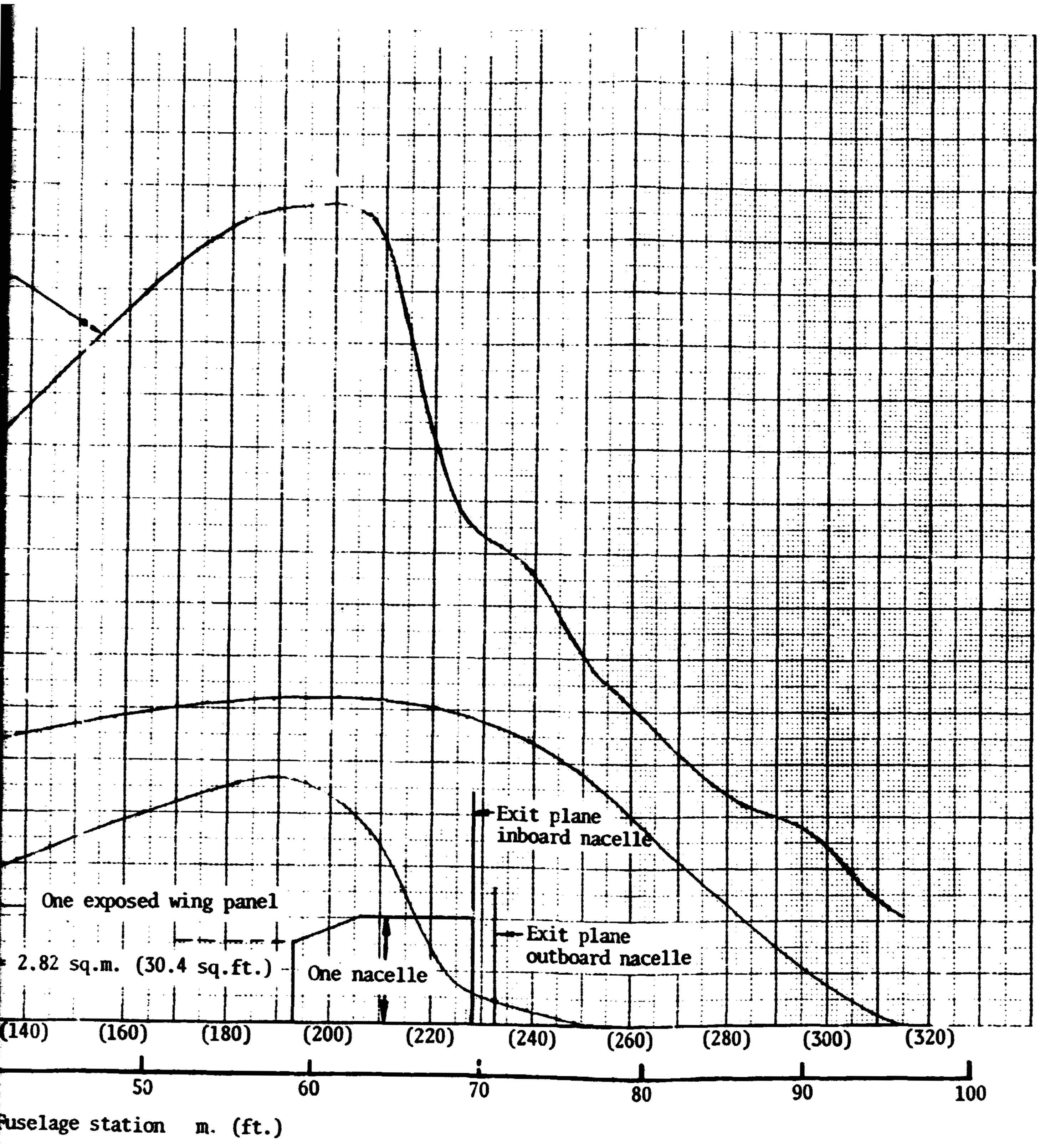


Figure 22. - Baseline vehicle cross-sectional area variation.

TABLE 14. - BASELINE CONFIGURATION SURFACE AREA AND LENGTH SUMMARY

COMPONENT	S_{wet} sq.m. (sq.ft.)	Length m. (ft.)
Fuselage	786 (8 450)	96 (315)
Wing	1 505 (16 987)	7.65-39.4 (25.1-129.)
Nacelles (4)	276. (3 088)	12.7 (35.1)
Center Line Vertical	20.1 (219)	4.9 (16.2)
Wing Verticals	91. (992)	7.9 (25.9)
Horizontal	89.5 (921)	5.8 (18.9)

TABLE 15. - BASELINE CONFIGURATION ESTIMATED SKIN FRICTION AND WAVE DRAG CHARCTERISTICS

S_{REF} = 929 sq.m. (10 000 sq. ft.)

M_o	ALTITUDE m.	(ft.)	AIRCRAFT C_{D_F}	C_{D_W}	NACELLE ΔC_{D_F}	ΔC_{D_W}
0.4	457	(1 500)	0.00568	----	0.00065	----
0.8	6 400	(21 000)	0.00537	----	0.00061	----
1.2	10 455	(34 300)	0.00508	0.00339	0.00058	-0.00009
1.4	11 521	(37 800)	0.00489	0.00305	0.00056	0.00003
1.8	13 594	(44 600)	0.00455	0.00237	0.00052	-0.00011
2.32	16 764	(55 000)	0.00420	0.00209	0.00049	-0.00012
2.7	18 288	(60 000)	0.00392	0.00200	0.00045	-0.00011

Estimation of Supersonic Drag

Parametric drag analysis.- The parametric nacelle wave drag analysis utilized the baseline configuration described in the previous section. The installation of the propulsion system followed several general ground rules in order to preserve the basic arrangement concepts and provide consistent comparisons concerning the effect of nacelle size variations. They are:

(1) Nacelle overhang of the wing trailing edge and vertical nacelle-wing separation was limited to the reference configuration values for structural reasons.

(2) The longitudinal and lateral separation distance between the inboard and outboard nacelles was preserved in order to maintain inlet flow quality.

(3) The reference configuration philosophy of locating the nacelle volume in a region of decreasing wing thickness was maintained.

(4) The maximum boattail angle considered was 10 degrees.

The outboard nacelle is moved inboard and forward as required along the midchord (approximate maximum thickness) line of the wing until its trailing edge overhang does not exceed 3 meters (10 feet). The inboard nacelle is shifted laterally by the same amount holding the longitudinal distance between the inboard and outboard nacelle inlet planes the same as the reference configuration.

The nacelle parametric variables considered in the present analysis were the ratio of nozzle area to capture area A_n/A_c, the ratio of maximum cross-sectional area to capture area A_{MAX}/A_c, the relative axial position of maximum area X_{AMAX}/ℓ, the ratio of nacelle length to capture diameter, ℓ/d_c, and the nacelle absolute capture area A_c. A summary of the number of variations and variable range analyzed is presented in table 16. For purposes of computation, the nacelles were assumed to be axisymmetric and the inlet, maximum area, and nozzle planes to be connected by straight lines.

TABLE 16. - NACELLE PARAMETER VALUES

PARAMETER	VALUES
Mach number	1.2, 2.32
A_n/A_c	1.0, 1.25, 1.5, 2.0
A_{MAX}/A_c	1.0, 1.25, 1.5, 2.0
X_{AMAX}/ℓ	0.4, 0.6, 0.8, $\leq$1.0 *
A_c	1.86, 2.79, 3.72 sq.m. (20, 30, 40 sq.ft.)
ℓ/d_c	5.5 and 7.0

* Maximum value considered corresponds to a boattail angle of ten degrees.

The parametric nacelle friction drag analysis is based on the use of fully turbulent flat plate levels in conjunction with the expression for surface areas (for four nacelles):

$$\frac{S_{WET}}{S_{ref}} = 2\frac{A_c}{S_{ref}}\frac{\ell}{d_c}\left[\frac{X_{AMAX}}{\ell} + \sqrt{\frac{A_{MAX}}{A_c}} + \left(1 - \frac{X_{AMAX}}{\ell}\right)\sqrt{\frac{A_n}{A_c}}\right]$$

$$\simeq 2\frac{A_c}{S_{ref}}\frac{\ell}{d_c}\left[1 + \sqrt{\frac{A_{MAX}}{A_c}}\right]$$

The largest deviation between the exact and approximate expression occurs for X_{AMAX}/ℓ approaching 0.4 and A_n/A_c approaching 2.0 with the former resulting in 10-percent greater area. It will be subsequently found that these differences are negligible in terms of the total installation drag for such cases. The parametric nacelle friction results are presented in reference 2.

Nacelle normalized cross-sectional area parametric extremes of the present study are presented in figure 23. Maximum-to-capture area ratio of 1 to 2 at 40, 60, and 80 percent of the nacelle length are shown for nozzle-to-capture area rations of 1 and 2. Wave drag results are discussed in detail in reference 2.

Briefly, the incremental nacelle wave drag is a strong function of the ratio of maximum-to-capture cross-sectional area, A_{MAX}/A_c, boattail area, and to a somewhat lesser extent relative axial position of maximum cross-sectional area, X_{AMAX}/ℓ. Nacelle shapes with negative wave drag exist because of favorable total system thickness interferences associated with the location of growing nacelle cross-sectional area in a region of decreasing wing thickness. The nacelle geometric variable behavior and sensitivity are unchanged by mach number, nacelle capture area, or nacelle fineness ratio. The incremental wave drag results are, in general, weak functions of the latter two variables for efficient installations.

Detailed nacelle wave drag variations with freestream mach number were defined for a range of levels covering high-positive, zero, and negative installation increments. These characteristics correspond to nacelles with large maximum cross-sectional area relative to the capture and nozzle area cylindrical, and near-truncated conical shapes, respectively. Figure 24 illus-

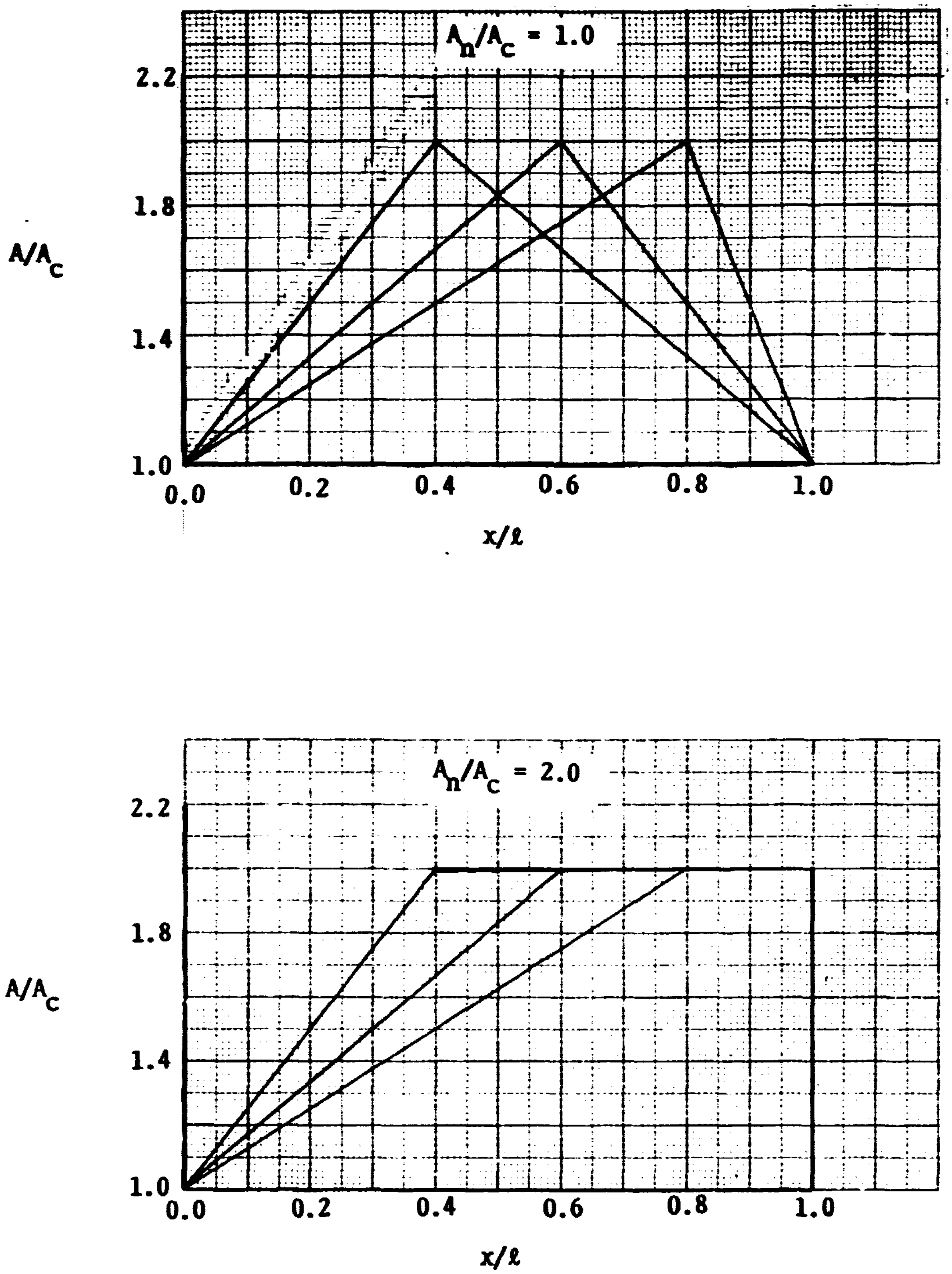


Figure 23. - Nacelle parametric cross-sectional area extremes.

trates the mach number difference for these extremes for the fineness ratio 5.5, medium-size nacelle. Examination of the results indicate that weak to moderate mach number variations are associated with small nacelle installation drags. Conversely, strong compressibility variations are exhibited for inefficient installations. The large benefit at transonic speeds is somewhat illusory as the thrust must be progressively penalized for nozzle contraction with decreasing mach numbers.

Drag table look-up computer program.- A table look-up computer program was developed (appendix) which yields the incremental wave and friction drags of nacelles as functions of nacelle geometry variables and airplane mach number. The drag increments are for the total vehicle relative to the vehicle with nacelles removed. The nacelle shape parameters used as inputs to the program are:

(1) A_c Inlet capture area

(2) A_{MAX} Nacelle maximum cross-sectional area

(3) A_n Nozzle exit area (supersonic cruise position)

(4) X_{MAX} Distance from inlet cowl leading edge to maximum cross-sectional area

(5) ℓ Nacelle total length

(6) S_{REF} Reference wing area

The output of this program includes for the nacelle of interest:

(1) The aforementioned input data

(2) Drag coefficients at mach 1.2, mach 2.32, and the input mach number for friction (CTF), wave (CDW), and total (CDO) drags

(3) The nondimensional parameters of position of maximum cross-sectional area (X_{AMAX}/ℓ), nozzle-to-capture area ration (An/Ac), maximum-to-capture area ration (A_{MAX}/A_c), and fineness ration (ℓ/d_c)

In addition, incremental drag coefficients of the reference airplane nacelle (reference 3) are printed. A sample output is shown in table 2. It has been found that the table look-up results correlate best with more detailed analyses when the maximum cross-sectional area and its position are based on the area that occurs at the intersection of straight lines originating from the inlet

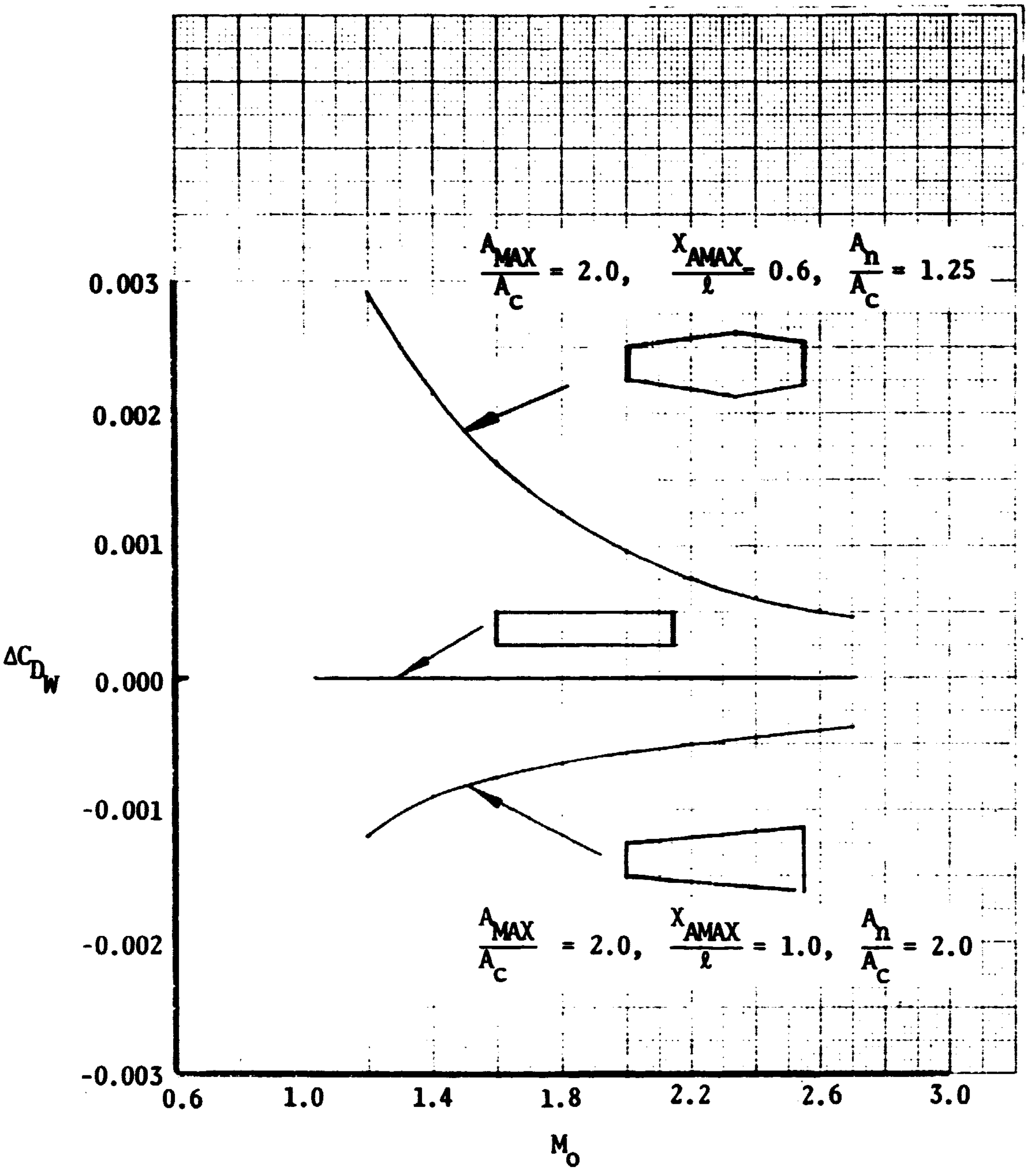


Figure 24. - Typical nacelle incremental wave drag variations with Mach number

$A_c = 2.79$ sq m (30 sq ft) $\ell/d_c = 5.5$.

which is tangent to the maximum slope of the forebody and from the nozzle which goes through the actual maximum area and whose slopes nearly match the slopes of the actual nacelle, as illustrated in figure 25. This method most closely approximates the parametric nacelle shape drag analysis because, in that study, nacelle shapes were defined by two straight-line segments. Using this method will result in nacelle drag increments at supersonic cruise within 0.5 drag count of the drag resulting from a detailed analysis.

Nacelle shape estimation.- Nacelle external shapes are determined by such installation items as engine accessories, compartment cooling, shrouds and insulation, aircraft accessories, engine clearance, engine mount geometry, nacelle structure, boundary layer gutters, etc. The engine configurations supplied by the engine manufacturers usually include only the engine case outline and nozzle dimensions. A method has been established to determine the engine external envelope and aircraft structure and equipment space allowances. Guidelines are presented for determining the engine buildup envelope, engine cowl, nozzle fairing, and inlet and inlet cowl shapes. Those installation items which have the largest effect on nacelle shape are then discussed. An example of the nacelle shape buildup is presented in figure 1.

Engine buildup envelope: The procedure to establish the engine buildup envelope is:

(1) Establish fan and gas generator case outline.

(2) Add 5 cm (2 in.) constant to all surfaces of the preceding outline to provide for wiring, plumbing, etc.

(3) Add 2.5 cm (1 in.) constant additional to outline for variable compressor geometry mechanisms where applicable.

(4) Establish mechanical power extraction drive station and radial location for engine accessories drive and for aircraft accessories power takeoff. Depending on engine configuration and accessory design, accessories may be on the engine or in the pylon or wing. For engine accessories where encapsulation is required for cooling, provide 0.595 cu m (21 cu ft) of volume proximate to engine accessories drive of item (4). Dimensions of the capsule may be varied for best packaging, but the capsule thickness at the gearbox should be 0.305 m (12 in.) minimum. For nonencapsulated engine accessories, provide 0.51 cu m (18 cu ft) of volume proximate to engine accessories drive of item (4). Arrangement of the accessories package may vary, but the minimum thickness at the gearbox must be 25 cm (10 in.). The dimensions of items (2) and (3) and (4) are additive and will usually establish the maximum radial dimensions of the gas generator section of the engine. All other engine and aircraft equipment in this portion of the nacelle should be contained within the volume of

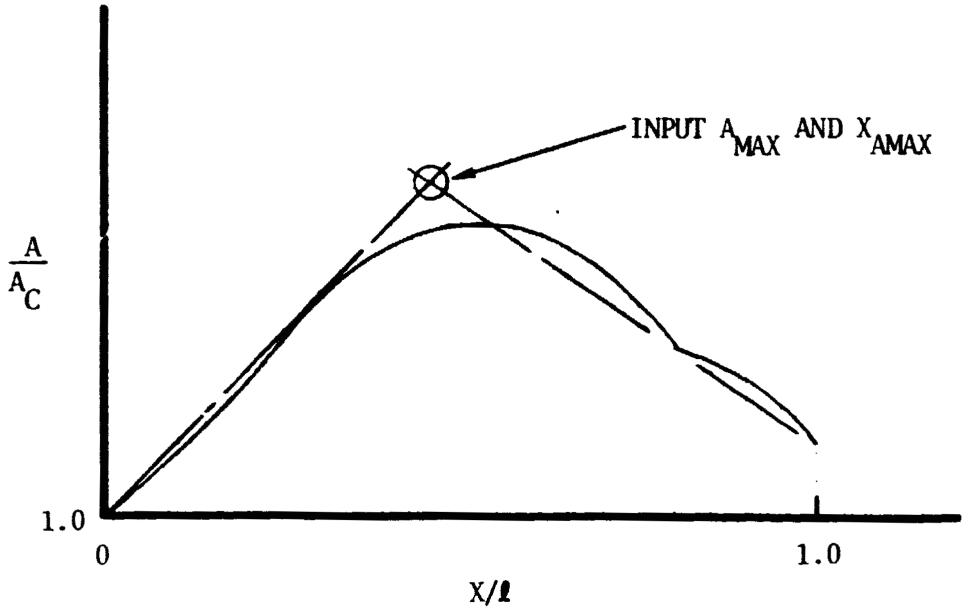


Figure 25. - Simulation of nacelle shape.

revolution established by this line of radii. For minimum aircraft drag, locate aircraft accessories within pylon or adjacent wing. The engine power takeoff pad and angle drive gearbox will be within the pylon and this will not impact the nacelle mold line.

(5) For engine fluid reservoirs, add 0.0566 cu m (2 cu ft) on left or right side of engine. The radial dimension is 15.2 cm (6 in.) additive to dimension of item (2) or (3).

(6) Equally space four compressor high-pressure bleed ports around compressor rear frame. The 12.7 cm (5 in.) diameter collector manifold (with flexible sections) will interconnect the ports and connect to the airframe duct in the pylon. The collector manifold diameter is additive to the allowance of item (2). Low-pressure bleed ports may be provided in place of or in addition to the preceding. The same space allowance must be made for these. One or more engine and inlet anti-icing air ducts will be routed from the bleed manifold forward to the engine front frame. These ducts will be 10.2 cm (4 in.) diameter and will be additive to the allowance of items (2) or (3).

(7) Determine location of engine mounting stations by engine internal structure. The nacelle/wing relationship should be considered in the placement of the engine load-carrying frames and the mounting provisions on the frames for best weight effectiveness of the total system.

(8) Main mounts - transfer thrust, side, and vertical loads: Provide 15.2 x 15.2 x 12.7 cm (6 x 6 x 5 in.) radial space additive to items (2) or (3) at two positions on engine main mount frame, circumferentially spaced greater than or equal to 90 degrees.

(9) Stabilizer mount - transfers vertical loads: Provide 10.2 x 10.2 x 20.3 cm (4 x 4 x 8 in.) radial space, additive to items (2) and (3).

(10) Locate local protrusions of miscellaneous engine equipment beyond envelope of items (2) and (3) to occur at random locations. These will be relatively small and will not exceed the maximum envelope noted in item (4).

Engine Cowl: The engine cowl shape may be determined by the following:

(1) The cowl inner skin mold line must maintain a minimum 2.5 cm (1 in.) clearance from all points on the engine buildup envelope developed in the preceding discussion.

(2) Cowl structural requirements will vary depending on the arrangement and location of engine mount points. Where mount points are in the proximity of the pylon structure, the cowl can be made nonstructural; i.e., sufficient to withstand internal and external airloads and flight dynamic forces. This will require 5 cm (2 in.) of structure (constant) from the engine front face station to the cowl-to-nozzle fairing interface. Where mount points are widely separated from the pylon structure a structural cowl must be provided to transfer the engine loads. Cowl thickness in the load paths will be 7 to 10 cm (3 to 4 in.). In these areas the structure can intrude into unoccupied space in the volume of revolution developed in the preceding items (4) and (5), but 2.5 cm (1 in.) clearance must be maintained from adjacent engine buildup equipment. Areas of the cowl outside the load paths can be 5 cm (2 in.) thickness.

Nozzle fairing: The nozzle fairing must fair smoothly into the engine cowl mold line developed in the preceding and fair smoothly to the base diameter dictated by the nozzle. The nozzle fairing leading edge step height from the engine case will vary depending upon the engine services (hydraulics, pneumatics, fuel, secondary airflow, etc) required to pass through it. This step height may require adjustments to the cowl outer mole line as it approaches the nozzle fairing interface.

Inlet and inlet cowl: Inlet and cowl shape can be determined by the following method:

(1) Establish inlet length and capture area based on appropriate nacelle design methodology and external constraints.

(2) Establish inlet flow path area geometry.

(3) Define inlet cowl external lines. Fair from inlet lip to engine cowl. The faired mold line should provide minimum rate of cross-sectional area increase.

(4) Establish requirement for the following airflow paths appropriate to inlet geometry and engine cycle used:

(a) Auxiliary air inlet

(b) Bypass air

(c) Engine secondary air

(d) Boundary layer bleed

(i) Centerbody or ramps

(ii) Cowl inner wall

(5) Determine cowl wall thickness by requirements of structural integrity plus space required for flow paths and door mechanisms associated with requirements established in item (4). A minimum thickness of 15.2 cm (6 in.) is suggested for the cowl wall from the inlet throat aft to the engine front face. This may be varied locally, but internal lines should be maintained. Thickness of the cowl structure will vary from approximately 0.16 cm (1/16 in.) at the inlet lip to the throat thickness established in the preceding.

Major nacelle shape elements: Three major elements establish the engine external envelope:

(1) The allowance over the total surface of the gas generator of space for engine variable geometry mechanism, plumbing, wiring, etc.

(2) The space required for the engine accessory gearbox and associated accessories. This package establishes the location and magnitude of the nacelle maximum cross-sectional area.

(3) The location of the main engine mounts on the engine as defined by the engine manufacturer. Where the main mounts are placed at the compressor front or midframe, sufficient structure is available in the adjacent nacelle, pylon, and wing to carry the multidirectional loads, and a simple, nonstructural cowl may be used. Where the main mounts are placed at the turbine frame, it is necessary to consider the cowl as a structural cylinder with penalties to the nacelle size and weight.

All other elements of the engine installation fall within the envelope defined by the preceding.

Estimation of Nacelle/Inlet Weight

Weight estimation of nacelle and inlet systems is a complex process and requires design detail not normally performed in the type of preliminary studies being considered here. The estimating procedure described in this section uses a simplified approach producing a first-order-type weight estimate keyed to gross definitions of the nacelle/inlet package. The procedure defined will provide the capability of maintaining consistency between nacelle weight estimates while making comparative analyses.

Two dimensional inlets.- To estimate the weights of engine nacelles with two-dimensional (2-D) inlets, the nacelle package is divided into the following components:

(1) Engine cowl

(2) Inlet cowl

(3) Ramps

(4) Air induction special features

  (a) Bypass system

  (b) Auxiliary inlet

  (c) Secondary air provisions

  (d) Inlet controls

(5) Engine mounts

The methods used to estimate the weights of the nacelle components are primarily based on a prior Rockwell inlet study for the Boeing SST. This study was conducted for Boeing and consisted of designing a 2-D inlet as a contender to be compared to Boeing's axisymmetric inlet design in the inlet selection for the SST. Unit weights used to estimate weights of the nacelle components were derived from data developed for this study.

Engine cowl: The engine cowl is defined as the total nacelle structure aft of the engine front face, including all structure that supports and surrounds the engine. The engine cowl weight is estimated at 34.2 kg/sq m (7.0 lb/sq ft) of nacelle external wetted area.

Inlet cowl: The inlet cowl is defined as the total nacelle/inlet structure forward of the engine front face, exclusive of the variable-geometry ramps and special air induction features. The inlet cowl weight is estimated at 24.4 kg/sq m (5.0 lb/sq ft) of wetted area.

Ramps: The ramps are defined to be the movable panels, including an actuation system, used to vary the inlet geometry in a 2-D variable-geometry inlet. Weight of the variable-geometry ramps is estimated at 48.8 kg/sq m (10.0 lb/sq ft) of movable ramp planform area.

Air induction special features: The bypass system consists of inlet air bypass doors, including actuation provisions. The system weight is estimated at 39.1 kg/sq m (8.0 lb/sq ft) of door area.

The auxiliary inlet is defined as the auxiliary air inlet doors and inlet actuation system. The weight of this system is estimated at 29.3 kg/sq m (6.0 lb/sq ft) of door area.

The secondary air provisions provide inlet air to the engine compartment for engine compartment cooling. The weights of these provisions are estimated with the following equation:

$$WT = 22.7\left(\frac{W_a}{287}\right)^{1/2} \text{ kg} \quad \text{or} \quad WT = 50\left(\frac{W_a}{633}\right)^{1/2} \text{ lb}$$

where W_a is engine design airflow, kg/sec (lb/sec).

The inlet controls are defined as the system provided to monitor the inlet conditions and transmit position signals to the movable inlet systems. The weight of this system is estimated at 22.7 kg (50.0 lb) per inlet.

Engine mounts: The engine mounts are the fittings used to support the engine in the nacelle. The weights of these fittings are estimated at 1.5 percent of the engine weight.

Axisymmetric inlets.- To estimate the weights of engine nacelles with axisymmetric inlets, the nacelle package is divided into the following components; this breakdown is similar to the one described for a 2-D inlet:

(1) Engine cowl

(2) Inlet cowl

(3) Spike

(4) Engine mounts

The procedures for weight estimation of the engine cowl and mounts are the same as those described for the 2-D inlet/nacelle. The methodologies to estimate the weights of the inlet cowl and spike were obtained from the Air Force Technical Report SEG-TR-67-1, Preliminary Design Methodology for Air Induction Systems.

Inlet Cowl: The inlet cowl is defined as the total nacelle/inlet structure forward of the engine front face, exclusive of the inlet spike and its systems. The inlet cowl weight is determined by the following statistical equation.

$$WT = 0.159\ (N)\ [(A_c)^{0.5}\ L\ (P_2)]^{0.731}\ \text{kg} \quad \text{or}$$

$$7.435\ (N)\ [(A_c)^{0.5}\ L\ (P_2)]^{0.731}\ \text{lb}$$

where:

N = number of inlets

A_c = capture area per inlet - sq m (sq ft)

L = subsonic duct length per inlet - m (ft)

P_2 = maximum steady-state static pressure at engine face at supersonic cruise mach - kg/sq m (psia)

Spike: The spike is defined to be the center body structure, including its systems and actuation. Weight of the spike is estimated with the following statistical equation;

$$WT = K\ (N)\ A_c$$

where:

K = 252.9 kg/sq m (51.8 lb/sq ft)

N = number of inlets

A_c = capture area per inlet = sq m (sq ft)

Estimation of Airplane Takeoff Gross Weight

Weight sensitivity analysis. - In considering possible trades of reduced drag through design changes in the engine envelope for some penalty in engine weight and performance, it is necessary to have visibility of the net impact of all these effects on the total airplane system. To evaluate these effects, the sensitivities of the airplane takeoff gross weight to variations of propulsion system parameters were determined. These sensitivity data were obtained by conducting design trades on the baseline airplane for variations of the following items:

(1) Incremental nacelle drag

(2) Propulsion system weight

(3) Engine specific fuel consumption

(4) Engine sizing condition thrust

In each case, the parameter of interest was varied independently and the airplane resized to the design mission range of 7408 km (4000 n mi) while maintaining thrust-to-weight and wingloading values equal to those for the baseline vehicle.

Incremental nacelle drag: Several variations of nacelle drag were investigated. These were chosen as representative of the combined wave and friction drag variations as found in the nacelle shape analysis to allow use of the trade data for any nacelle geometry analyzed in this program.

The results of this trade are shown in figure 26, which shows relative takeoff gross weight (TOGW) versus nacelle drag at mach 2.32 for several variations of the drag increment at mach 1.2.

Propulsion system weight trades: Airplane TOGW was calculated for several propulsion system weight increments. Incremental propulsion weight, in this case, is defined as a percent of the sum of the engine, nacelle, and miscellaneous propulsion systems (198 kg, (445 lb) per nacelle) weights. The results of this trade are shown in figure 27, which plots relative TOGW versus propulsion weight increment.

Engine specific fuel consumption trades: Four separate trades were performed with SFC increments applied independently to the following mission segments:

(1) Maximum power climb legs only

(2) Supersonic cruise legs only

(3) Subsonic cruise and loiter legs only

(4) The entire mission

The results of this trade are presented in figure 27 as relative TOGW versus percent change in SFC.

T/W	3.16 n/kg	(0.323 lb/lb)
W/S	354. kg/sq m	(72.5 lb/sq ft)
Range	7408 km	(4000 nmi)

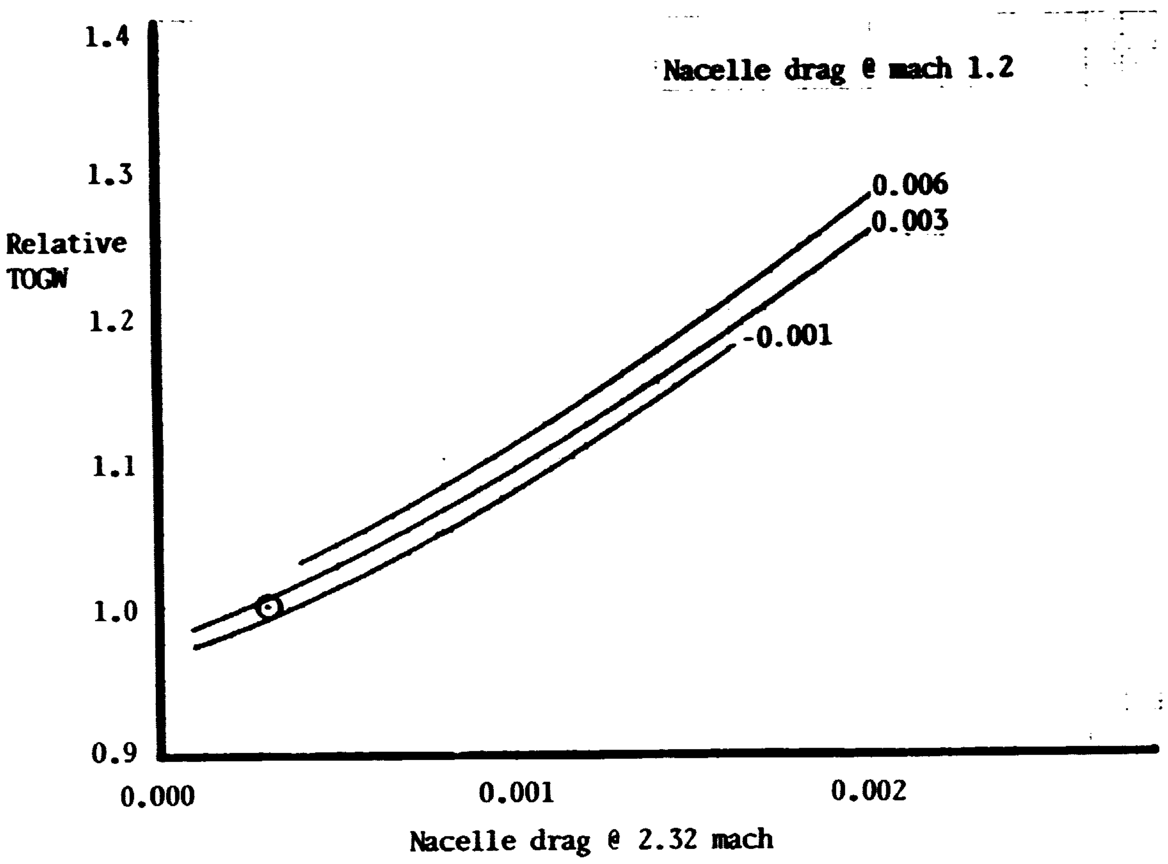
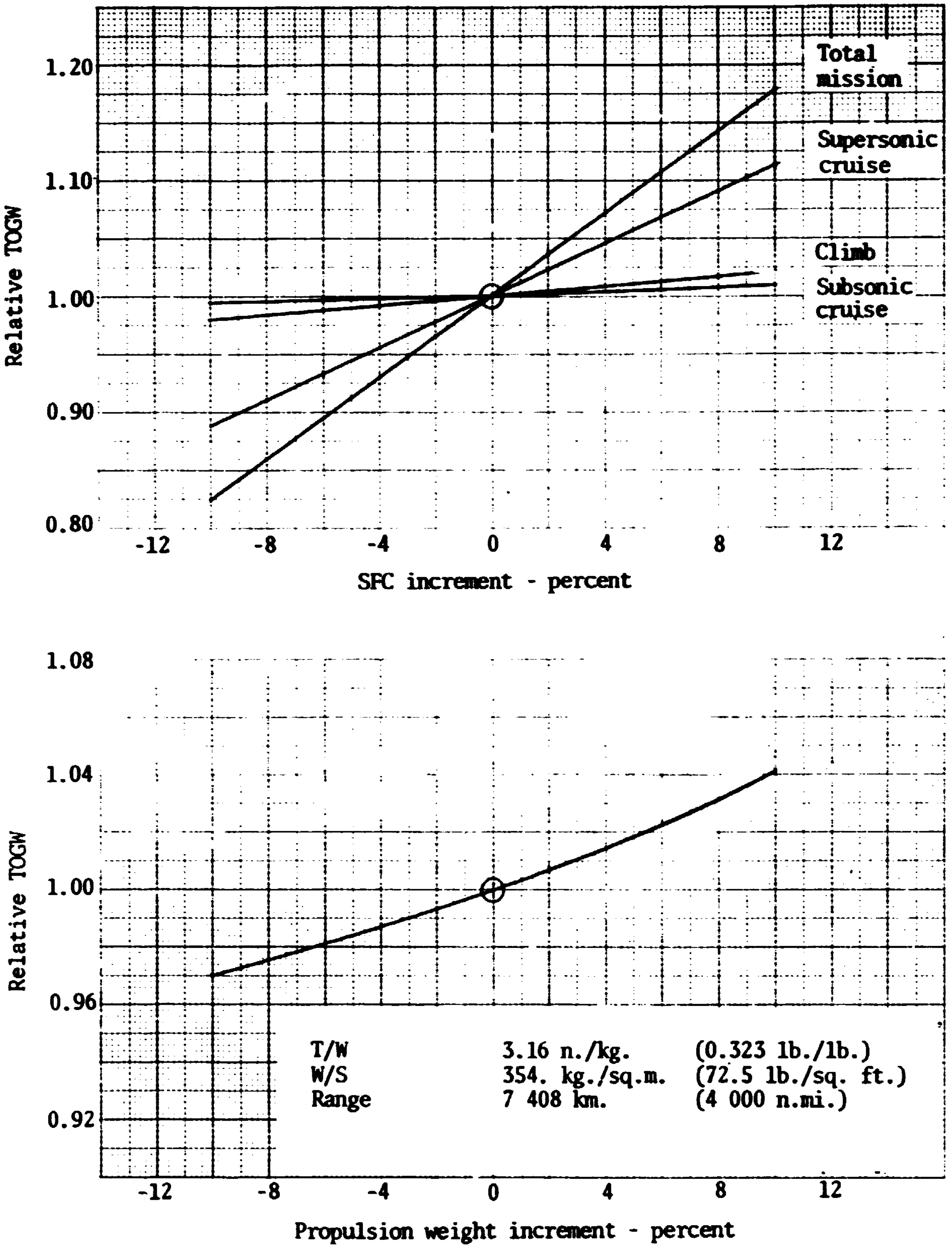


Figure 26. - Nacelle drag sensitivity trade.



T/W	3.16 n./kg.	(0.323 lb./lb.)
W/S	354. kg./sq.m.	(72.5 lb./sq. ft.)
Range	7 408 km.	(4 000 n.mi.)

Figure 27. - Propulsion weight and SFC sensitivity trades.

Engine sizing thrust: Figure 28 presents relative TOGW versus percent change in thrust at the engine sizing condition. In this trade, it is assumed that the thrust available at the engine sizing condition varies without change in propulsion characteristics at other flight conditions. In the current study, all engines were sized at takeoff.

Application of sensitivities. - To demonstrate the method of applying the vehicle sensitivities, an example using the VCE 112C engine is in the following paragraphs. The VCE 112C is discussed in detail later under "Validation of the Approximate Method." Additional examples are also given therein. The baseline airplane characteristics and sensitivities were originally computed using a friction drag that was approximately one count too high and an ambient temperature increment that was incorrect. Thus the baseline airplane should have been somewhat lighter. The baseline airplane was recomputed and resulted in a takeoff gross weight of 316 783 kg (698 375 lb), a propulsion system weight (four nacelles) of 30 882 kg (68 081 lb), and drag coefficients of 0.0040 and 0.0030 at mach 1.2 and 2.32, respectively. Figure 26 has been revised relative to that shown in reference 2 for this reason.

A nacelle drawing (figure 29) was made with engine accessories located on the engine without encapsulation for cooling. Weight for the nacelle was estimated to be 8750 kg (19 298 lb), which includes 198 kg (445 lb) for miscellaneous propulsion systems. The revised baseline nacelle weighed 7880 kg (17 020 lb). Thus, the VCE 112C nacelle is 12 percent heavier than the baseline. From figure 27, the relative TOGW ratio, R_{WT}, for this change is 1.059.

In order to maintain the takeoff distance, a new engine must have the same effective thrust-to-weight ratio between 0.0 and 0.3 mach (approximate liftoff speed) as the baseline. The effective thrust occurs at approximately mach 0.25. Because the VCE 112C has a significantly different thrust lapse rate with mach number than the baseline (as shown in figure 30) the effective thrust is 17 percent lower than the baseline. Extrapolating figure 28 to a thrust increment of 17 percent yields a relative TOGW ratio due to takeoff thrust, R_{FNE}, of 1.10.

Figures 31 and 32 show installed performance of the 100-percent size VCE 112C and VSCE 502B propulsion systems. Because the Breguet range factor, M x L/ D/ SFC, maximizes near minimum SFC, the airplane will tend to fly at or near minimum SFC; cruise altitude will be adjusted to achieve this. Therefore, the SFC increment may be taken at the minimum of each engine. This assumption is slightly optimistic because the lift-drag ratio will also change and will affect the operating point. Thus, the VCE has about 6.3-percent higher SFC at supersonic cruise and 4.6 percent lower SFC at subsonic cruise than the baseline. From figure 27, this results in a relative TOGW due to a change in supersonic cruise SFC, R_{SFC}, of 1.071 and due to a change

T/W	3.16 n./kg.	(0.323 lb./lb.)
W/S	354. kg./sq.m.	(72.5 lb./sq.ft.)
Range	7 408 km.	(4 000 n.mi.)

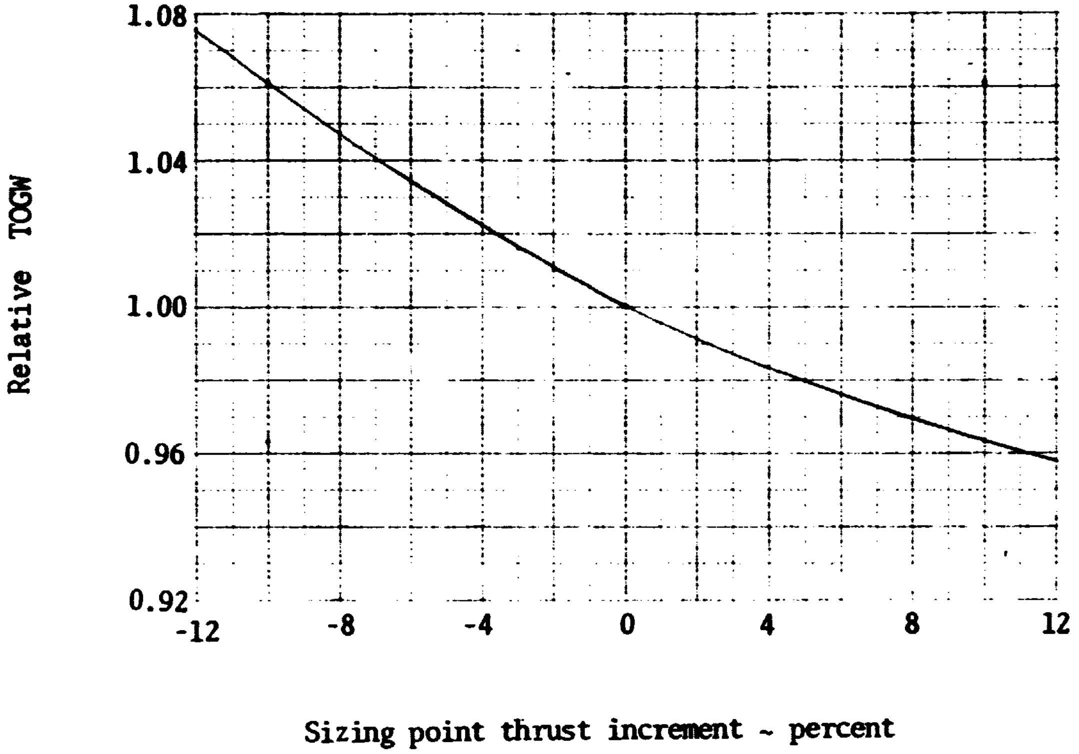
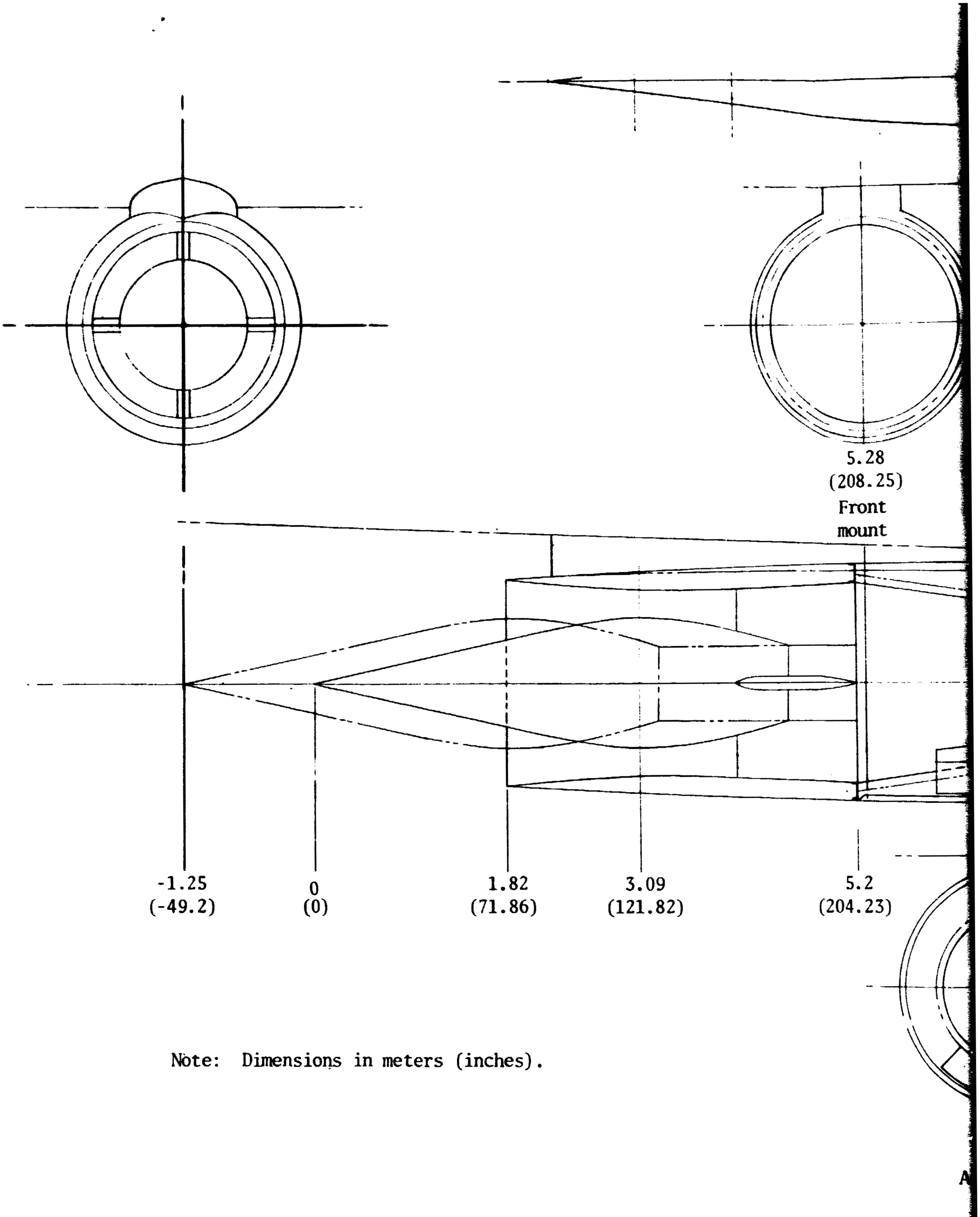


Figure 28. - Sizing point thrust sensitivity trade.



Note: Dimensions in meters (inches).

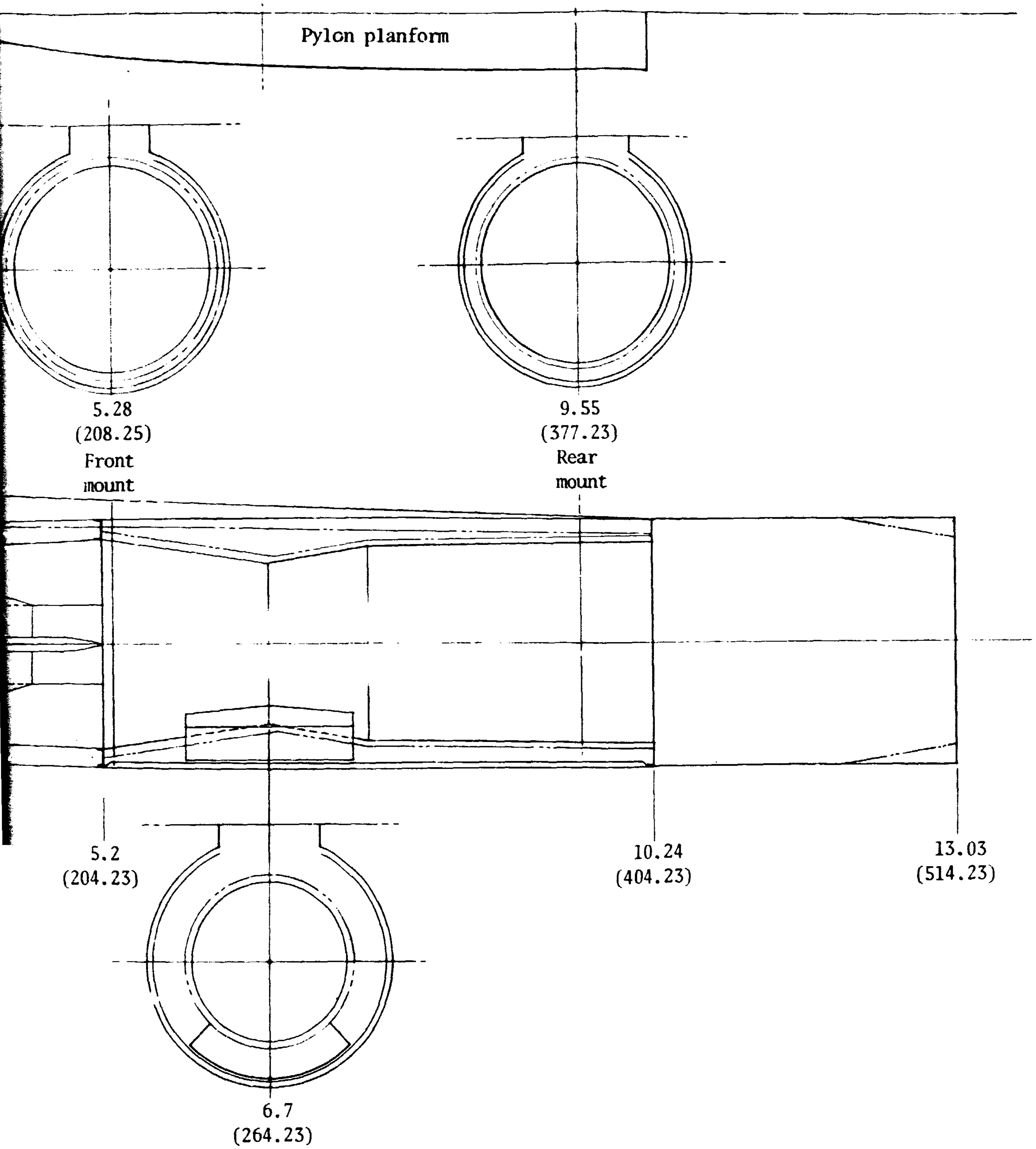


Figure 29.- VCE 112C nacelle.

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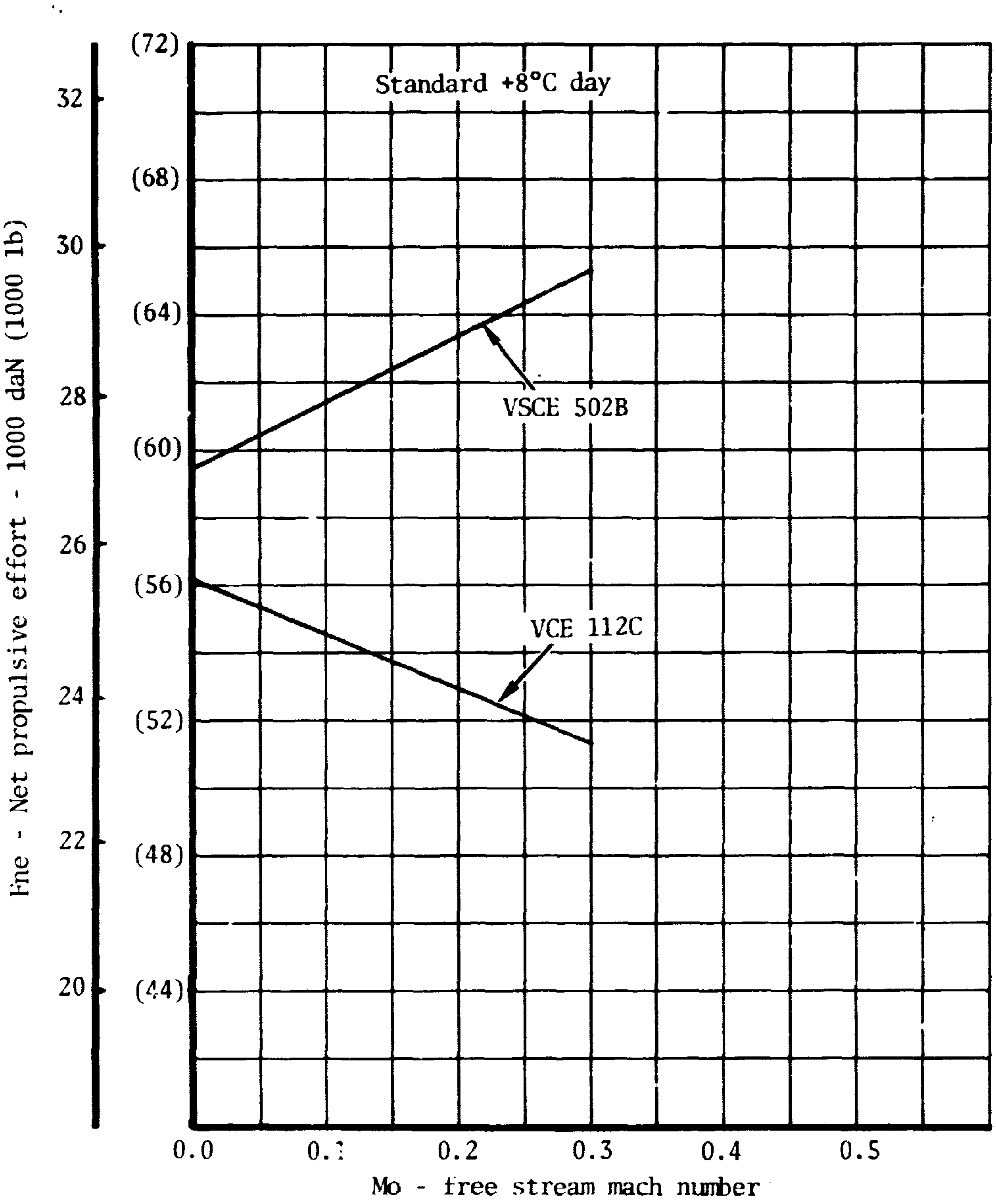

Figure 30.- VSCE 502B and VCE 112C takeoff thrust.

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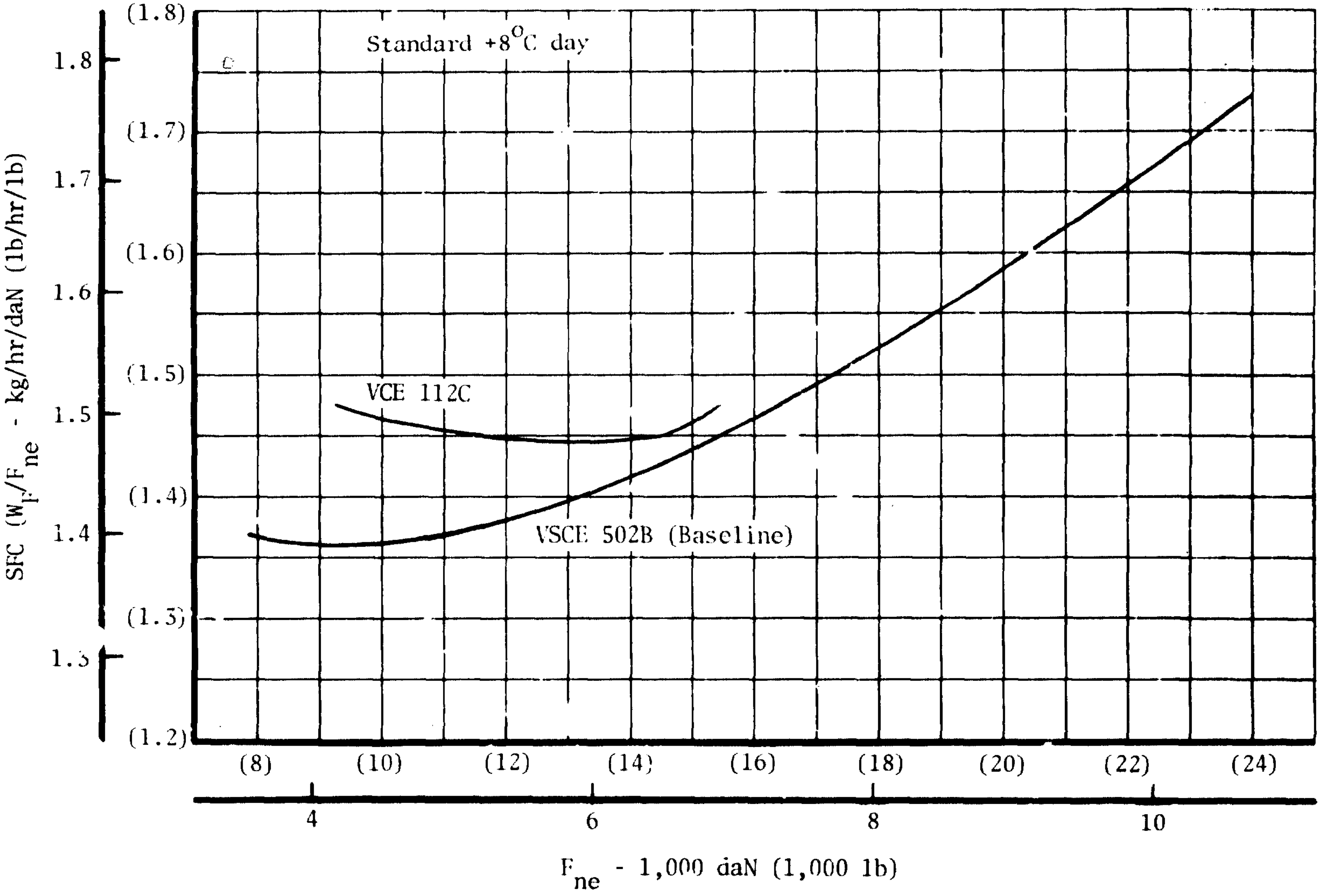


Figure 31 - Installed performance comparison of baseline and VCE 112C at Mach 2.32, 19 800m (65 000 ft).

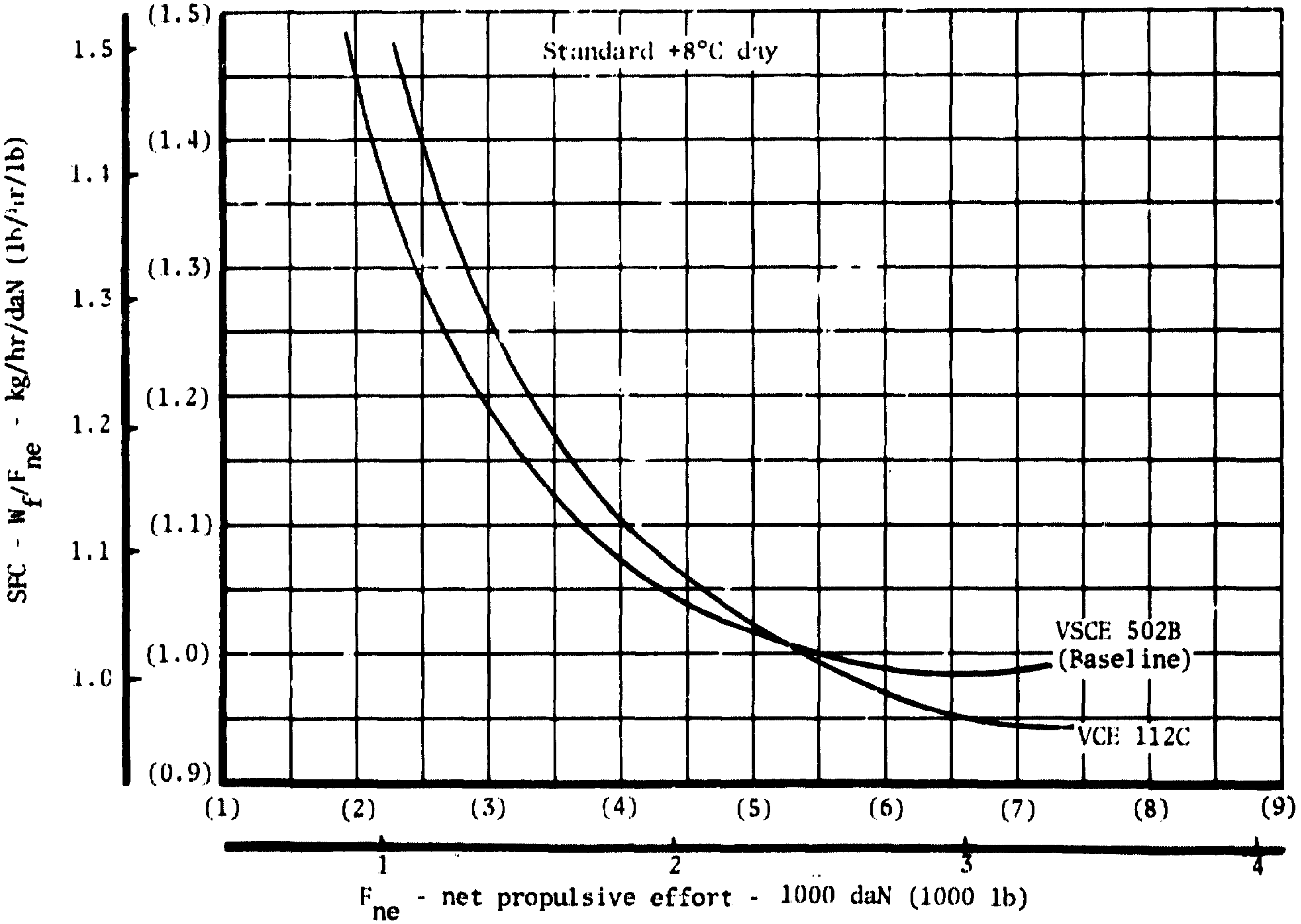


Figure 32.- Baseline and VCE 112C performance, Mach 0.9, 13,700m (45 000 ft).

in subsonic cruise SFC of 0.994.

The nacelle shape of the VCE 112C is similar to that of the baseline but has a smaller nozzle area. The drags used in the mission analysis computer program are indicated in table 17. From figure 26, the relative TOGW ratio due to change in drag, R_{C_D}, is 1.021.

TABLE 17. - COMPARISON OF BASELINE AND VCE 112C NACELLE DRAG INCREMENTS

Mission analysis computer program values		
	ΔC_D, mach 1.2	ΔC_D, mach 2.32
VSCE 502B (baseline)	0.00040	0.00030
VSCE 112C	0.00085	0.00048

The ratios R_{WT}, R_{FNE}, R_{SFC}, and R_{C_D} are then multiplied together to obtain the total relative TOGW ratio, R_{TOTAL}:

$$R_{TOTAL} = R_{WT} \times R_{FNE} \times R_{SFC_{SUB}} \times R_{SFC_{SUPER}} \times R_{C_D} = 1.266$$

The new TOGW is obtained by multiplying R_{TOTAL} by the baseline TOGW of 316 783 kg (698 375 lb). Thus, it is estimated that a vehicle meeting the performance requirements using the VCE 112C engine would weigh 401 092 kg (884 258 lb).

Validation of the Approximate Method

Standard preliminary design procedures were applied in the installation of four candidate engines in the baseline supersonic transport airplane. Drag and weight estimates were made utilizing conventional procedures. The airplanes were then sized to the design mission utilizing an automated reiterative process. The results of this task provide a more exact evaluation of the candidate engines than is obtainable with the more approximate methods resulting from the earlier task, and thus serve as a reference for evaluation of the applicability of the approximate methods.

Propulsion.- Four engines were selected so that the sensitivity method could be validated for a wide range of engine types:

(1) PWA VSCE 502B duct-burning turbofan

(2) PWA VCE 112C variable-cycle engine

(3) GE GE21/J10 B1 low bypass turbojet

(4) GE GE21/J11 B3 double-bypass variable-cycle engine

Characteristics of these engines are summarized in table 18. The engine and installations are discussed in the following paragraphs. While there may be different weight and performance margins and noise and technology assumptions for the four engines, the data were used as supplied by the engine manufacturers without modification for these differences. Hence, results discussed later should not be interpreted as representative of the final SCAR engine studies. (Engine studies are currently still under way.)

TABLE 18.- ENGINE SUMMARY

	ENGINE			
	VSCE 502B	VCE 112C	GE21/J10 B1	GE21/J11 B3
Design airflow, kg/sec (lb/sec)	408 (900)	408 (900)	318/341 (700/750)	318/382 (700/840)
Bypass ratio	1.3	2.5	0.1	0.3
Sea-level static takeoff thrust, daN (lb)*	26 500 (59 500)	25 000 (56 200)	23 300 (52 300)	18 300 (41 100)
Takeoff specific thrust, daN/kg/sec (lb/lb/sec)*	74 (76)	71 (72)	75 (77)	55 (56)
Dry weight, kg (lb)	6077 (13 400)	6191 (13 650)	7280 (16 050)	5964 (13 150)
Overall length, m (in.)	6.8 (266)	7.9 (310)	7.0 (275)	6.9 (273)
Maximum diameter, m (in.)	2.24 (88)	2.19 (86)	1.96 (77)	2.01 (79)

*As installed for this study, standard plus 8° C day

VSCE 502B: Refined performance data (dated January 1976) for the VSCE 502B engine were used to calculate revised installed propulsion performance data. All performance installation effects used were the same as for the baseline data. The noise calculation procedure was identical to that for the baseline. Installed performance changes were very small relative to the baseline. Performance data at important flight conditions are shown in figures 30, 33, and 34.

The nacelle was revised slightly compared to the baseline, to include engine accessories (unencapsulated) and more realistic structure allowances and boundary layer diverter, as shown in figure 35. This engine configuration lent itself well to establishing an efficient nacelle shape. A well-defined waist at the compressor midframe provided space for the required accessory gearbox volume without forcing the nacelle maximum diameter much beyond the nozzle diameter. Location of the engine main mount at the engine front frame enabled transfer of the mount loads directly into the pylon/wing structure.

VCE 112C: Installed performance data for the VCE 112C (408 kg/sec (900 lb/sec)) were calculated in the same manner as the baseline. Because the supersonic cruise airflow is the same as that of the VSCE 502B, the same capture area was used. The only significant difference in procedures was that only a 4 dB reduction in noise due to the coannular effect was used (instead of 8 dB) because the exhaust characteristics and nozzle configuration of the VCE 112C are such that an 8 dB reduction could not be achieved. This results in some thrust reduction at mach 0.3 takeoff power (figure 30) while the airplane is on the ground in order to stay within FAR 36 noise requirements. Thrust is reduced even further at the takeoff noise measurement point. Figures 33 and 34 compare installed performance of the VSCE 502B and VCE 112C.

The installation of this engine into a nacelle (figure 29) is quite similar to that of the VSCE 502B. The only significant changes are a longer engine and a slightly reduced nozzle diameter.

GE21/J10 B1: Installed performance of the GE21/J10 B1 was calculated in a manner similar to the baseline except that a 2-D mixed compression inlet with a capture area of 2.07 sq m (3 208 sq in.) was used. The GE21/J10 B1 has approximately 16-percent lower supersonic cruise airflow relative to takeoff airflow than does the VSCE 502B. If an axisymmetric inlet had been used and sized for supersonic cruise, the static takeoff inlet recovery would have been 4 percent lower than the VSCE 502B. The 2-D inlet has more throat area variation capability and larger auxiliary doors than the axisymmetric inlet. Thus, the takeoff recovery is actually slightly higher than that for the VSCE 502B/axisymmetric inlet. Performance data at important flight conditions are presented in figures 36 through 38. The noise calculation procedure was identical to that for the baseline. An exhaust noise reduction of 8 dB at all flight conditions was used due to the coannular noise reduction effect.

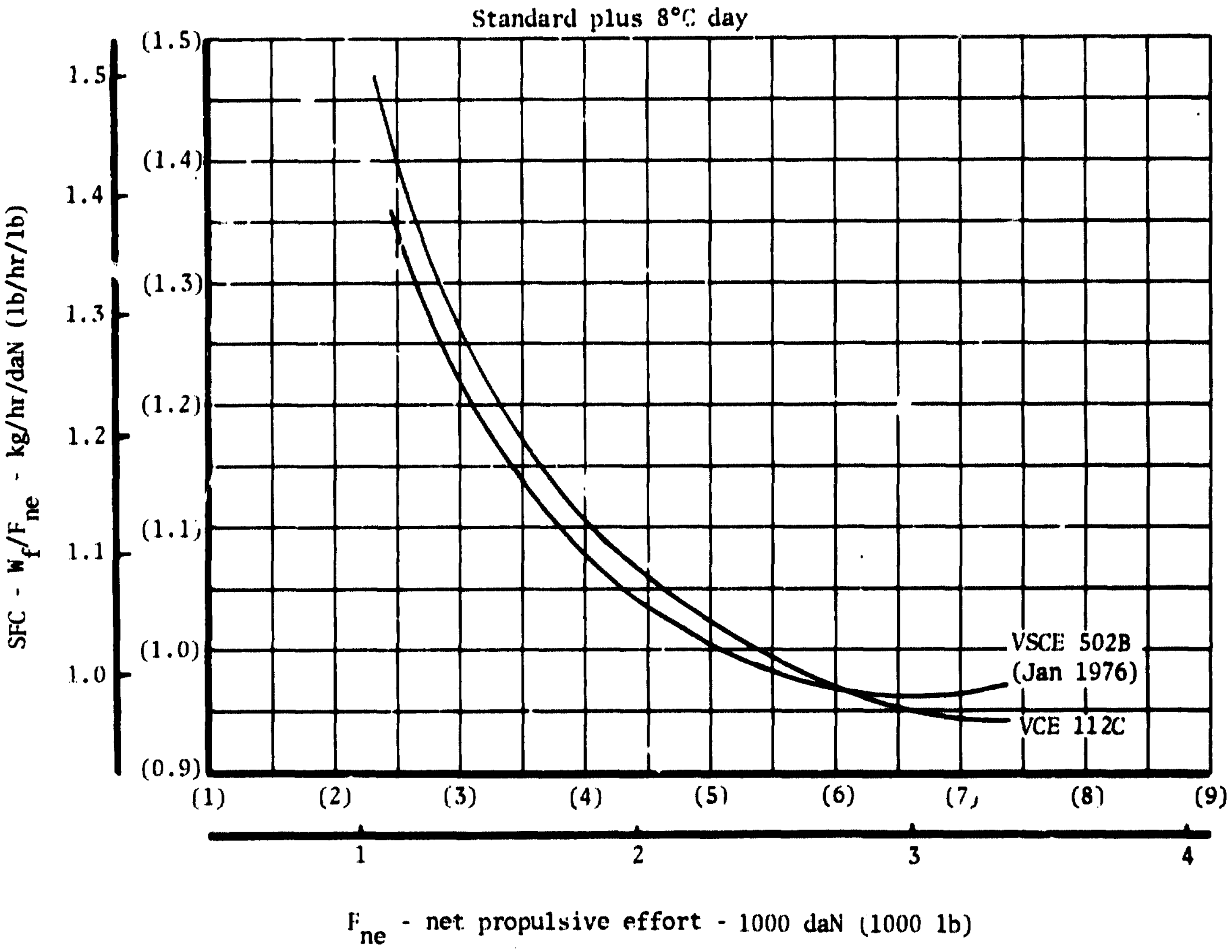


Figure 33.- VCE 502B and VCE 112B performance, Mach 0.9, 13 700m (45 000 ft).

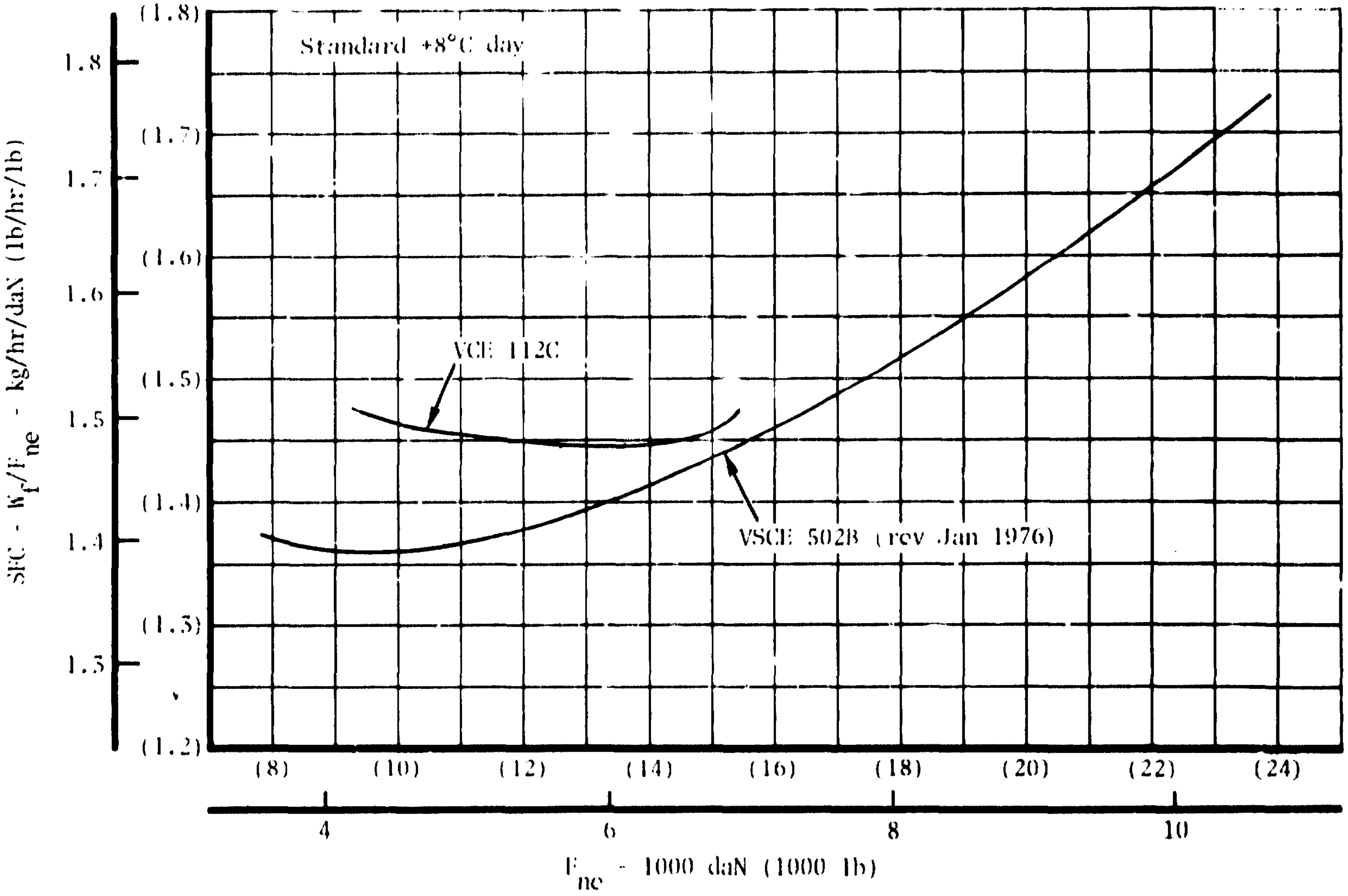
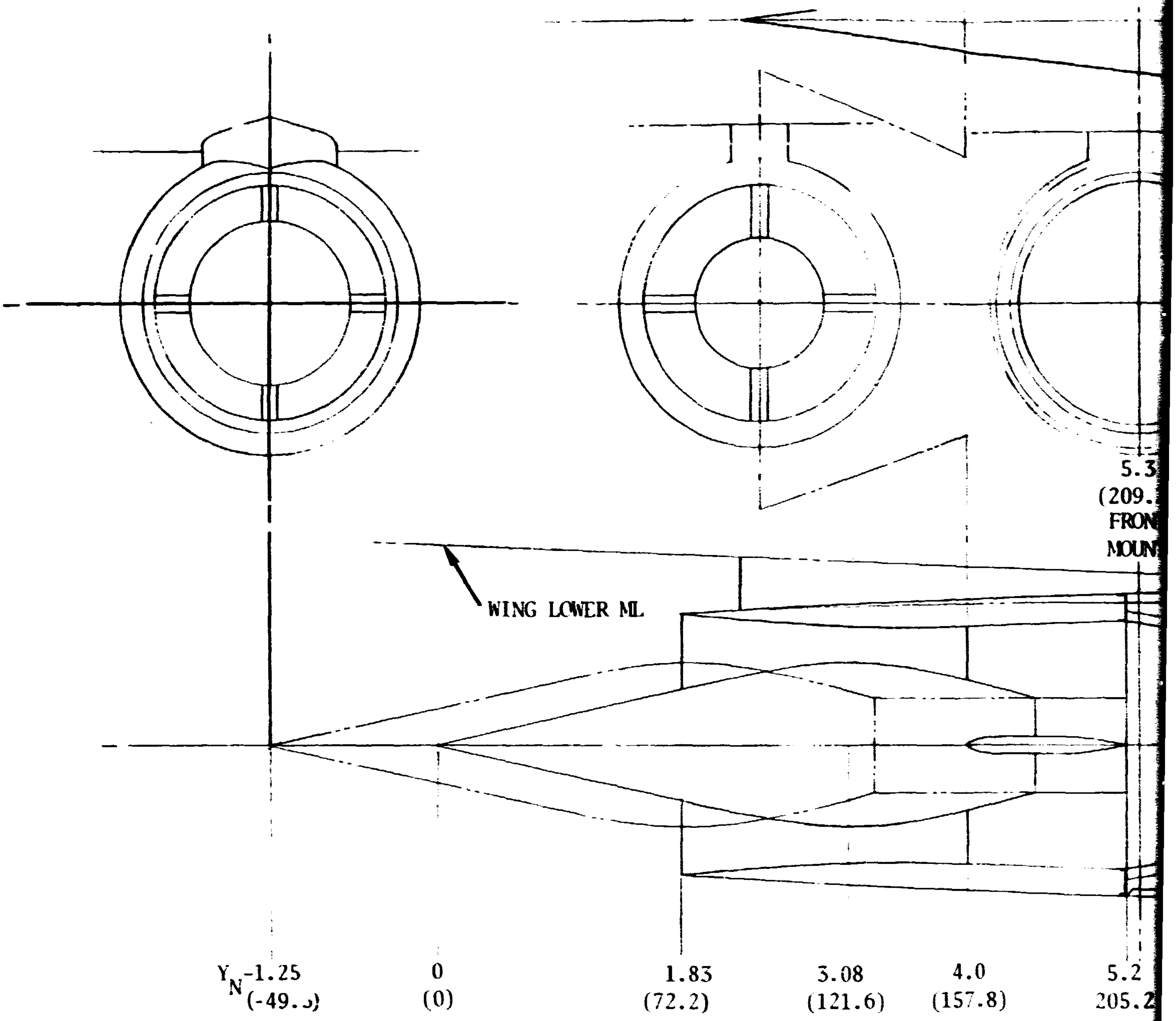


Figure 34.- VSCE 502B and VCE 112C installed performance at Mach 2.32, 19 800 m (65 000 ft).



Dimensions in meters (inches)

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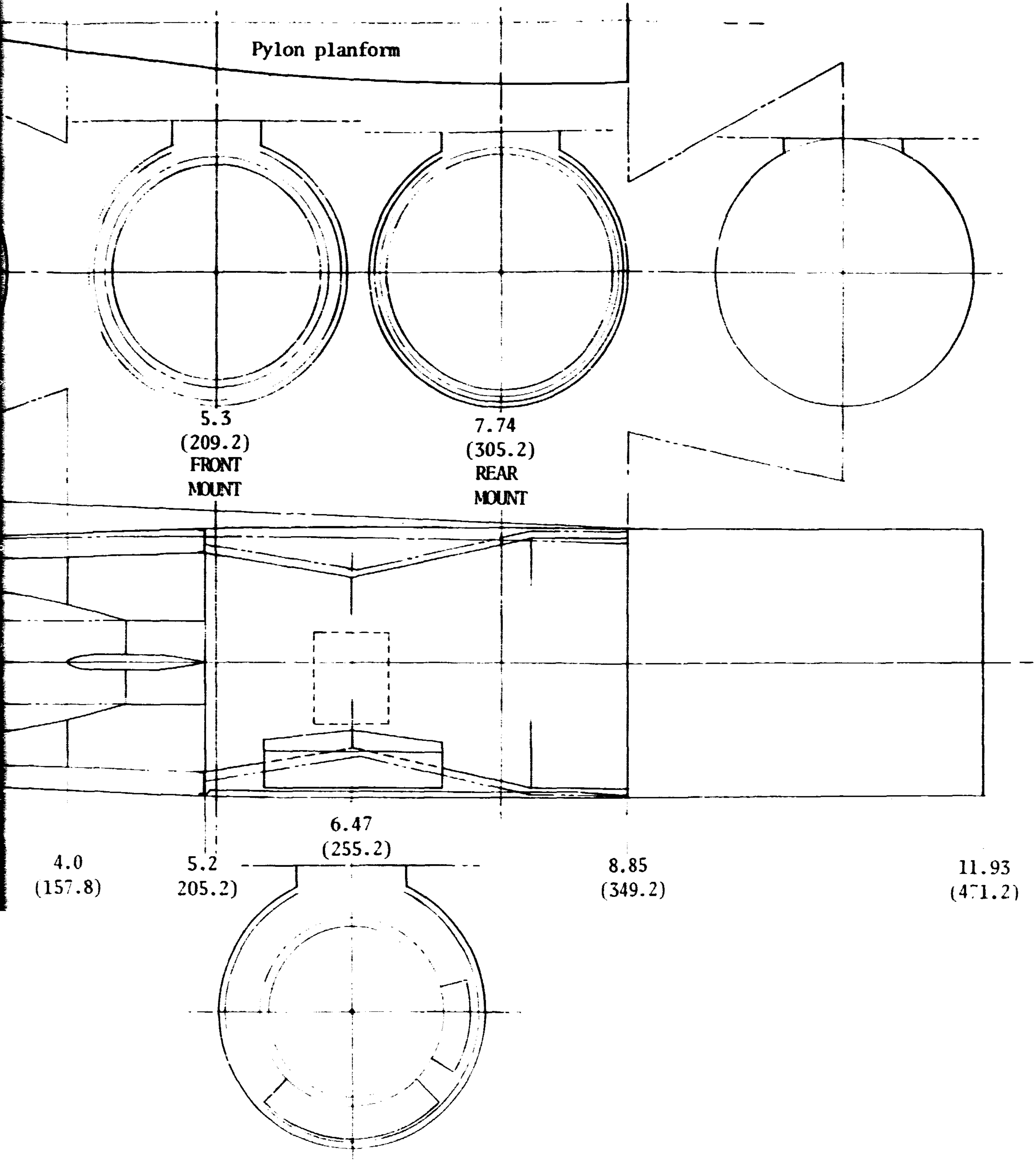

Figure 35. - VSCE 502B nacelle.

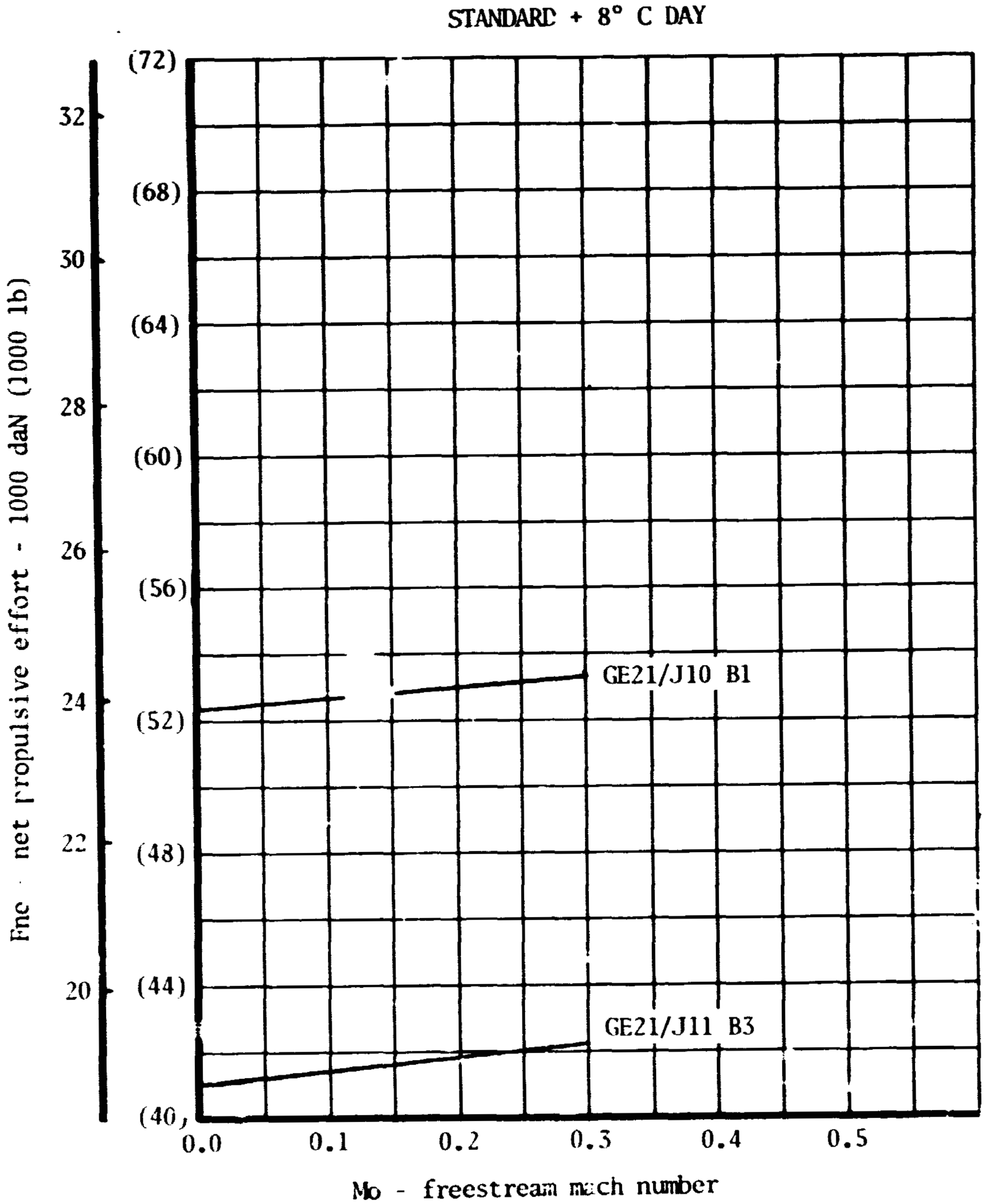

Figure 36.- GE21/J10 B1 and GE21/J11 B3 takeoff thrust.

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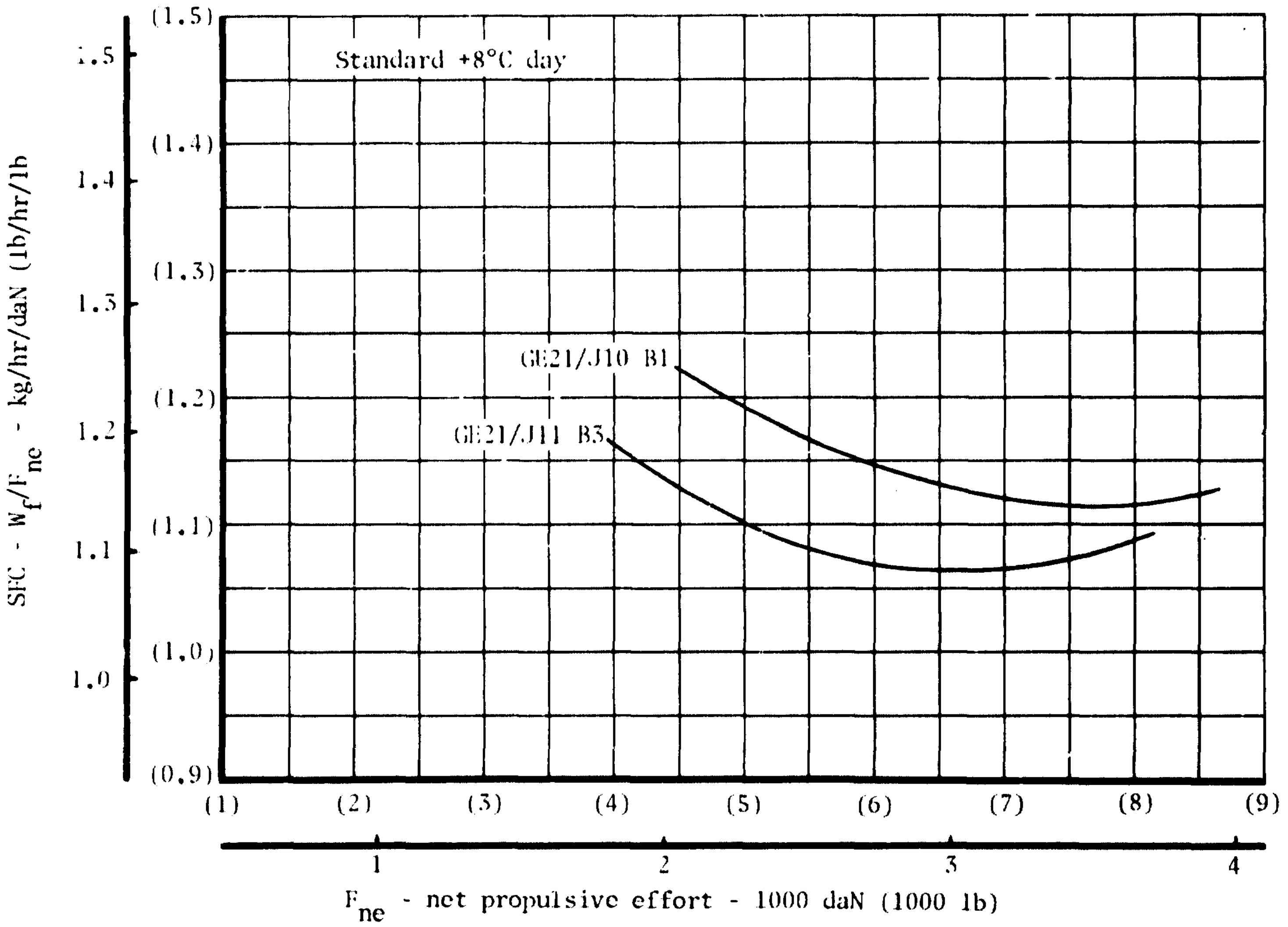


Figure 37.- GE21/J10 B1 and GE21/J11 B3 performance, Mach 0.9, 13,700 m (45 000 ft).

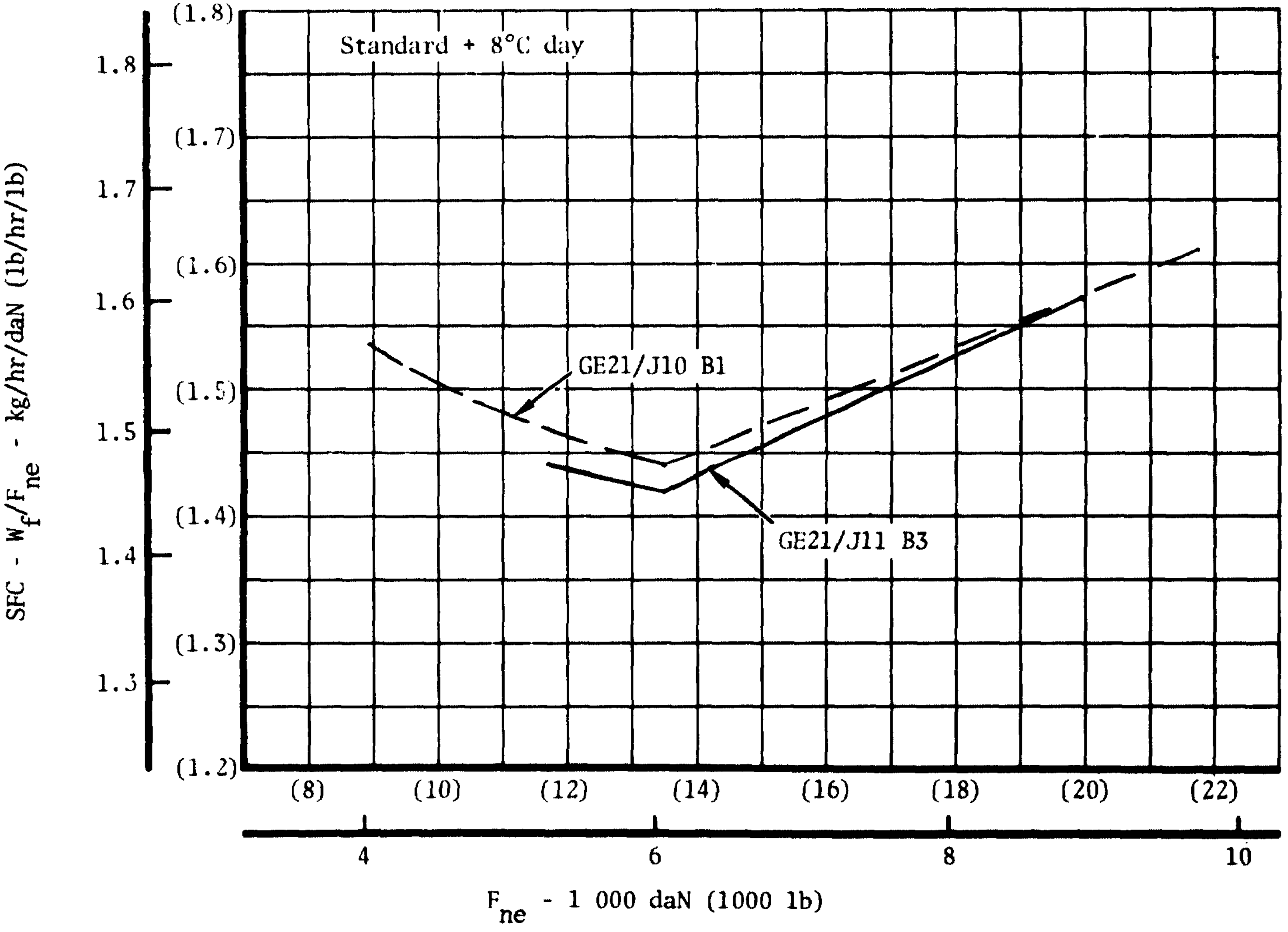


Figure 38. - GE21/J10 B1 and GE21/J11 B3 installed performance at Mach 2.32, 19 800 m (65 000 ft).

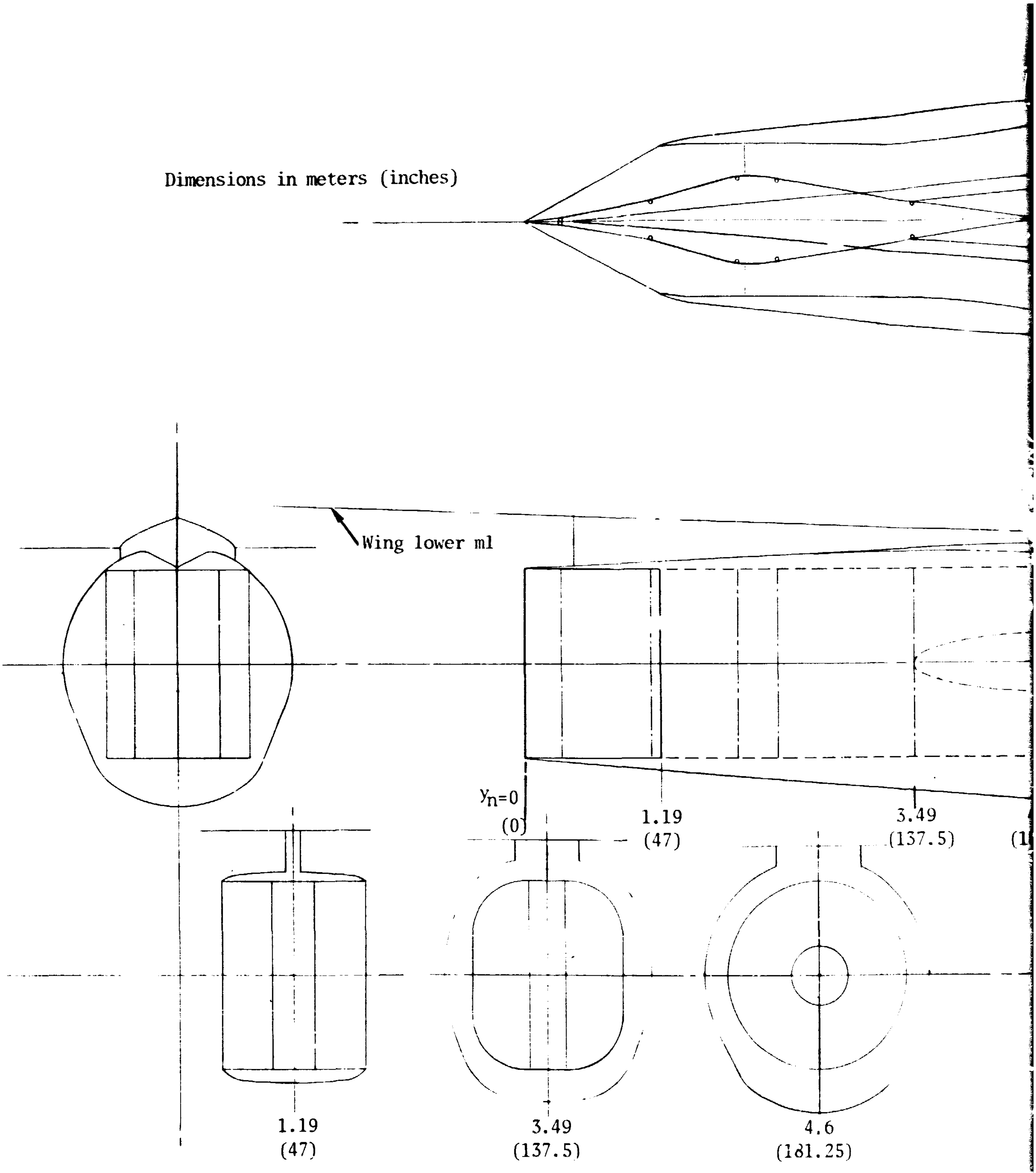
The near-cylindrical configuration of this engine penalized the nacelle shape when the required volume for the encapsulated engine accessories package was added (figure 39). The package was shaped to minimize the added cross section. Location of the main mount at the turbine frame forced the engine cowl to be designed as a structural element and added more to the required cross section.

GE21/J11 B3: Relative to the GE21/J10 B1, the GE21/J11 B3 has even higher takeoff airflow and the same supersonic cruise airflow, thus creating a greater takeoff airflow/inlet matching problem. Therefore, the 2-D inlet was used. Because the engine operates without augmentation at takeoff and the exhaust velocities are low, the sideline noise is quite low while the airplane is on the ground (approximately 6 dB below FAR 36 requirements). However, this significantly reduces takeoff thrust (figure 36) and increases engine size to meet takeoff distance requirements. Some thrust cutback is still required at the takeoff noise measurement point. Installed performance is compared to the GE21/J10 B1 in figures 37 and 38.

This engine is similar in configuration to the GE21/J10 B1 except that the main engine mount was located at the compressor midframe. This enabled the cowl to be made nonstructural and reduced somewhat the nacelle maximum cross section. All other details of the engine and inlet lines development for the two engines are identical, as shown in figure 40.

Mass properties.- Weight estimates were made for the four candidate engine installations. The engine weights, including nozzles and thrust reversers, were furnished by the engine manufacturers. Weight increments for residual fluids and miscellaneous engine/airframe interfacing provisions were added to the manufacturer's quoted weights to obtain the installed engine weight. The weight summaries of the engines are presented in tables 19 and 20. The nacelle/inlet weights for these engine installations were calculated from their respective nacelle lines development layout drawings figures 29, 35, 39, and 40. Summaries of the nacelle/inlet weights are shown in tables 21 and 22. The difference in nacelle weights between the PWA VSCE 502B, and VCE 112C engine installations is primarily due to the longer engine cowl length of the VCE 112C installation. For a given inlet capture area, an axisymmetric inlet would weigh less than a 2-D inlet. However, the 2-D inlet/nacelles for the GE GE21/J10 B1 and GE21/J11 B3 are of similar weight as the axisymmetric PWA engine nacelles. This results from the smaller inlet capture areas and engine dimensions of the GE engines.

Aerodynamics.- Normalized cross-sectional area shapes of the four candidate nacelles of this study are presented in figures 41 and 42. The estimated nacelle incremental skin friction, wave drag, and total drag characteristics



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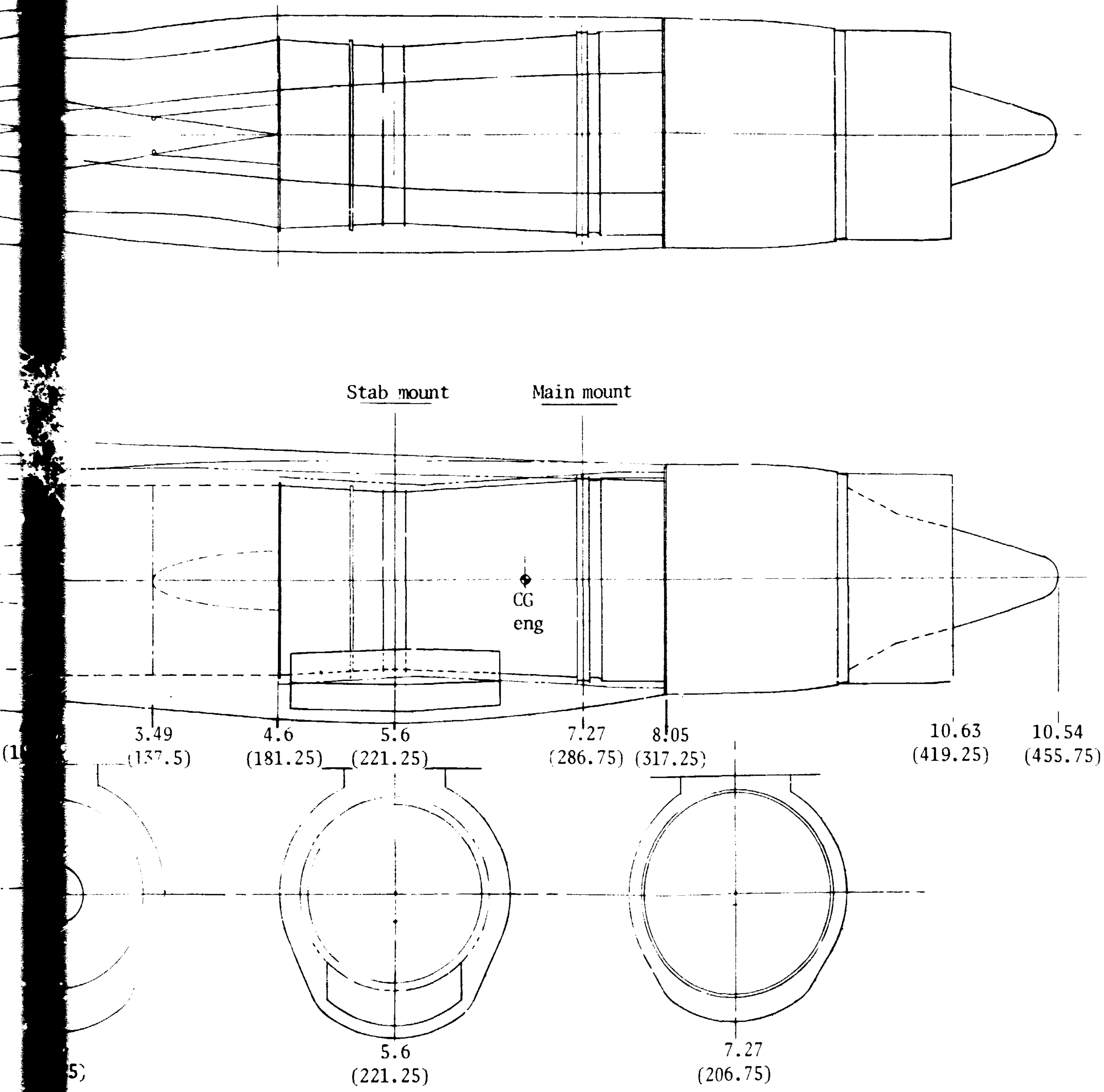
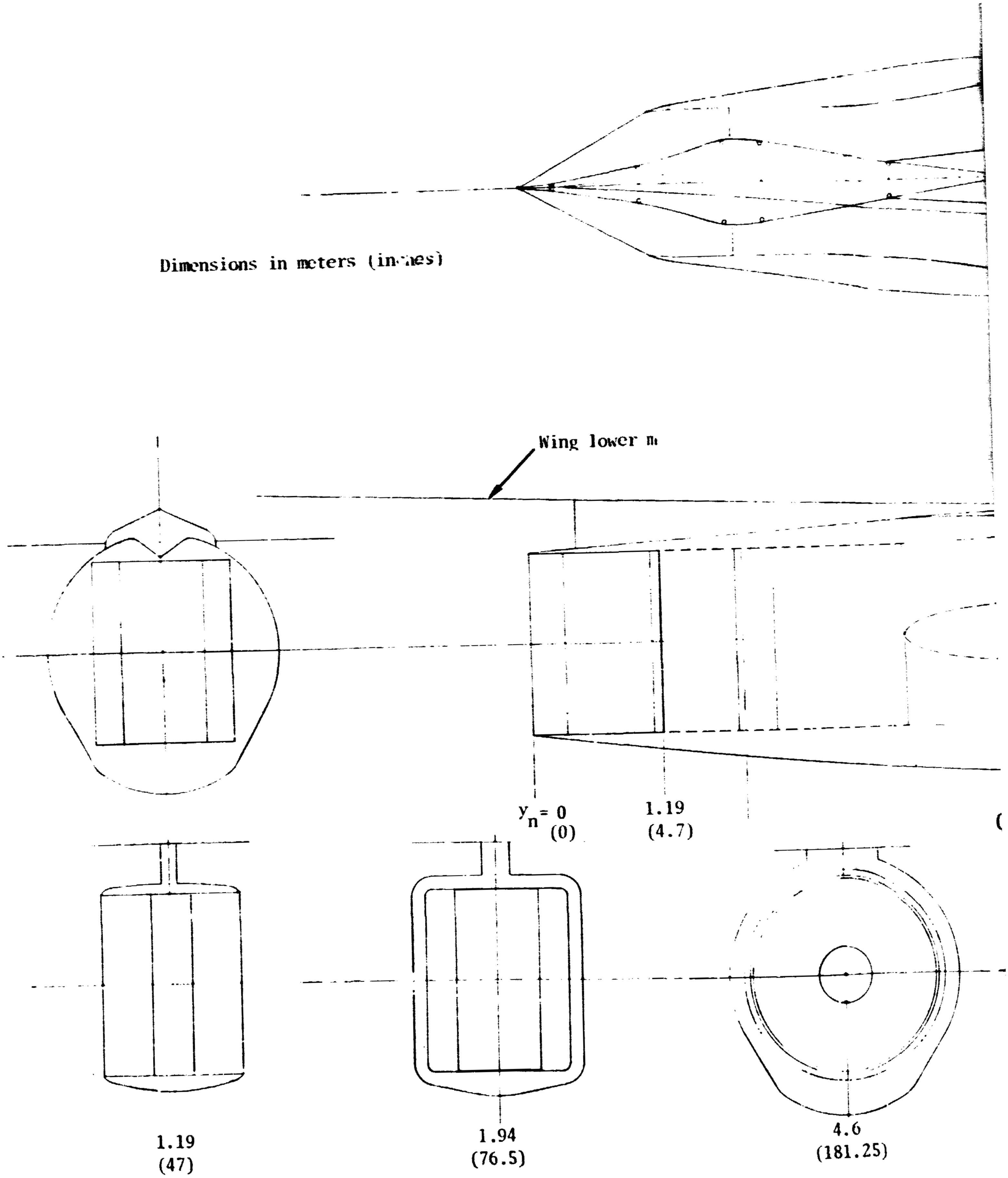


Figure 39.- GE21/J10 B1 nacelle.


Dimensions in meters (inches)

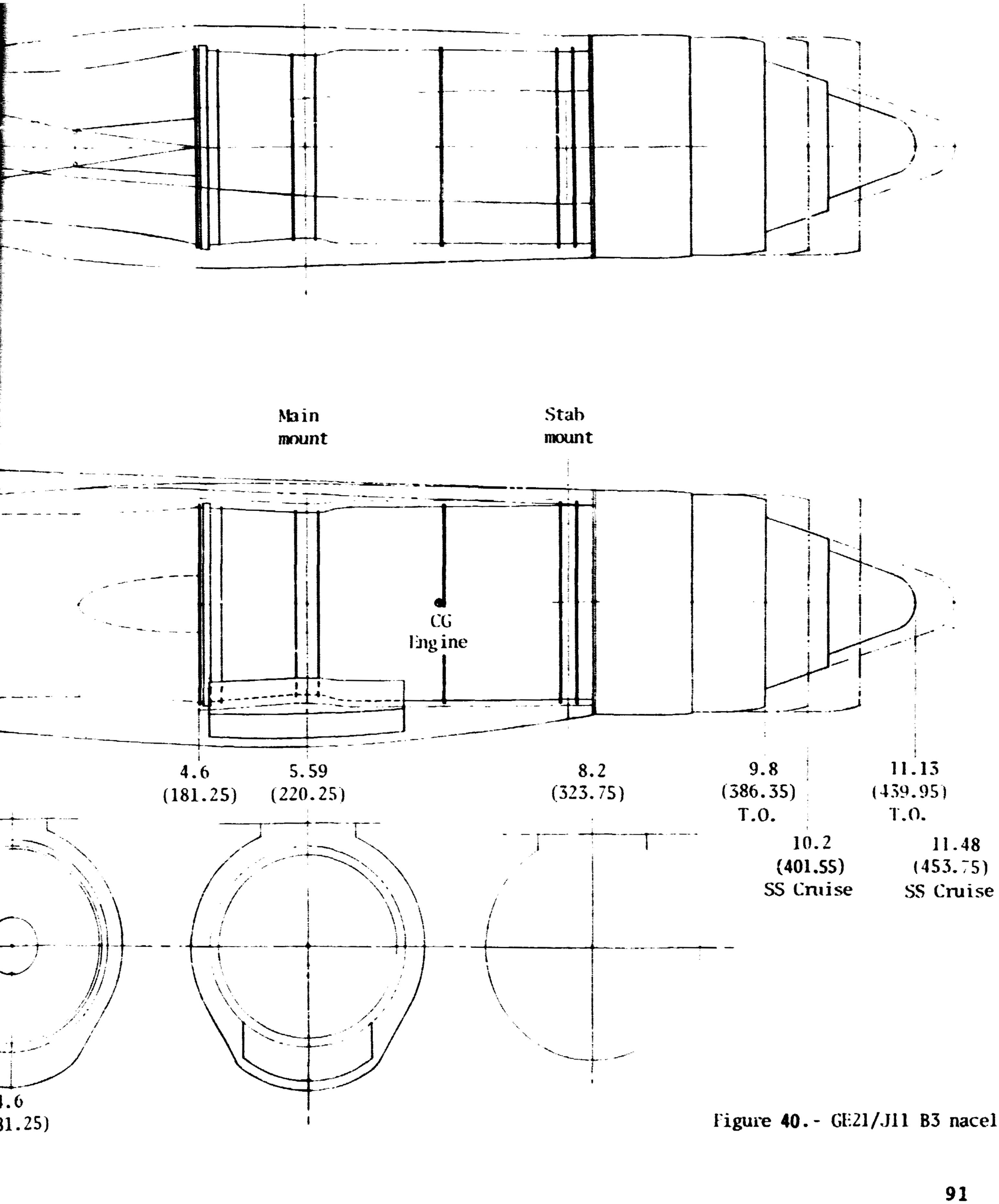


Figure 40.- GE21/J11 B3 nacelle.

TABLE 19.- ENGINE WEIGHTS, INTERNATIONAL UNITS

Engines	Kilograms/Engine			
	Pratt & Whitney		General Electric	
	VSCE 502B	VCE 112C	GE21/J10 B1	GE21/J11 B3
Bare engine (including nozzle & thrust reverser)	6077	6191	7280	5964
Residual fluids	23	23	23	23
Miscellaneous provisions	23	23	23	23
Engine as installed	6123	6237	7326	6010

TABLE 20.- ENGINE WEIGHTS, ENGLISH UNITS

Engines	Pounds/engine			
	Pratt & Whitney		General Electric	
	VSCE 502B	VCE 112C	GE21/J10 B1	GE21/J11 B3
Bare engine (including nozzle & thrust reverser)	13 400	13 650	16 050	13 150
Residual fluids	50	50	50	50
Miscellaneous provisions	50	50	50	50
Engine as installed	13 500	13 750	16 150	13 250

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TABLE 21.- NACELLE/INLET WEIGHTS, INTERNATIONAL UNITS

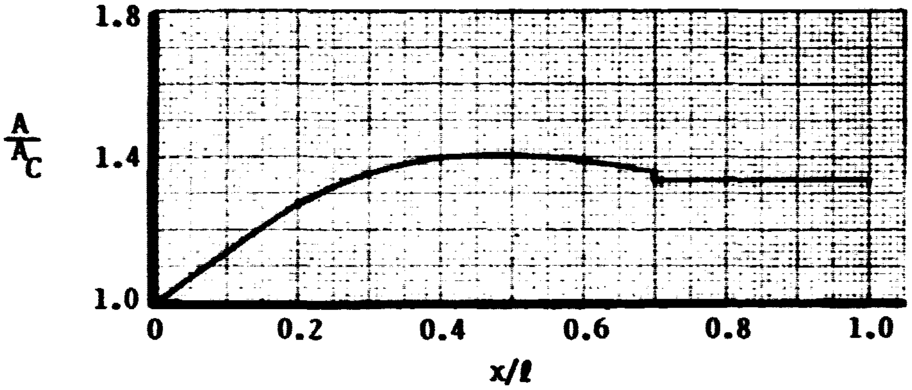
Nacelle/inlet	Kilograms/nacelle			
	Axisymmetric		Two-dimensional	
	VSCE 502B	VCE 112C	GE21/J10 B1	GE21/J11 B3
Engine cowl	816	1124	706	760
Inlet cowl	370	365	566	598
Spike	740	733		
Ramps			517	517
*Air induction features				
Bypass			49	49
Auxiliary inlet			30	30
Secondary air provisions				
Inlet controls			45	45
Engine mounts	92	93	110	90
Total nacelle/inlet	2018	2315	2047	2113
*Included with spike weight in axisymmetric inlets.				

TABLE 22.- NACELLE/INLET WEIGHTS, ENGLISH UNITS

Nacelle/inlet	Pounds/nacelle			
	Axisymmetric		Two-dimensional	
	VSCE 502B	VCE 112C	GE21/J10 B1	GE21/J11 B3
Engine cowl	1798	2477	1557	1673
Inlet cowl	816	804	1247	1319
Spike	1632	1616		
Ramps			1140	1140
*Air induction features				
Bypass			107	107
Auxiliary inlet			67	67
Secondary air provisions			53	53
Inlet controls			100	100
Engine mounts	203	206	242	199
Total nacelle/inlet	4449	5103	4513	4658
*Included with spike weight in axisymmetric inlets				

Revised VSCE 502B

Capture area, sq m (sq ft)	2.93 (31.5)
Length, m (ft)	10.13 (33.25)
Surface area, sq m (sq ft)	67.26 (724.0)



VCE 112C

Capture area, sq m (sq ft)	2.93 (31.5)
Length, m (ft)	11.25 (36.9)
Surface area, sq m (sq ft)	74.22 (798.9)

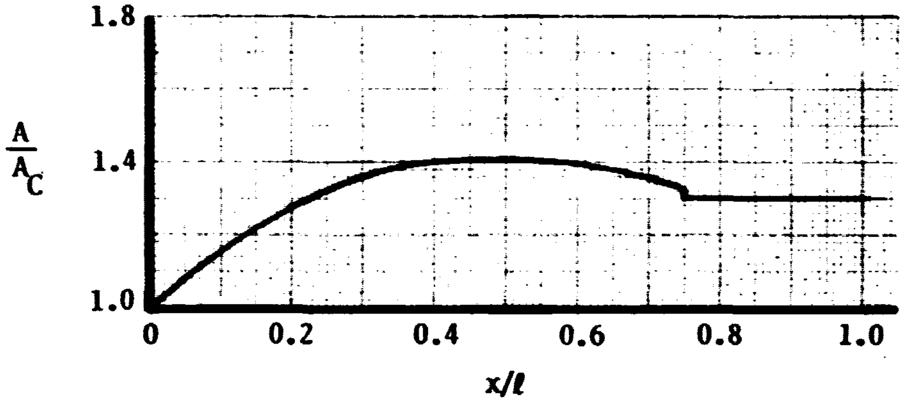
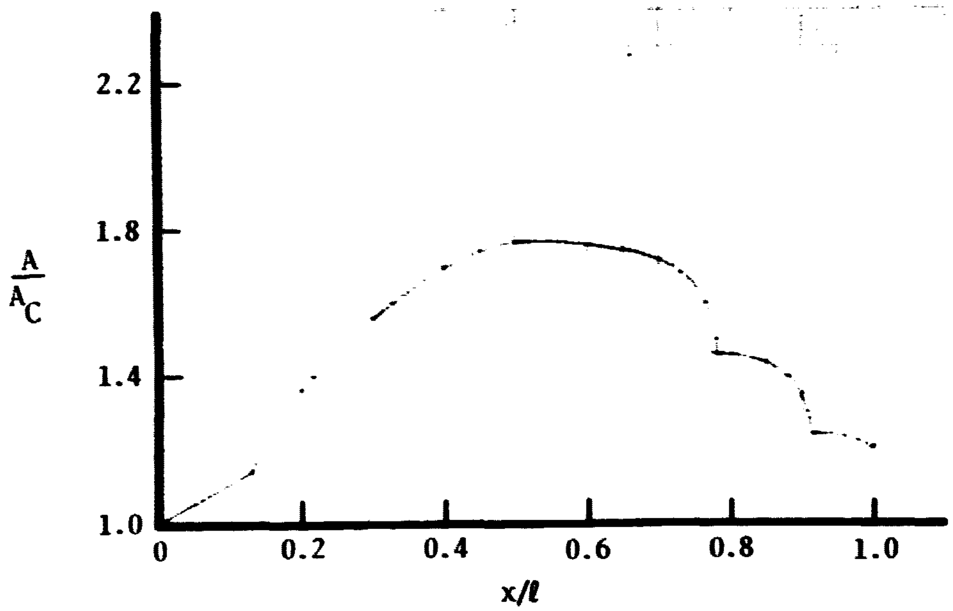


Figure 41.- VSCE 502B and VCE 112C nacelle cross-sectional area variation.

GE21/J10 B1

Capture area, sq m (sq ft)	2.06	(22.2)
Length, m (ft)	10.63	(34.9)
Surface area, sq m (sq ft)	55.7	(599.7)



GE21/J11 B3

Capture area, sq m (sq ft)	2.06	(22.2)
Length, m (ft)	10.21	(33.5)
Surface area, sq m (sq ft)	59.30	(638.3)

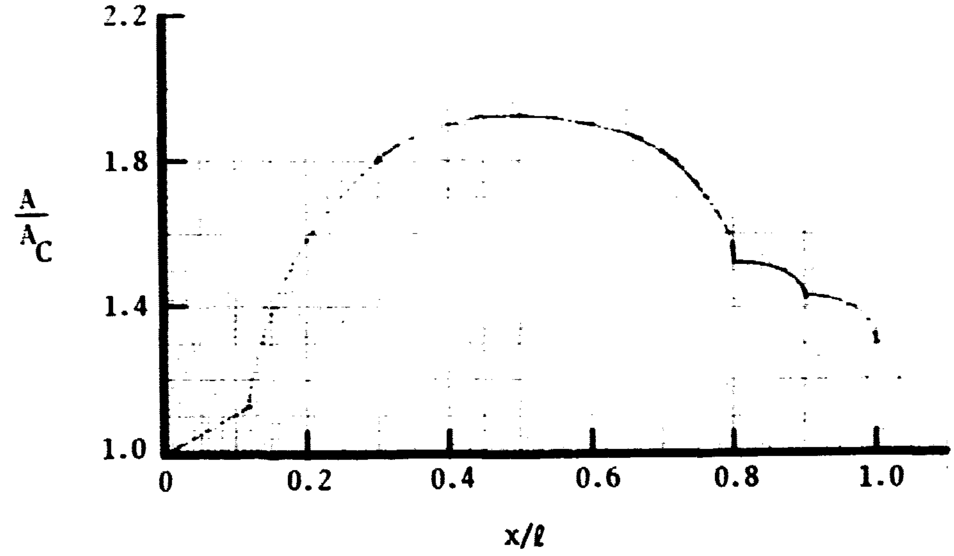


Figure 42.- GE 21/J10 B1 and GE 21/J11 B3 nacelle cross-sectional area variation.

for all of the nacelles are presented in table 23. Included in the table are the incremental drags obtained from the computer table look-up program of the parametric drag analysis results. The differences between the estimated drags and the parametric results are attributed to the following considerations:

(1) The parametric study, which is the basis of data for the table look-up program, was made with a resized wing with the nacelles relocated further inboard and forward in accordance with the ground rules of the study.

(2) The current nacelles deviate from a linear radius connection of the inlet face, maximum area, and nozzle stations.

(3) In some cases, the ratio of the distance to the maximum area to the total length (X_{AMAX}/ℓ) falls outside of the parametric study envelope, thereby requiring extrapolation.

(4) Drag coefficients for intermediate mach numbers are obtained by using a cubic curve fit based on the total drag (CDO) increments at mach 1.2 and 2.32. However, since wave drag does not follow such a simplified solution, interpolated or extrapolated drags will deviate from an estimated value by varying amounts. In the case of the reference nacelle, the deviation was -0.00017 at mach 1.4.

Performance and sizing.- Performance calculated for the aircraft having the four selected propulsion systems installed includes all items as described earlier under "Baseline Airplane Definition." In addition, performance has been calculated for an "economic" mission as described in the following paragraphs. As on the design mission, the economic mission is calculated for a standard-plus-8° C (14.4° F) day.

A profile of the economic mission is shown in figure 43. This mission consists mainly of a mach 2.32 cruise as in the design mission; however, it is preceded by a subsonic climb and cruise totaling 741 km (400 n mi). Fuel reserves are calculated just as in the design mission for an alternate airport located 463 km (250 n mi) beyond the destination airport. The economic mission is an off-design mission in that the airplane, as sized to 7408 km (4000 n mi) range on the design mission, carries a reduced payload equal to 55 percent of the design payload and fuel is then off-loaded to yield a total economic mission range of 4630 km (2500 n mi) plus fuel reserves.

The economic mission consists of the following legs:

(1) Warmup and takeoff - 10 minutes at idle power plus 1 minute at maximum power

TABLE 23. - DRAG COMPARISON

NASA LARC CR132374 Reference Configuration						
	Estimated			Parametric		
M	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}
1.2	0.00072	-0.00041	0.00031	0.00066	-0.00034	0.00031
1.4	0.00070	-0.00017	0.00052			0.00035
1.8	0.00065	-0.00022	0.00043			0.00040
2.32	0.00060	-0.00018	0.00042	0.00057	-0.00014	0.00043
2.7	0.00056	-0.00015	0.00041			0.00044
Basepoint VSCE 502B						
	Estimated			Parametric		
M	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}
1.2	0.00060	-0.00007	0.00053	0.00055	0.00002	0.00057
1.4	0.00058	0.00011	0.00069			
1.8	0.00054	-0.00004	0.00050			0.00046
2.32	0.00050	-0.00008	0.00042	0.00049	-0.00007	0.00042
2.7	0.00047	-0.00009	0.00038			
Baseline VSCE 502B						
	Estimated			Parametric		
M	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}
1.2	0.00058	-0.00009	0.00049	0.00053	0.00002	0.00655
1.4	0.00056	0.00005	0.00059			
1.8	0.00052	-0.00011	0.00041			0.00045
2.32	0.00049	-0.00012	0.00037	0.00047	-0.00005	0.00042
2.7	0.00045	-0.00011	0.00034			
P&W VSCE 502B (Revised)						
	Estimated			Parametric		
M	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}
1.2	0.00055	0.00014	0.00069	0.00052	0.00021	0.00073
1.4	0.00053	0.00032	0.00085			
1.8	0.00050	0.00011	0.00061			0.00053
2.32	0.00046	0.00000	0.00046	0.00047	-0.00001	0.00046
2.7	0.00043	-0.00004	0.00039			

TABLE 23. - Concluded

GE 21/J10 B1

	Estimated			Parametric		
M	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}
1.2	0.00045	0.00161	0.00206	0.00049	0.00153	0.00202
1.4	0.00044	0.00164	0.00208			
1.8	0.00041	0.00097	0.00138			0.00123
2.32	0.00038	0.00060	0.00098	0.00044	0.00051	0.00095
2.7	0.00035	0.00043	0.00078			

GE 21/J11 B3

	Estimated			Parametric		
M	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}
1.2	0.00048	0.00235	0.00283	0.00049	0.00227	0.00276
1.4	0.00047	0.00223	0.00270			
1.8	0.00044	0.00140	0.00184			0.00157
2.32	0.00040	0.00083	0.00123	0.00044	0.00071	0.00115
2.7	0.00038	0.00061	0.00099			

P&W VCE 112C

	Estimated			Parametric		
M	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}	ΔC_{D_P}	ΔC_{D_W}	ΔC_{D_O}
1.2	0.00060	0.00028	0.00088	0.00057	0.00032	0.00089
1.4	0.00058	0.00043	0.00101			
1.8	0.00054	0.00017	0.00071			0.00063
2.32	0.00050	0.00004	0.00054	0.00050	0.00005	0.00055
2.7	0.00046	0.00000	0.00046			

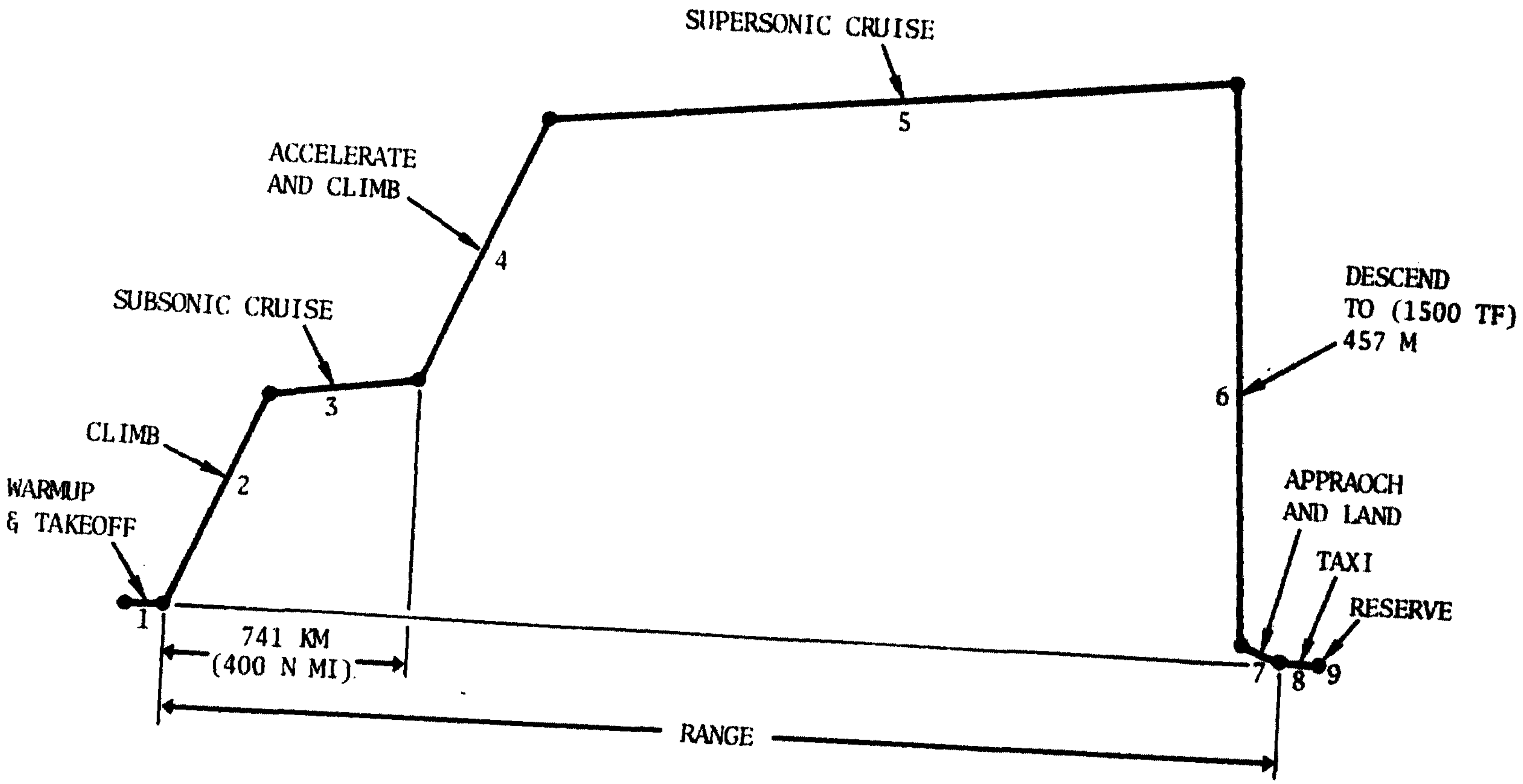


Figure 43.- Economic mission profile.

(2) Climb - Maximum power climb to cruise altitude and mach number

(3) Cruise - Subsonic cruise at mach number and altitude for best range

(4) Climb - Maximum power climb and accelerate to cruise altitude and mach number

(5) Cruise - Supersonic cruise at mach 2.32 at altitude for best cruise range

(6) Descend - Descend and decelerate to 457 m (1500 feet) altitude using idle power

(7) Approach and land - Descend to sea level using idle power

(8) Taxi - 5 minutes at idle power

(9) Reserve - Fuel reserves for an alternate airport located 463 km (250 n mi) from destination airport

For each of the four selected propulsion systems, a "basepoint" airplane was developed. This basepoint is similar to the basepoint described earlier, in that it is the NASA reference airplane but with the selected propulsion system installed. This airplane is then scaled using the Vehicle Sizing and Performance Evaluation Program (VSPEP) to yield a baseline airplane. Again, this baseline is similar to the baseline described earlier, in that it is the minimum gross weight airplane that meets all specified performance requirements.

To gain some insight as to what could be expected for each of the four resized airplanes, an engine scale trade was performed on each. The results of these trades are presented in figures 44 and 45 which show design mission range and balanced field length versus engine airflow at sea level static conditions. The gross wing area was maintained constant at 1022 sq m (10 996 sq ft) and airplane gross weight was maintained at that for the basepoint with the first selected propulsion system installed or 377 632 kg (744 350 lb). Results of these trades indicate that the airplanes having the GE21 engines could be expected to result in a higher gross weight to meet the design requirements. In addition the VCE 112C and the GE21/J11 engined airplanes can be expected to pay an engine size penalty to meet the balanced field length requirement thereby increasing the gross weight of those vehicles.

In the case of the first selected propulsion system, which uses a revised VSCE 502B engine installation, sizing was performed maintaining takeoff thrust-to-weight (based on sea-level static installed thrust) at 3.13 n/kg (0.32 lb/lb). Wingloading was then varied and the VSPEP program allowed to search for the

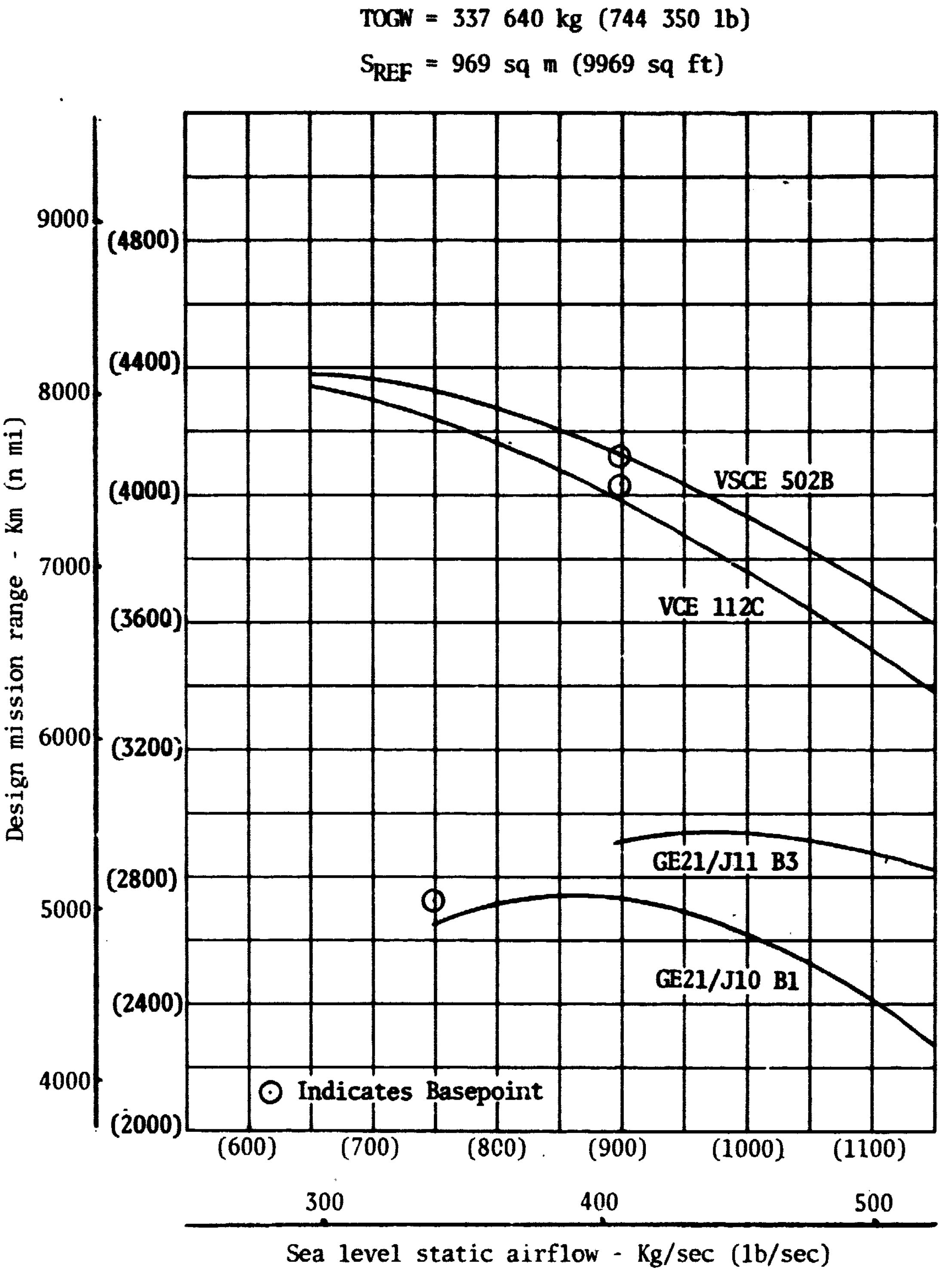


Figure 44. - Design mission range versus engine size.

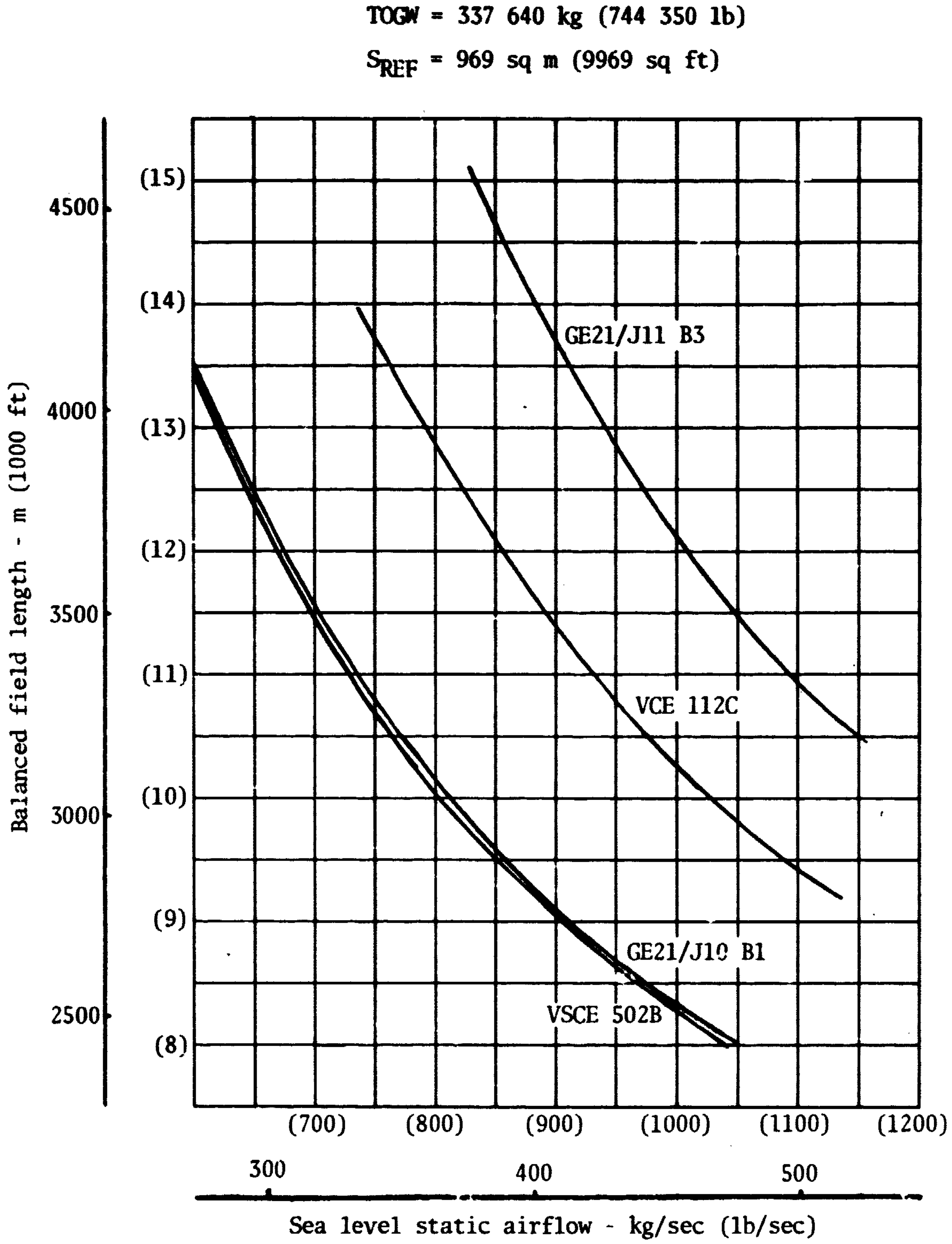


Figure 45. - Balanced field length versus engine size.

gross weight yielding 7408 km (4000 n mi) on the design mission. These results were then cross-plotted to obtain the wingloading for a minimum gross weight baseline airplane. Plots of gross weight and balanced field length versus wingloading (based on gross wing area) for a family of airplanes having a design range of 7408 km (4000 n mi) are shown in figure 46. All other performance requirements were easily met.

For the last three selected propulsion systems, it was originally intended to maintain thrust-to-weight at 3.13 n/kg (0.32 lb/lb) and wingloading at that value obtained for the VSCE 502B baseline, which is 345 kg/sq m (70.7 lb/sq ft), and simply scale gross weight to yield the required design range. However, due to considerable differences in thrust lapse rate at takeoff for each engine, this method would not suffice to maintain balanced field length near the required distance. For this reason, the thrust-to-weight was varied in each of the last three cases while maintaining wingloading constant at 345 kg/sq m. Plots of gross weight and balanced field length versus thrust-to-weight ratio are presented in figures 47 through 49 for families of airplanes having a design mission range of 7408 km (4000 n mi.).

Airplane characteristics for both the basepoint and the resized baseline vehicles are presented in tables 24 through 27 for each of the four selected propulsion systems. Design mission summaries are shown for each baseline airplane in tables 28 through 35.

Performance for each baseline airplane was also calculated for the economic mission. Payload for this mission was 55 percent of that carried on the design mission or 15 256 kg (33 565 lb). Fuel was then off-loaded from the baseline to yield 4630 km (2500 n mi.) on the economic mission. Characteristics of each of the four baseline airplanes on the economic mission are shown in tables 36 through 39.

The results of the economic mission were used to compute direct operating cost (DOC) and return on investment (ROI) for the VSCE 502B and the VCE 112C. The DOC and ROI calculations were supplied by Pratt and Whitney Aircraft and are presented in table 40. Input to the DOC and ROI calculations included the following airplane and mission data supplied by Rockwell: airframe weight, engine weight, mission fuel, TOGW, block time, and engine design thrust. These data are included for each of the four airplanes in tables 36 through 39. Economic mission summaries for each baseline airplane are presented in tables 41 through 48.

Sensitivity method verification.- To verify that the sensitivity method of determining aircraft takeoff gross weights is valid for preliminary studies, takeoff gross weights were estimated using the sensitivities for the four engines. These results were then compared with the results of the detailed

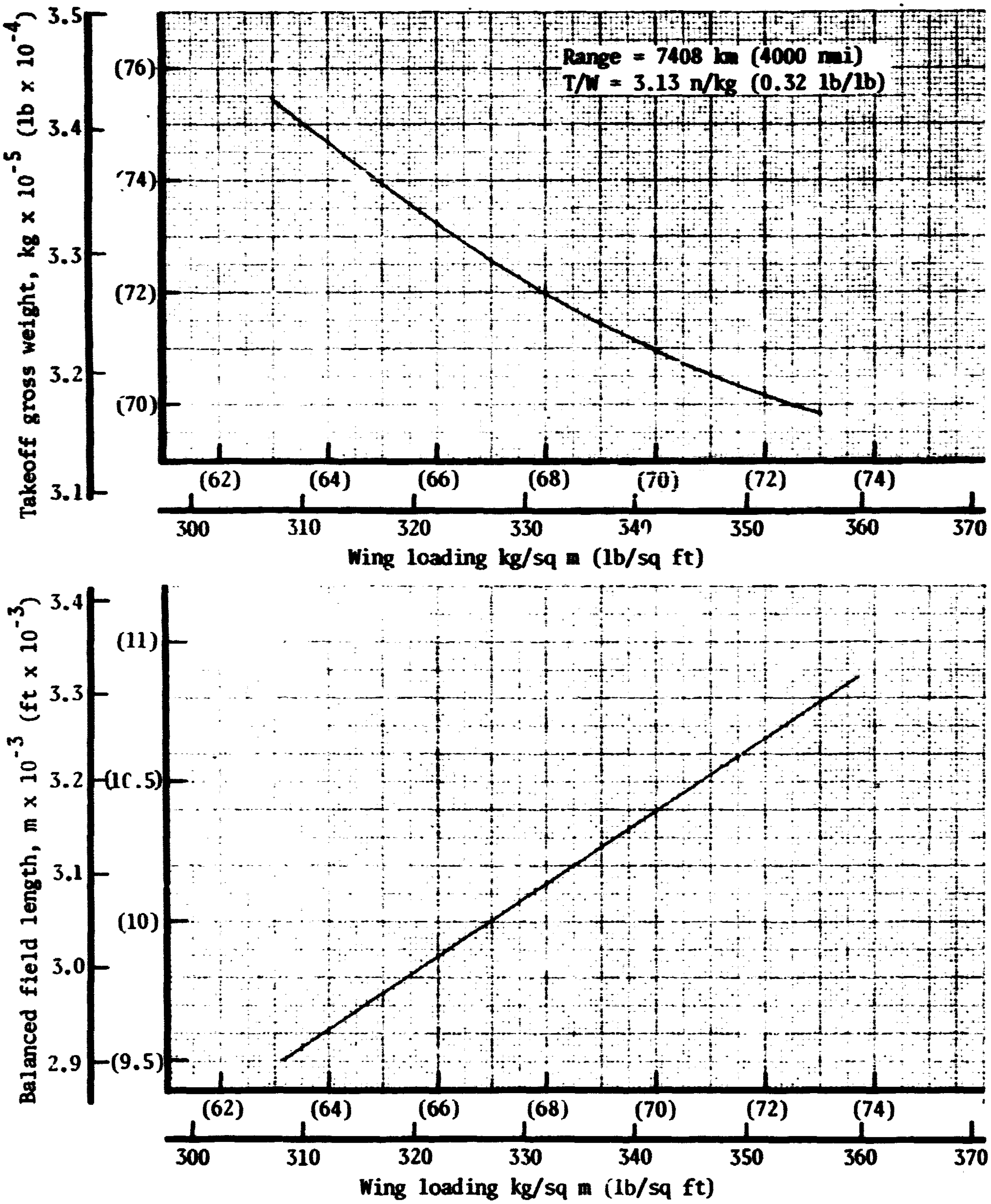


Figure 46.- Sizing with VSCE 502B engines.

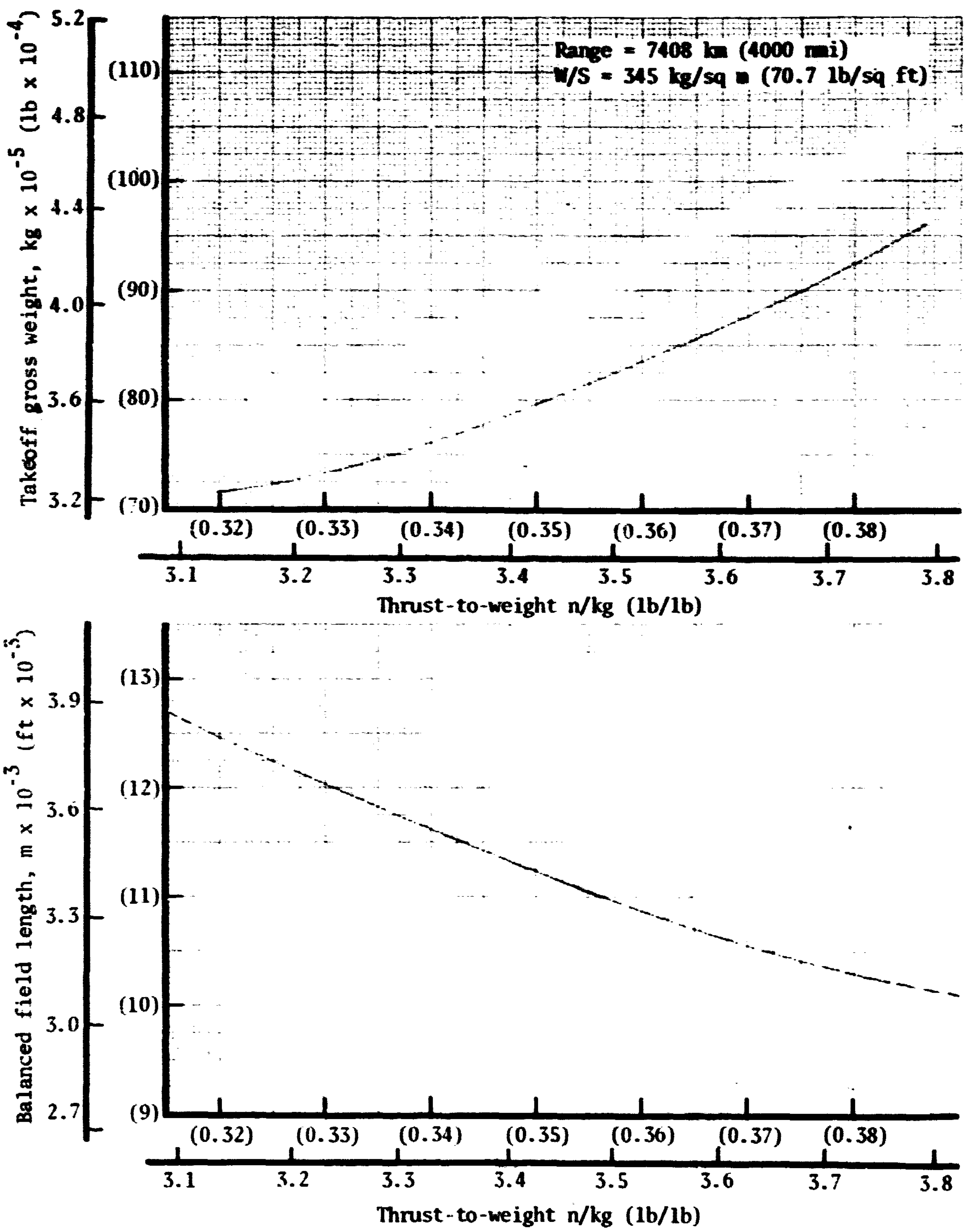


Figure 47. - Sizing with VCE 112C engines.

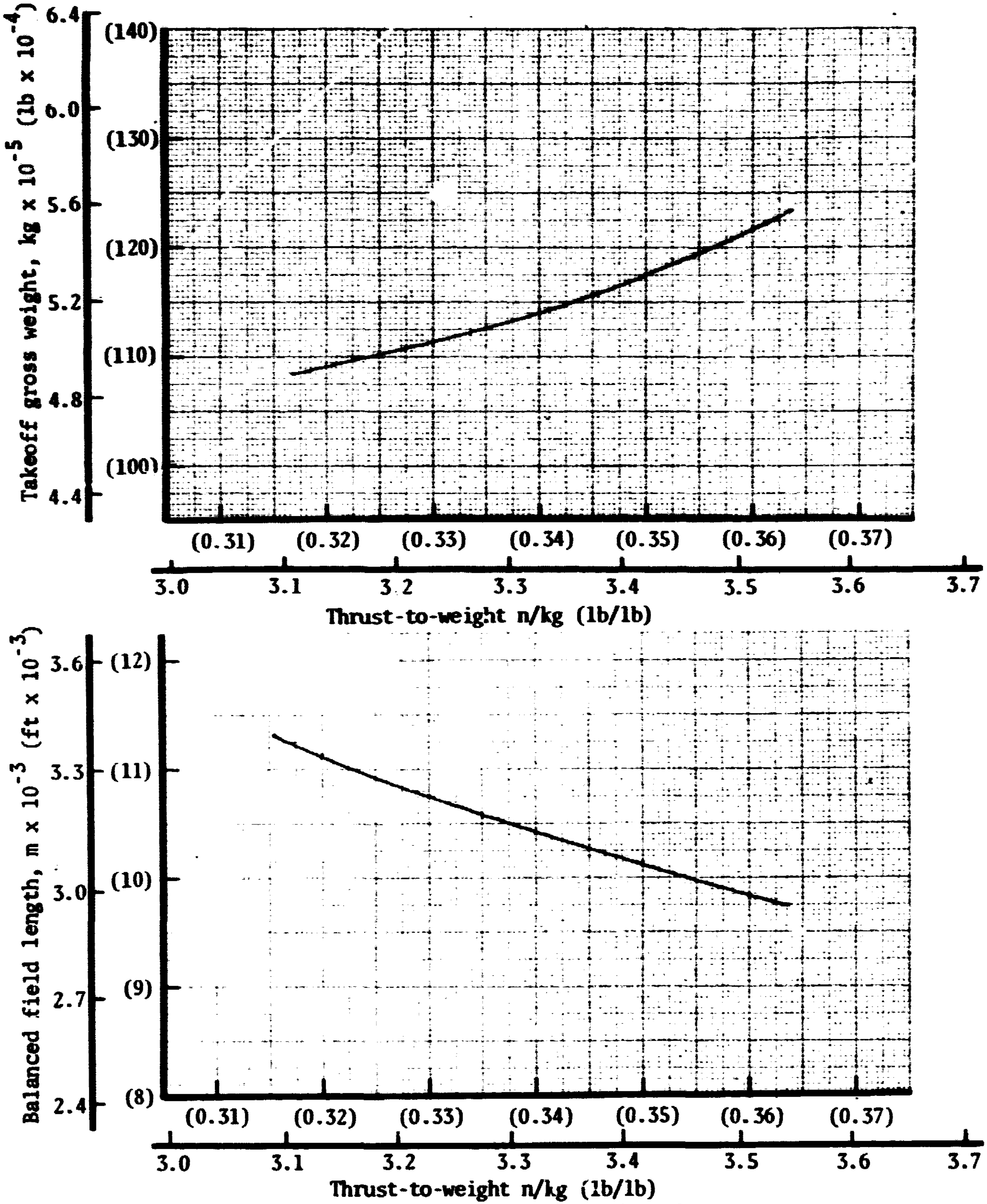


Figure 48.- Sizing with GE21/J10 B1 engines.

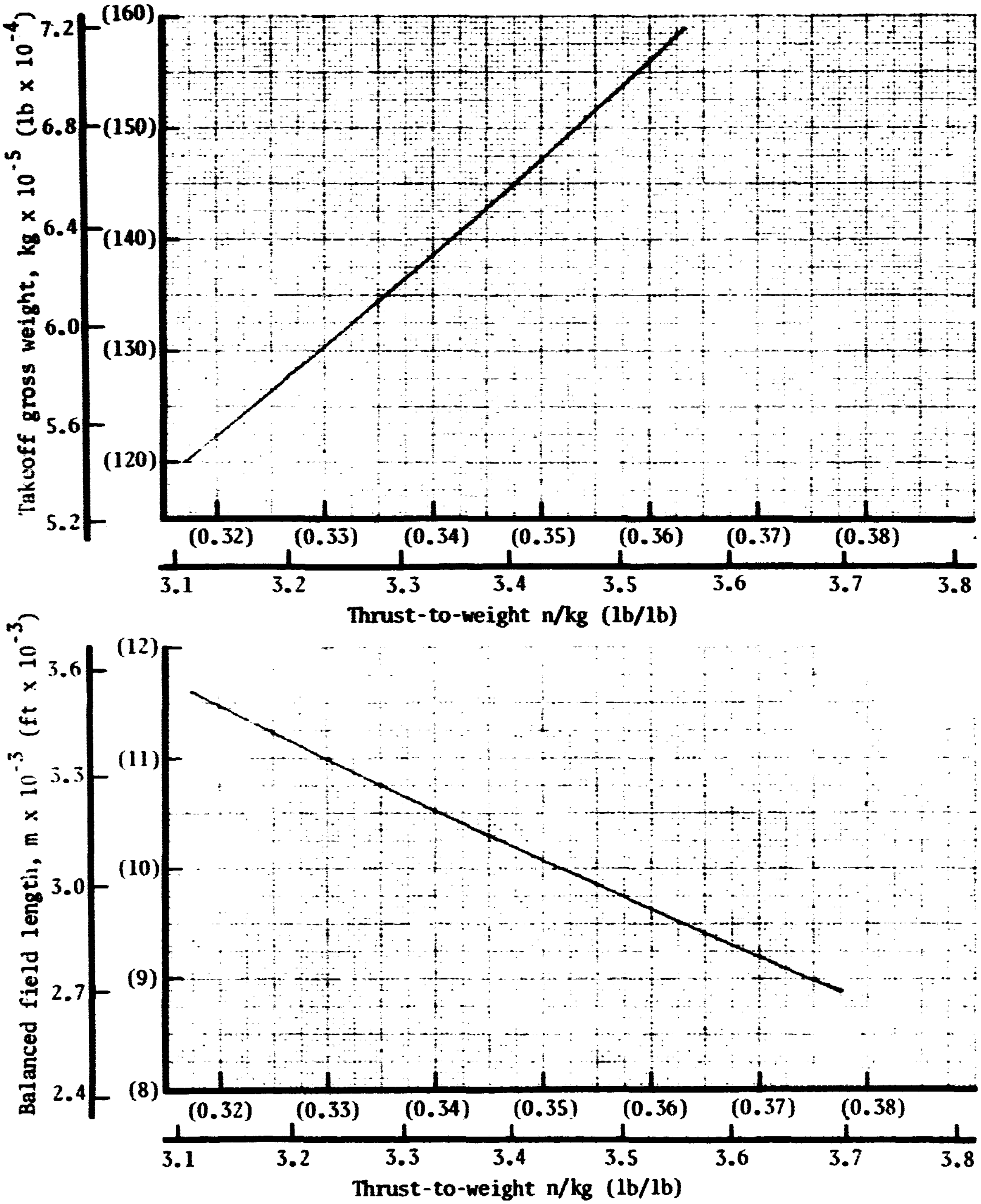


Figure 49.- Sizing with GE21/J11 B3 engines.

TABLE 24. - AIRPLANE CHARACTERISTICS WITH **REFINED VSCE 502B ENGINES**

	Basepoint		Baseline	
Engine airflow, kg/sec (lb/sec)	408	(900)	387	(854)
Thrust-to-weight, n/kg (lb/lb)	3.13	(0.3199)	3.13	(0.320)
Reference wing area, sq m (sq ft)	926	(9969)	841	(9049)
Gross wing area sq m (sq ft)	1022	(10 996)	927	(9981)
Wing loading (gross area), kg/sq m (lb/sq ft)	331	(67.69)	345	(70.71)
TOGW, kg (lb)	337 632	(744 350)	320 141	(705 790)
Fuel weight, kg (lb)	158 683	(349 835)	148 772	(327 986)
Max wing fuel, kg (lb)	208 222	(459 050)	180 061	(396 966)
Design range, km (n mi)	7610	(4109)	7410	(4001)
Eng out range, km (n mi)	6553	(3538)	6384	(3447)
Normal T.O. dist m (ft)	2635	(8645)	2741	(8991)
Bal field length, m (ft)	3076	(10 092)	3197	(10 489)
Thrust-to-drag 2.32 m/18 300 m (60 000 ft)		1.921		1.899
Thrust-to-drag 1.2 m/climb		1.937		1.930
Initial cruise L/D		9.626		9.566
Initial cruise SFC (installed) kg/hr/daN (lb/hr/lb)	1.391	(1.364)	1.389	(1.362)

TABLE 25. - AIRPLANE CHARACTERISTICS WITH VCE 112C ENGINES

	Basepoint		Baseline	
Engine airflow, kg/sec (lb/sec)	408	(900)	600	(1323)
Thrust-to-weight, N/kg (lb/lb)	2.94	(.3004)	3.64	(.372)
Reference wing area, sq m (sq ft)	926	(9969)	1057	(11 380)
Gross wing area, sq m (sq ft)	1 022	(10 996)	1166	(12 552)
Wing loading (gross area), kg/sq m (lb/sq ft)	332	(68.02)	345	(70.7)
TOGW, kg (lb)	339 272	(747 966)	402 618	(887 622)
Fuel weight, kg (lb)	158 683	(349 835)	190 934	(420 938)
Max wing fuel, kg (lb)	208 222	(459 050)	253 954	(559 863)
Design range, km (n mi)	7419	(4006)	7410	(4001)
Eng out range, km (n mi)	6504	(3512)	6434	(3472)
Normal T.O. dist m (ft)	3341	(10 960)	2715	(8907)
Bal field length, m (ft)	3957	(12 982)	3206	(10 519)
Thrust-to-drag at 2.32 M/18 300 m (60 000 ft)		1.220		1.483
Thrust-to-drag at 1.2 M/climb		1.730		2.050
Initial cruise L/D		9.605		9.601
Initial cruise SFC (installed) kg/hr/daN (lb/hr/lb)	1.470	1.442	1.491	(1.462)

TABLE 26.- AIRPLANE CHARACTERISTICS WITH GE21/J10 B1 ENGINES

	Basepoint		Baseline	
Engine airflow, kg/sec (lb/sec)	340	(750)	624	(1375)
Thrust-to-weight, n/kg (lb/lb)	2.71	(.2769)	3.31	(.338)
Reference wing area, sq m (sq ft)	926	(9969)	1351	(14 540)
Gross wing area, sq m (sq ft)	1022	(10 996)	1490	(16 038)
Wing loading (gross area), kg/sq m (lb/sq ft)	335	(68.68	345	(70.71)
TOGW, kg (lb)	342 556	(755 206)	514 441	(1 134 149)
Fuel weight, kg (lb)	158 683	(349 835)	255 446	(563 161)
Max wing fuel, kg (lb_	208 222	(459 050)	366 785	(808 622)
Design range, km (n mi)	5045	(2724)	7410	(4001)
Eng out range, km (n mi)	4939	(2667)	6295	(3399)
Normal, T.O. dist m (ft)	3348	(10 983)	2736	(8977)
Bal field length, m (ft)	3909	(12 823)	3197	(10 490)
Thrust-to-drag at 2.32 M/18 300 m (60 000 ft)		1.084		1.286
Thrust-to-drag at 1.2 M/climb		1.235		1.694
Initial cruise L/D		8.923		9.514
Initial cruise SFC (installed) kg/hr/daN (lb/hr/lb)	1.568	(1.538)	1.457	(1.429)

TABLE 27.- AIRPLANE CHARACTERISTICS WITH GE21/J11 B3 ENGINES

	Basepoint		Baseline	
Engine airflow, kg/sec (lb/sec)	381	(840)	1093	(2409)
Thrust-to-weight, n/kg (lb/lb)	2.16	(.2210)	3.33	(.340)
Reference wing area, sq m (sq ft)	926	(9969)	1653	(17 787)
Gross wing area, sq m (sq ft)	1022	(10 996)	1823	(19 619)
Wing loading (gross area), kg/sq m (lb/sq ft)	330	(67.68)	345	(70.71)
TOGW, kg (lb)	337 557	(744 186)	62[illegible]6	(1 387 359)
Fuel weight, kg (lb)	158 683	(349 835)	312 330	(688 569)
Max wing fuel, kg (lb)	204 139	(450 050)	496 237	(1 094 016)
Design range, km (n mi)			7412	4002)
Eng out range, km (n mi)			6245	(3372)
Normal T.O. dist m (ft)*			2706	(8878)
Bal field length, m (ft)			3205	(10 515)
Thrust-to-drag at 2.32 M/18 300 m (60 000 ft)				1.511
Thrust-to-drag at 1.2 M/climb				2.078
Initial cruise L/D				9.412
Initial cruise SFC (installed) kg/hr/daN (lb/hr/lb)			1.447	(1.419)

*T.O. distance using maximum power. This results in noise levels below FAR 36.

TABLE 28. - REFINED VSCE 502B BASELINE DESIGN MISSION SUMMARY, INTERNATIONAL UNITS

LEG NO.	OPERATION	WEIGHT KG.	ALTITUDE METERS	MACH NO.	FUEL USED KG.	TIME MIN.	TOTAL TIME MIN.	RANGE KM.	TOTAL RANGE KM.
	INITIAL WEIGHT	320140.9							
1	WU & TO	316337.4	0.0	0.299	3803.4	10.000	10.000	0.0	0.0
2	CL TO15C	314196.4	457.2	0.500	2141.1	1.337	11.337	10.72	10.72
3	CLB-ACC	290050.4	17221.5	2.320	24146.0	12.525	23.862	287.30	298.02
4	CRUISE	238657.2	18402.3	2.320	51393.2	81.462	105.324	3407.20	3705.22
5	CRUISE	195887.7	19756.2	2.320	42769.4	80.963	186.288	3386.35	7091.57
6	DESCEND	194324.4	457.2	0.500	1563.4	17.680	203.967	305.45	7397.02
7	DES-LAND	194084.7	0.0	0.300	239.6	1.607	205.574	13.43	7410.45
8	TAXI-ALL	193449.6	0.0	0.0	635.2	5.000	210.574	0.0	7410.45
9	5PCT ALL	187114.9	0.0	0.0	6334.6	0.0	210.574	0.0	7410.45
10	CLTO 15C	186529.2	457.2	0.500	585.8	0.739	211.313	5.66	7416.11
11	CLB-ACC	181900.4	11990.1	0.900	4628.8	8.236	219.549	124.09	7540.20
12	CRUISE	179047.9	12092.4	0.900	2852.4	13.521	233.071	219.39	7759.59
13	DESCEND	178189.5	3048.0	0.466	858.5	9.375	242.446	119.41	7879.00
14	LOITER	171902.2	3048.0	0.454	6287.3	30.000	272.446	0.0	7879.00
15	DES-LAND	171359.3	0.0	0.300	542.8	3.877	276.323	35.05	7914.05
			TOTAL FUEL USED=		148781.2				

TABLE 29.- REFINED VSCE 502B BASELINE DESIGN MISSION SUMMARY, ENGLISH UNITS

NASA CR-132374 AST REF. CONFIG. WITH VSCE 502B-02 ENGINES
LEWIS BASELINE T/W=.32 W/S=78. RDES=4000 NM

LEG NO.	OPERATION	WEIGHT POUNDS	ALTITUDE FEET	MACH NO.	FUEL USED POUNDS	TIME MIN.	TOTAL TIME MIN.	RANGE N. M.	TOTAL RANGE N. M.
	INITIAL WEIGHT	705789.9							
1	WU & TO	697404.8	0.0	0.299	8385.1	10.000	10.000	0.0	0.0
2	CL TO15C	692684.6	1500.0	0.500	4720.2	1.337	11.337	5.79	5.79
3	CLB-ACC	639451.8	56500.9	2.320	53232.7	12.525	23.862	155.13	160.92
4	CRUISE	526149.2	60374.9	2.320	113302.6	81.462	105.324	1839.71	2000.62
5	CRUISE	431858.7	64816.8	2.320	94290.5	80.963	186.288	1828.45	3829.08
6	DESCEND	428411.9	1500.0	0.500	3446.7	17.680	203.967	164.93	3994.00
7	DES-LAND	427883.7	0.0	0.300	528.2	1.607	205.574	7.25	4001.25
8	TAXI-ALL	426483.3	0.0	0.0	1400.4	5.000	210.574	0.0	4001.25
9	5PCT ALL	412517.9	0.0	0.0	13965.4	0.0	210.574	0.0	4001.25
10	CLTO 15C	411226.6	1500.0	0.500	1291.4	0.739	211.313	3.06	4004.31
11	CLB-ACC	401021.7	39337.6	0.900	10204.8	8.236	219.549	67.00	4071.31
12	CRUISE	394733.2	39673.3	0.900	6288.6	13.521	233.071	118.46	4189.77
13	DESCEND	392840.6	10000.0	0.466	1892.6	9.375	242.446	64.48	4254.24
14	LOITER	378979.5	10000.0	0.454	13861.1	30.000	272.446	0.0	4254.24
15	DES-LAND	377782.7	0.0	0.300	1196.7	3.877	276.323	18.93	4273.17
			TOTAL FUEL USED=		328007.1				

TABLE 30. - VCE 112C BASELINE DESIGN MISSION SUMMARY, INTERNATIONAL UNITS

LEG NO.	OPERATION	WEIGHT KG.	ALTITUDE METERS	MACH NO.	FUEL USED KG.	TIME MIN.	TOTAL TIME MIN.	RANGE KM.	TOTAL RANGE KM.
	INITIAL WEIGHT	402618.3							
1	WU & TO	398212.2	0.0	0.299	4406.2	10.000	10.000	0.0	0.0
2	CL TO15C	396092.0	457.2	0.500	2120.1	1.334	11.334	10.60	10.60
3	CLB-ACC	370960.4	18063.6	2.320	25131.6	12.991	24.324	320.56	331.16
4	CRUISE	301835.9	19678.5	2.320	69124.4	80.672	104.996	3374.17	3705.33
5	CRUISE	244642.1	21247.6	2.320	57193.9	81.124	186.120	3397.49	7102.82
6	DESCEND	242332.6	457.2	0.500	2309.5	16.797	202.917	295.10	7397.91
7	DES-LAND	241980.9	0.0	0.300	351.7	1.523	204.440	12.82	7410.73
8	TAXI-ALL	240996.6	0.0	0.0	984.3	5.000	209.440	0.0	7410.73
9	5PCT ALL	232915.6	0.0	0.0	8081.1	0.0	209.440	0.0	7410.73
10	CLTO 15C	232263.8	457.2	0.500	651.7	0.619	210.059	4.78	7415.51
11	CLB-ACC	226368.2	12684.3	0.900	5895.6	9.457	219.516	130.89	7546.40
12	CRUISE	222708.3	12798.6	0.900	3660.0	13.063	232.579	211.96	7758.35
13	DESCEND	221396.2	3048.0	0.442	1312.0	9.346	241.925	120.16	7878.52
14	LOITER	212458.7	3048.0	0.432	8937.6	30.000	271.925	0.0	7878.52
15	DES-LAND	211690.4	0.0	0.300	768.3	3.533	275.458	31.74	7910.25

TOTAL FUEL USED= 190927.5

TABLE 31. - VCE 112C BASELINE DESIGN MISSION SUMMARY, ENGLISH UNITS

LEG NO.	OPERATION	WEIGHT POUNDS	ALTITUDE FEET	MACH NO.	FUEL USED POUNDS	TIME MIN.	TOTAL TIME MIN.	RANGE N. M.	TOTAL RANGE N. M.
	INITIAL WEIGHT	887621.6							
1	WU & TO	877907.6	0.0	0.299	9713.9	10.000	10.000	0.0	0.0
2	CL TO15C	873233.5	1500.0	0.500	4674.1	1.334	11.334	5.73	5.73
3	CLB-ACC	817827.9	59263.7	2.320	55405.6	12.991	24.324	173.09	178.81
4	CRUISE	665434.4	64562.1	2.320	152393.4	80.672	104.996	1821.87	2000.68
5	CRUISE	539343.6	69710.1	2.320	126090.9	81.124	186.120	1834.47	3835.15
6	DESCEND	534252.1	1500.0	0.500	5091.5	16.797	202.917	159.34	3994.49
7	DES-LAND	533476.7	0.0	0.300	775.3	1.523	204.440	6.92	4001.41
8	TAXI-ALL	531306.7	0.0	0.0	2170.1	5.000	209.440	0.0	4001.41
9	5PCT ALL	513490.9	0.0	0.0	17815.7	0.0	209.440	0.0	4001.41
10	CL TO 15C	512054.2	1500.0	0.500	1436.7	0.619	210.059	2.58	4003.99
11	CLB-ACC	499056.6	41515.1	0.900	12997.6	9.457	219.516	70.67	4074.66
12	CRUISE	490987.8	41990.3	0.900	8068.8	13.063	232.579	114.45	4189.11
13	DESCEND	488095.2	10000.0	0.442	2892.6	9.346	241.925	64.88	4253.98
14	LOITER	468391.3	10000.0	0.432	19703.9	30.000	271.925	0.0	4253.98
15	DES-LAND	466697.6	0.0	0.300	1693.7	3.533	275.458	17.14	4271.12
			TOTAL FUEL USED=		420924.0				

TABLE 32. - GE21/J10 [illegible] BASELINE DESIGN MISSION SUMMARY, INTERNATIONAL UNITS

LEG NO.	OPERATION	WEIGHT KG.	ALTITUDE METERS	MACH NO.	FUEL USED KG.	TIME MIN.	TOTAL TIME MIN.	RANGE KM.	TOTAL RANGE KM.
	INITIAL WEIGHT	514441.3							
1	WU & TO	509639.1	0.0	0.299	4802.2	10.000	10.000	0.0	0.0
2	CL TO ISC	506022.2	457.2	0.500	3316.6	1.280	11.280	10.16	10.16
3	CLB-ACC	461066.2	17538.4	2.320	44954.0	18.868	30.148	477.15	487.31
4	CRUISE	380125.6	18715.0	2.320	81542.7	76.936	107.084	3217.88	3705.19
5	CRUISE	308672.2	19901.2	2.320	71453.3	80.827	187.911	3380.66	7085.85
6	DESCEND	306096.3	457.2	0.500	2575.9	18.055	205.965	310.60	7396.45
7	DES-LAND	305700.4	0.0	0.300	395.8	1.649	207.614	13.94	7410.38
8	TAXI-ALL	304077.2	0.0	0.0	1623.2	5.000	212.614	0.0	7410.38
9	SPCT ALL	294189.0	0.0	0.0	10488.2	0.0	212.614	0.0	7410.38
10	CLTO ISC	293079.6	457.2	0.500	1109.5	0.492	213.106	3.84	7414.22
11	CLB-ACC	279368.5	17288.8	0.950	13711.0	10.597	223.612	190.12	7604.34
12	CRUISE	277377.4	17286.6	0.950	1991.1	6.362	229.974	108.96	7713.30
13	DESCEND	275666.6	3048.0	0.348	1710.8	12.115	242.089	163.93	7877.23
14	LOITER	259781.6	3048.0	0.350	15885.0	30.000	272.089	0.0	7877.23
15	DES-LAND	258988.7	0.0	0.300	792.9	3.480	275.569	30.86	7908.09

TOTAL FUEL USED= 255452.1

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TABLE 33. - GE21/J10 B1 BASELINE DESIGN MISSION SUMMARY, ENGLISH UNITS

LEG NO.	OPERATION	WEIGHT POUNDS	ALTITUDE FEET	MACH NO.	FUEL USED POUNDS	TIME MIN.	TOTAL TIME MIN.	RANGE N. M.	TOTAL RANGE N. M.
	INITIAL WEIGHT	1134149.0							
1	WU & TO	1123562.0	0.0	0.299	10587.0	10.000	10.000	0.0	0.0
2	CL TO15C	1116911.3	1500.0	0.500	6651.0	1.280	11.280	5.48	5.48
3	CLB-ACC	1017604.3	57540.6	2.320	99106.7	18.868	30.148	257.64	263.12
4	CRUISE	838033.4	61384.7	2.320	179770.4	76.936	107.084	1737.49	2000.61
5	CRUISE	680505.7	65292.6	2.320	157527.7	80.827	187.911	1825.38	3825.99
6	DESCEND	674826.9	1500.0	0.500	5678.4	18.055	205.965	167.71	3993.69
7	DES-LAND	673954.2	0.0	0.300	872.7	1.649	207.614	7.52	4001.22
8	TAXI-ALL	671698.4	0.0	0.0	2255.7	5.000	212.614	0.0	4001.22
9	5PCT ALL	648575.9	0.0	0.0	23122.6	0.0	212.614	0.0	4001.22
10	CLTO 15C	646129.4	1500.0	0.500	2446.0	0.492	213.106	2.07	4003.29
11	CLB-ACC	615902.2	56721.8	0.950	30227.7	10.507	223.612	102.66	4105.95
12	CRUISE	611512.6	56714.7	0.950	4389.6	6.362	229.974	56.83	4164.77
13	DESCEND	607741.0	10000.0	0.348	3771.6	12.115	242.089	88.51	4253.24
14	LOITER	572720.5	10000.0	0.350	35520.5	30.000	272.084	0.0	4253.24
15	DES-LAND	570972.6	0.0	0.300	1747.4	3.486	275.569	16.66	4269.95
			TOTAL FUEL USED=		563176.4				

TABLE 34. - GE21/J11 B3 BASELINE DESIGN MISSION SUMMARY, INTERNATIONAL UNITS

LEG NO.	OPERATION	WEIGHT KG.	ALTITUDE METERS	MACH NO.	FUEL USED KG.	TIME MIN.	TOTAL TIME MIN.	RANGE KM.	TOTAL RANGE KM.
	INITIAL WEIGHT	629295.4							
1	WU & TO	622324.6	0.0	0.299	6970.8	10.000	10.000	0.0	0.0
2	CL TO15C	619027.4	457.2	0.500	3297.2	0.914	10.914	7.04	7.04
3	CLB-ACC	573152.9	18712.9	2.320	45874.5	12.897	23.811	321.51	328.55
4	CRUISE	467000.2	20118.3	2.320	105887.3	80.733	104.544	3376.88	3705.43
5	CRUISE	378848.1	21470.4	2.320	87886.7	81.401	185.945	3414.13	7119.56
6	DESCEND	374795.3	457.2	0.500	4052.8	16.151	202.096	284.82	7404.38
7	DES-LAND	374172.1	0.0	0.300	623.3	1.483	203.579	12.47	7416.85
8	TAXI-ALL	372379.6	0.0	0.0	1792.9	5.000	208.579	0.0	7416.85
9	5PCT ALL	359560.4	0.0	0.0	12819.3	0.0	208.579	0.0	7416.85
10	CLTO 15C	358252.1	457.2	0.500	1308.3	0.340	208.919	2.56	7419.41
11	CLB-ACC	347471.4	14352.7	0.950	10780.2	5.438	214.357	87.67	7507.08
12	CRUISE	340263.0	14535.0	0.950	7208.8	14.056	228.413	234.74	7741.82
13	DESCEND	337646.0	3048.0	0.320	2616.5	10.351	238.764	134.59	7876.41
14	LOITER	318150.9	3048.0	0.304	19495.6	30.000	268.764	0.0	7876.41
15	DES-LAND	316980.6	0.0	0.300	1170.3	2.922	271.686	25.58	7901.99
			TOTAL FUEL USED=		312314.8				

TABLE 35. - GE21/J11 B3 BASELINE DESIGN MISSION SUMMARY, ENGLISH UNITS

LEG NO.	OPERATION	WEIGHT POUNDS	ALTITUCE FEET	MACH NO.	FUEL USED POUNDS	TIME MIN.	TOTAL TIME MIN.	RANGE N. M.	TOTAL RANGE N. M.
	INITIAL WEIGHT	1387359.0							
1	WU & TO	1371991.0	0.0	0.299	15368.0	10.000	10.000	0.0	0.0
2	CL TO15C	1364722.0	1500.0	0.500	7269.0	0.914	10.914	3.80	3.80
3	CLB-ACC	1263586.0	61394.0	2.320	101136.0	12.897	23.811	173.60	177.40
4	CRUISE	1029559.3	66005.1	2.320	233441.7	80.733	104.544	1823.34	2000.74
5	CRUISE	835217.1	70441.0	2.320	193757.2	81.401	185.945	1841.30	3842.04
6	DESCEND	826282.2	1500.0	0.500	8934.9	16.151	202.096	152.70	3994.74
7	DES-LAND	824908.2	0.0	0.300	1374.1	1.483	203.579	6.73	4001.47
8	TAXI-ALL	820956.6	0.0	0.0	3952.6	5.000	208.579	0.0	4001.47
9	SPCT ALL	792694.9	0.0	0.0	28261.7	0.0	208.579	0.0	4001.47
10	CLTO 15C	789810.6	1500.0	0.500	2884.4	0.340	208.919	1.39	4002.86
11	CLB-ACC	766043.2	47089.1	0.950	23766.3	5.438	214.357	47.34	4050.20
12	CRUISE	750151.6	47686.9	0.950	15892.7	14.056	228.413	129.99	4180.18
13	DESCEND	744332.1	10000.0	0.320	5768.4	10.351	238.764	72.67	4252.85
14	LOITER	701402.7	10000.0	0.304	42980.4	30.000	268.764	0.0	4252.85
15	DES-LAND	698822.7	0.0	0.300	2580.1	2.922	271.686	13.81	4266.66
				TOTAL FUEL USED=	688536.3				

TABLE 36. - ECONOMIC MISSION CHARACTERISTICS WITH REFINED VSCE 502B ENGINES

	Baseline	
TOGW, kg (lb)	254 141	(560 284)
Fuel weight, kg (lb)	95 229	(209 943)
Design range, km (nmi)	4630	(2500)
Far 36 T.O. dist m (ft)	1753	(5750)
Bal field length, m (ft)	2081	(6826)
Airframe weight, kg (lb)	112 768	(248 611)
Engine weight, kg (lb)	23 128	(50 988)
Mission fuel weight, kg (lb)	76 501	(168 655)
Block time, min (min)		(167)
Engine thrust, n (lb)	251 160	(56 463)

TABLE 37. - ECONOMIC MISSION CHARACTERISTICS WITH VCE 112C ENGINES

	Baseline	
TOGW, kg (lb)	320 966	(707 608)
Fuel weight, kg (lb)	121 739	(268 390)
Range, km (nmi)	4630	(2500)
Far, 36 T.O. dist m (ft)	1724	(5656)
Bal field length, m (ft)	2070	(6794)
Airframe weight, kg (lb)	138 186	(304 645)
Engine weight, kg (lb)	37 932	(83 626)
Mission fuel weight, kg (lb)	96 639	(213 048)
Block time, min (min)		(167)
Engine thrust, n (lb)	367 178	(82 549)

TABLE 38. - ECONOMIC MISSION CHARACTERISTICS WITH GE21/J10 B1 ENGINES

	Baseline	
TOGW, kg (lb)	417 609	(920 670)
Fuel weight, kg (lb)	171 070	(377 144)
Design range, km (nmi)	4630	(2500)
Far 36 T.O. dist m (ft)	1816	(5959)
Bal field length, m (ft)	2159	(7083)
Airframe weight, kg (lb)	166 931	(368 020)
Engine weight, kg (lb)	56 360	(124 253)
Mission fuel weight, kg (lb)	130 675	(288 088)
Block time, min (min)		(169)
Engine thrust, n (lb)	426 300	(95 836)

TABLE 39. - ECONOMIC MISSION CHARACTERISTICS WITH GE21/J11 B3 ENGINES

	Baseline	
TOGW, kg (lb)	519 218	(1 144 680)
Fuel weight, kg (lb)	214 709	(473 353)
Design range, km (nmi)	4630	(2500)
Far 36 T.O. dist, m (ft)	1855	(6087)
Bal field length, m (ft)	2232	(7323)
Airframe weight, kg (lb)	207 300	(457 018)
Engine weight, kg (lb)	73 812	(162 728)
Mission fuel weight, kg (lb)	162 334	(357 886)
Block time, min (min)		(166)
Engine thrust, n (lb)	524 557	(117 925)

TABLE 40. - DOC, IOC, AND ROI

	VSCE 502B	VCE 112C
Direct operating cost, cents/seat statute mile	2.17	2.73
Indirect operating cost, cents/seat statute mile	0.91	0.98
Return on investment, %	20.2	11.0

Assumptions:

1. 1974 dollars
2. 1967 ATA DOC model updated to 1974
3. Lockheed California Co. IOC model
4. 4000 hours annual utilization
5. 15-year life
6. Fuel cost of 35 cents per gallon
7. Revenue of 8.5 cents per passenger statute mile
8. 55 percent load factor
9. 2500 n.mi. trip distance

TABLE 41. - VSCE 502B BASELINE ECONOMIC MISSION SUMMARY, INTERNATIONAL UNITS

LEG NO.	OPERATION	WEIGHT KG.	ALTITUDE METERS	MACH NO.	FUEL USED KG.	TIME MIN.	TOTAL TIME MIN.	RANGE KM.	TOTAL RANGE KM.
	INITIAL WEIGHT	254140.6							
1	WU & TO	250337.2	0.0	0.299	3803.4	10.000	10.000	0.0	0.0
2	CL/1500	249074.7	457.2	0.500	1262.5	0.849	10.849	6.73	6.73
3	CLIMB	242143.7	10040.1	0.900	6931.0	3.524	14.373	48.12	54.85
4	CRUISE	230545.3	10411.0	0.900	11598.4	41.802	56.174	685.97	740.81
5	CL/ACCEL	220048.7	18950.7	2.320	10496.6	5.667	61.841	162.34	903.16
6	CRUISE	180043.9	20397.5	2.320	40004.8	81.576	143.417	3413.21	4316.36
7	DESCEND	178512.9	457.2	0.500	1531.0	17.303	160.720	300.22	4616.58
8	DES/LAND	178275.1	0.0	0.300	237.7	1.596	162.316	13.45	4630.03
9	TAXI	177639.9	0.0	0.0	635.2	5.000	167.316	0.0	4630.03
10	5% RES.	173814.9	0.0	0.0	3825.0	0.0	167.316	0.0	4630.03
11	CL/1500	173289.6	457.2	0.500	525.3	0.662	167.978	5.07	4635.10
12	CL/ACCEL	168790.1	12497.3	0.900	4499.5	8.594	176.573	129.76	4764.86
13	CRUISE	166239.4	12594.8	0.900	2550.7	12.975	189.548	210.53	4975.38
14	DESCEND	165367.9	3048.0	0.450	871.5	9.597	199.145	122.73	5098.11
15	LOITER	159438.6	3048.0	0.440	5929.2	30.000	229.145	0.0	5098.11
16	DES/LAND	158516.4	0.0	0.300	522.3	3.724	232.869	33.51	5131.62
			TOTAL FUEL USED=		95223.7				

TABLE 42. - VSCE 502B BASELINE ECONOMIC MISSION SUMMARY, ENGLISH UNITS

LEG NO.	OPERATION	WEIGHT POUNDS	ALTITUDE FEET	MACH NO.	FUEL USED POUNDS	TIME MIN.	TOTAL TIME MIN.	RANGE N. M.	TOTAL RANGE N. M.
	INITIAL WEIGHT	560284.1							
1	WU & TO	551899.1	0.0	0.299	8385.1	10.000	10.000	0.0	0.0
2	CL/1500	549115.8	1500.0	0.500	2783.2	0.849	10.849	3.63	3.63
3	CLIMB	533835.6	32939.8	0.900	15280.2	3.524	14.373	25.98	29.61
4	CRUISE	508265.4	34156.7	0.900	25570.2	41.802	56.174	370.39	400.00
5	CL/ACCEL	485124.5	62174.3	2.320	23140.9	5.667	61.841	87.66	487.66
6	CRUISE	396928.9	66920.9	2.320	89195.6	81.576	143.417	1842.95	2330.61
7	DESCEND	393553.6	1500.0	0.500	3375.4	17.303	160.720	162.10	2492.71
8	DES/LAND	393029.4	0.0	0.300	524.1	1.596	162.316	7.26	2499.97
9	TAXI	391629.1	0.0	0.0	1400.4	5.000	167.316	0.0	2499.97
10	5% RES.	383196.3	0.0	0.0	8432.7	0.0	167.316	0.0	2499.97
11	CL/1500	382038.2	1500.0	0.500	1158.1	0.662	167.978	2.74	2502.71
12	CL/ACCEL	372118.6	41001.6	0.900	9919.7	8.594	176.573	70.06	2572.77
13	CRUISE	366495.1	41321.5	0.900	5623.4	12.975	189.548	113.67	2686.45
14	DESCEND	364573.9	10000.0	0.450	1921.2	9.597	199.145	66.27	2752.72
15	LOITER	351502.1	10000.0	0.440	13071.7	30.000	229.145	0.0	2752.72
16	DES/LAND	350350.7	0.0	0.300	1151.4	3.724	232.869	18.09	2770.81

TOTAL FUEL USED= 209933.4

TABLE 43. - VCE 112C BASELINE ECONOMIC MISSION SUMMARY, INTERNATIONAL UNITS

LEG NO.	OPERATION	WEIGHT KG.	ALTITUDE METERS	MACH NO.	FUEL USED KG.	TIME MIN.	TOTAL TIME MIN.	RANGE KM.	TOTAL RANGE KM.
	INITIAL WEIGHT	320965.7							
1	WU & TO	316559.6	0.0	0.299	4406.2	10.000	10.000	0.0	0.0
2	CL/1500	315299.3	457.2	0.500	1260.2	0.805	10.805	6.40	6.40
3	CLIMB	308794.2	10627.0	0.900	6505.1	3.411	14.217	45.95	52.35
4	CRUISE	292980.3	11294.8	0.900	15813.9	42.313	56.530	688.46	740.81
5	CL/ACCEL	281330.4	20226.5	2.320	11649.4	6.256	62.786	195.15	935.96
6	CRUISE	227925.5	21726.3	2.320	53405.5	80.944	143.729	3392.36	4328.32
7	DESCEND	225662.4	457.2	0.500	2263.1	16.445	160.175	289.75	4618.07
8	DES/LAND	225313.0	0.0	0.300	349.4	1.514	161.689	12.72	4630.79
9	TAXI	224328.7	0.0	0.0	984.3	5.000	166.689	0.0	4630.79
10	5% RES.	219496.8	0.0	0.0	4831.9	0.0	166.689	0.0	4630.79
11	CL/1500	218896.4	457.2	0.500	600.4	0.570	167.259	4.40	4635.19
12	CL/ACCEL	213294.7	13076.8	0.900	5601.6	9.226	176.485	127.26	4762.45
13	CRUISE	209811.7	13192.4	0.900	3483.0	13.164	189.649	213.59	4976.04
14	DESCEND	208488.1	3048.0	0.428	1323.6	9.483	199.132	122.07	5098.11
15	LOITER	199967.3	3048.0	0.418	8520.8	30.000	229.132	0.0	5098.11
16	DES/LAND	199226.1	0.0	0.300	741.2	3.404	232.536	30.45	5128.55

TOTAL FUEL USED= 121734.4

TABLE 44. - VCE 112C BASELINE ECONOMIC MISSION SUMMARY, ENGLISH UNITS

LEG NO.	OPERATION	WEIGHT POUNDS	ALTITUDE FEET	MACH NO.	FUEL USED POUNDS	TIME MIN.	TOTAL TIME MIN.	RANGE N. M.	TOTAL RANGE N. M.
	INITIAL WEIGHT	707608.4							
1	WU & TO	697894.4	0.0	0.299	9713.9	10.000	10.000	0.0	0.0
2	CL/1500	695116.1	1500.0	0.500	2778.4	0.805	10.805	3.46	3.46
3	CLIMB	680774.3	34865.5	0.900	14341.2	3.411	14.217	24.81	28.27
4	CRUISE	645911.1	37056.3	0.900	34863.7	42.313	56.530	371.73	400.00
5	CL/ACCEL	620229.6	66360.0	2.320	25682.4	6.256	62.786	105.37	505.37
6	CRUISE	502489.7	71279.5	2.320	117738.9	80.944	143.729	1831.70	2337.06
7	DESCEND	497500.4	1500.0	0.500	4989.5	16.445	160.175	156.45	2493.51
8	DES/LAND	496730.2	0.0	0.300	770.2	1.514	161.689	6.87	2500.38
9	TAXI	494560.1	0.0	0.0	2170.1	5.000	166.689	0.0	2500.38
10	5% RES.	483907.7	0.0	0.0	10652.4	0.0	166.689	0.0	2500.38
11	CL/1500	482583.9	1500.0	0.500	1323.7	0.570	167.259	2.38	2502.76
12	CL/ACCEL	470234.4	42909.3	0.900	12349.5	9.226	176.485	68.72	2571.48
13	CRUISE	462555.7	43282.3	0.900	7678.7	13.164	189.649	115.33	2686.80
14	DESCEND	459637.7	10000.0	0.428	2918.0	9.483	199.132	65.91	2752.71
15	LOITER	440852.5	10000.0	0.418	18785.2	30.000	229.132	0.0	2752.71
16	DES/LAND	439218.4	0.0	0.300	1634.1	3.404	232.536	16.44	2769.15
			TOTAL FUEL USED=		268390.0				

TABLE 45. - GE21/J10 B1 BASELINE ECONOMIC MISSION SUMMARY, INTERNATIONAL UNITS

LEG NO.	OPERATION	WEIGHT KG.	ALTITUDE METERS	MACH NO.	FUEL USED KG.	TIME MIN.	TOTAL TIME MIN.	RANGE KM.	TOTAL RANGE KM.
	INITIAL WEIGHT	417609.0							
1	WU & TO	412807.1	0.0	0.299	4801.8	10.000	10.000	0.0	0.0
2	CL/1500	410924.7	457.2	0.500	1882.4	0.805	10.805	6.38	6.38
3	CLIMB	399927.5	10355.3	0.900	10997.3	4.033	14.838	56.32	62.71
4	CRUISE	377390.7	10765.7	0.900	22536.7	41.519	56.357	678.11	740.81
5	CL/ACCEL	356615.6	19079.6	2.320	20775.2	9.402	65.759	282.65	1023.46
6	CRUISE	290890.4	20244.4	2.320	65725.2	78.574	144.333	3287.02	4310.48
7	DESCEND	288352.2	457.2	0.500	2538.1	17.781	162.114	306.12	4616.59
8	DES/LAND	287957.5	0.0	0.300	394.7	1.645	163.758	13.88	4630.47
9	TAXI	286934.3	0.0	0.0	1023.2	5.000	168.758	0.0	4630.47
10	5% RES.	280400.6	0.0	0.0	6533.7	0.0	168.758	0.0	4630.47
11	CL/1500	279357.5	457.2	0.500	1043.1	0.463	169.221	3.61	4634.07
12	CL/ACCEL	266916.7	17285.0	0.950	12440.8	10.914	180.135	187.66	4821.73
13	CRUISE	264997.7	17291.9	0.950	1919.0	6.675	186.810	114.32	4936.04
14	DESCEND	263318.3	3048.0	0.354	1679.4	11.899	198.709	161.04	5097.09
15	LOITER	247298.6	3048.0	0.333	16019.7	30.000	228.709	0.0	5097.09
16	DES/LAND	246531.1	0.0	0.300	767.5	3.364	232.073	29.69	5126.77
			TOTAL FUEL USED=		171077.6				

TABLE 46. - GE21/J10 B1 BASELINE ECONOMIC MISSION SUMMARY, ENGLISH UNITS

LEG NO.	OPERATION	WEIGHT POUNDS	ALTITUDE FEET	MACH NO.	FUEL USED POUNDS	TIME MIN.	TOTAL TIME MIN.	RANGE N. M.	TOTAL RANGE N. M.
	INITIAL WEIGHT	920670.3							
1	WU & TO	910084.1	0.0	0.299	10586.2	10.000	10.000	0.0	0.0
2	CL/1500	905934.1	1500.0	0.500	4149.9	0.805	10.805	3.45	3.45
3	CLIMB	881689.2	33574.1	0.900	24244.9	4.033	14.838	30.41	33.86
4	CRUISE	832004.2	35320.6	0.900	49685.0	41.519	56.357	366.14	400.00
5	CL/ACCEL	786202.9	62597.0	2.320	45801.4	9.402	65.759	152.62	552.61
6	CRUISE	641303.6	66418.6	2.320	144899.2	78.574	144.333	1774.82	2327.43
7	DESCEND	635708.0	1500.0	0.500	5595.6	17.781	162.114	165.29	2492.72
8	DES/LAND	634837.7	0.0	0.300	870.2	1.645	163.758	7.49	2500.21
9	TAXI	632582.0	0.0	0.0	2255.7	5.000	168.758	0.0	2500.21
10	5% RES.	618177.6	0.0	0.0	14404.4	0.0	168.758	0.0	2500.21
11	CL/1500	615878.0	1500.0	0.500	2299.6	0.463	169.221	1.95	2502.16
12	CL/ACCEL	588450.7	56709.4	0.950	27427.3	10.914	180.135	101.33	2603.49
13	CRUISE	584219.9	56732.0	0.950	4230.7	6.675	186.810	61.72	2665.21
14	DESCEND	580517.6	10000.0	0.354	3702.4	11.899	198.709	86.95	2752.16
15	LOITER	545200.2	10000.0	0.333	35317.4	30.000	228.709	0.0	2752.16
16	DES/LAND	543508.1	0.0	0.300	1692.1	3.364	232.073	16.03	2768.19
			TOTAL FUEL USED=		377162.2				

TABLE 47. - GE21/J11 B3 BASELINE ECONOMIC MISSION SUMMARY, INTERNATIONAL UNITS

LEG NO.	OPERATION	WEIGHT KG.	ALTITUDE METERS	MACH NO.	FUEL USED KG.	TIME MIN.	TOTAL TIME MIN.	RANGE KM.	TOTAL RANGE KM.
	INITIAL WEIGHT	519218.1							
1	WU & TO	512247.2	0.0	0.299	6970.8	10.000	10.000	0.0	0.0
2	CL/1500	510007.9	457.2	0.500	2239.4	0.622	10.622	4.79	4.79
3	CLIMB	496818.7	10771.1	0.900	13189.1	3.312	13.934	45.68	50.47
4	CRUISE	468672.7	11072.3	0.900	28146.1	42.473	56.407	690.34	740.81
5	CL/ACCEL	447330.5	20390.2	2.320	21342.2	6.511	62.918	198.93	939.74
6	CRUISE	363297.9	21743.0	2.320	84032.6	81.088	144.006	3399.06	4338.80
7	DESCEND	359297.4	457.2	0.500	4000.5	15.934	159.940	279.36	4618.15
8	DES/LAND	358676.6	0.0	0.300	620.8	1.478	161.418	12.40	4630.55
9	TAXI	356883.7	0.0	0.0	1792.9	5.000	166.418	0.0	4630.55
10	5% RES.	348767.0	0.0	0.0	8116.7	0.0	166.418	0.0	4630.55
11	CL/1500	347508.7	457.2	0.500	1258.4	0.327	166.744	2.46	4633.00
12	CL/ACCEL	337006.2	14621.4	0.950	10502.4	5.184	171.929	83.87	4716.87
13	CRUISE	329949.1	14798.4	0.950	7057.2	14.347	186.276	245.72	4962.59
14	DESCEND	327394.1	3048.0	0.340	2555.1	10.132	196.408	133.45	5096.04
15	LOITER	305666.8	3048.0	0.321	21727.2	30.000	226.408	0.0	5096.04
16	DES/LAND	304492.4	0.0	0.300	1173.4	2.936	229.343	25.74	5121.78
			TOTAL FUEL USED=		214724.7				

TABLE 48. - GE21/J11 B3 BASELINE ECONOMIC MISSION SUMMARY, ENGLISH UNITS

LEG NO.	OPERATION	WEIGHT POUNDS	ALTITUDE FEET	MACH NO.	FUEL USED POUNDS	TIME MIN.	TOTAL TIME MIN.	RANGE N. M.	TOTAL RANGE N. M.
	INITIAL WEIGHT	1144680.0							
1	WU & TO	1129312.0	0.0	0.290	15368.0	10.000	10.000	0.0	0.0
2	CL/1500	1124375.0	1500.0	0.500	4937.0	0.622	10.622	2.59	2.59
3	CLIMB	1095298.0	35338.1	0.900	29077.0	3.312	13.934	24.66	27.25
4	CRUISE	1033246.5	36320.5	0.900	62051.5	42.473	56.407	372.75	400.00
5	CL/ACCEL	986195.0	66897.0	2.320	47051.5	6.511	62.918	107.41	507.41
6	CRUISE	800934.9	71335.2	2.320	185260.1	81.088	144.006	1835.31	2342.72
7	DESCEND	792115.2	1500.0	0.500	8819.7	15.934	159.940	150.84	2493.56
8	DES/LAND	790746.6	0.0	0.300	1368.6	1.478	161.418	6.69	2500.25
9	TAXI	786794.1	0.0	0.0	3952.5	5.000	166.418	0.0	2500.25
10	5% RES.	768899.7	0.0	0.0	17894.3	0.0	166.418	0.0	2500.25
11	CL/1500	766125.5	1500.0	0.500	2774.2	0.327	166.744	1.33	2501.58
12	CL/ACCEL	742971.7	47970.5	0.950	23153.8	5.184	171.929	45.29	2546.87
13	CRUISE	727413.4	48551.1	0.950	15558.4	14.347	186.276	132.67	2679.54
14	DESCEND	721780.4	10000.0	0.340	5632.9	10.132	196.408	72.06	2751.60
15	LOITER	673880.1	10000.0	0.321	47900.4	30.000	226.408	0.0	2751.60
16	DES/LAND	671292.1	0.0	0.300	2588.0	2.936	229.343	13.90	2765.50
			TOTAL FUEL USED=		473387.9				

analyses discussed previously. The calculations and results are summarized in table 49. The nacelle drag increments are those used in the detailed analysis and are shown in table 49. Specific fuel consumption increments were obtained from plots of installed performance (figures 31 through 34, 37, and 38). Takeoff thrust increments were obtained from figures 30 and 36. Propulsion weight increments were obtained by adding 198 kg (445 lb) per engine for miscellaneous propulsion systems to the nacelle and engine weights of tables 19 through 22. Included in the table 49 is a column for the "revised" baseline.

Table 49 indicates good agreement of the sensitivity method relative to the detailed analysis for engines with small changes relative to the baseline (VSCE 502B and VCE 112C). The error increases as the total takeoff gross weight ratio, R_{TOTAL}, increases. Reasons for error include the following:

(1) Reading and extrapolating the sensitivity curves may produce some errors.

(2) Sensitivities for changes in transonic acceleration thrust were not included. Tables 24 through 27 indicate a wide range in thrust-drag ratio at mach 1.2. Thus, acceleration times and fuel used may vary widely from the baseline.

(3) The assumption that the aircraft will cruise at minimum SFC is optimistic; the lift-drag ratio characteristics may tend to drive the operating point to a high SFC.

(4) Scaling factors of the detailed analysis are determined for small changes and are therefore of questionable accuracy for large changes in aircraft characteristics.

While the differences in takeoff gross weight using the two methods are large for the large aircraft, the accuracy of the sensitivity method is sufficient to indicate when changes may be of interest and when they are definitely not advantageous. Thus, the sensitivity method allows the user to easily identify problem areas. For example, from table 49, the largest contributor to vehicle weight increase of the VCE 112C is effective takeoff thrust ($R_{FNE\ TO}$ is 1.10) while the largest contributor of the GE21/J10 B1 is propulsion system weight (R_{Wt} is 1.16).

TABLE 49. - TAKEOFF GROSS WEIGHT SENSITIVITY CALCULATIONS

Vehicle/engine Variable	Baseline VSCE 502B	Revised Baseline VSCE 502B	Refined VSCE 502B	VCE 112C	GE 21/J10 B1	GE 21/J11 B3
Propulsion weight, kg (lb)	31 498 (69 493)	30 882 (68 081)	33 374 (73 576)	35 014 (77 192)	38 298 (84 432)	33 300 (73 412)
SFC, kg/hr,daN (lb/hr/lb)						
Supercruise	1.387 (1.36)	1.387 (1.36)	(0.387 (1.36)	1.474 (1.445)	1.469 (1.44)	1.448 (1.42)
Subcruise	1.005 (0.985)	1.005 (0.985)	0.981 (0.962)	0.964 (0.945)	1.137 (1.115)	1.086 (1.065)
Effective takeoff thrust, daN (lb)	27 899 (62 723)	26 957 (60 604)	28 480 (64 028)	23 187 (52 130)	23 677 (53 231)	18 713 (42 070)
Nacelle drag coefficient						
mach 1.2	0.00057	0.00040	0.00061	0.00085	0.00202	0.00276
mach 2.32	0.00047	0.00030	0.00033	0.00048	0.00095	0.00115
R_{WT}	1.000	1.000	1.032	1.059	1.16	1.031
R_{SFC}						
Supercruise	1.000	1.000	1.000	1.071	1.068	1.050
Subcruise	1.000	1.000	0.998	0.994	1.013	1.008
$R_{Fne\ TO}$	1.000	1.000	0.978	1.100	1.077	1.320
R_{CD}	1.000	1.000	1.003	1.021	1.083	1.118
R_{total}	1.000	1.000	1.010	1.266	1.464	1.610
TOGW, kg (lb)						
Sensitivities	323 048 (712 188)	316 783 (698 375)	320 146 (705 568)	401 092 (884 258)	463 708 (1 022 283)	510 136 (1 124 638)
Detailed	323 048 (712 188)	316 783 (698 375)	320 228 (705 790)	402 625 (887 622)	514 450 (1 134 149)	629 306 (1 387 359)
Error, %	-	-	-0.03	-0.4	-9.9	-18.9

DISCUSSION OF RESULTS

Engine shape, airflow-lapse rate with mach number, thrust-lapse rate with mach number, SFC, and noise characteristics have large effects on aircraft takeoff gross weight. As an example of engine shape effects, a comparison of cross-sectional area variation of nacelles with VSCE 502B and VCE 112C engines is shown in figure 3. The only significant difference in shape is that the VCE 112C has a smaller nozzle exit area. This results in drag and takeoff gross weight changes as shown in table 4. Thus, a nozzle that is 0.043 m (1.7 in.) smaller in diameter results in takeoff gross weight increment of 3 200 kg (7 000 lb) just due to the nacelle drag change. As shown in figure 25, a one-drag-count change results in about a 1-percent change in takeoff gross weight.

Engine airflow lapse rate with mach number directly affects inlet capture area. For example, the GE21/J10 B1 has approximately 16-percent lower supersonic cruise airflow relative to takeoff airflow than does the VSCE 502B. The smaller capture area results in approximately 4-percent lower inlet recovery at static conditions and therefore reduced takeoff thrust. In addition, the smaller capture area results in a more rapid increase of nacelle cross-sectional area with nacelle length, and therefore higher drag.

Engine takeoff thrust and thrust lapse rate with mach number has a significant effect on engine size required to meet takeoff distance requirements. For example, the VCE 112C has 6-percent lower takeoff thrust at static conditions and 20-percent lower thrust at mach 0.3 (at reduced power to meet noise requirements) than the VSCE 502B for a given static takeoff airflow. This resulted in a considerable increase in engine size to meet balanced field length requirements

As indicated in figure 27, a change of 1 percent in SFC at supersonic cruise results in a 1-percent change in aircraft takeoff gross weight or about 3 200 kg (7 000 lb).

Engine exhaust noise characteristics have a significant impact on aircraft takeoff gross weight. All four engines were assumed to employ thrust cutback at the takeoff noise measurement point. However, all the engines did not take full advantage of the extra ground attenuation while the aircraft was still on the ground. For example, the GE21/J11 B3 has 20-percent lower thrust-per-unit airflow than the VSCE 502B. Thus, the GE21/J11 B3 yields approximately 6 db lower sideline noise at takeoff on the ground, but it must be sized larger to meet the takeoff distance requirement.

RECOMMENDATIONS

The sensitivity method has been shown to be a valid method for preliminary assessment of propusion system modifications, and it is therefore recommended to be used for this purpose. Continued airframe/propulsion integration studies and coordination effort between engine and airframe manufacturers in the aforementioned high-sensitivity areas are also recommended.

APPENDIX

ADVANCED SUPERSONIC TRANSPORT

NACELLE INSTALLATION DRAG INCREMENT

COMPUTER PROGRAM

SUMMARY

This appendix describes a computer program developed to determine nacelle incremental drags for the NASA arrow-wing supersonic transport configuration. Program inputs include freestream Mach number and parameters defining nacelle geometry. Data points are stored internal to the program to represent wave and friction drag values with up to six independent variables. Given a set of input parameters, the program sets up arrays so as to perform an internal search. Then, a cubic is fit to these data points, and the drag increments are determined.

The computer program requires 40K bytes of memory, and each case, consisting of four evaluations of nacelle drag, requires about .1 seconds of execution time on a IBM 370/168.

This appendix relies heavily on references 1 and 2; thus, the reader should have a copy of those references as he reads the following.

SYMBOL LIST.- The following symbols appear in the coding for Subroutine NDRAG:

AC - Capture area, sq. ft.
ACM - Capture area, sq. m.
AC1 - Input value of AC saved, sq. m. (sq. ft.)
AMAX - Maximum area sq. ft.
AMAXM - Maximum area sq. m.
AN - Nozzle area sq. ft.
ANM - Nozzle area sq. m.
CDO12 - Nacelle drag increment at Mach 1.2
CDO232 - Nacelle drag increment at Mach 2.32
CDOM - Nacelle drag increment at input Mach number
CDF12 - Friction drag increment at Mach 1.2
CDF232 - Friction drag increment at Mach 2.32
CDW12 - Wave drag increment at Mach 1.2
CDW232 - Wave drag increment at Mach 2.32
DC - Diameter of capture area, m (ft.)
DER - Straight line slope for curve defining Mach number effect on total drag
F2TM2 - Conversion factor from sq. ft. to sq. m.
FTM - Conversion factor from feet to meters
IP - Set to 1 for use in equation defining CDOM
M - Mach number
M2TF2 - Conversion factor from sq. m. to sq. ft.
MTF - Conversion factor from meter to feet
L - Total nacelle length, M. (ft.)
LIPN - Set to 2 for use in equation definig CDOM
LM Total nacelle length, m.
PI - π
SI - Set to 929 sq. m. (10000 sq. ft.) for basepoint wing area
S(2) - Slope at point where Mach is 1.2
S(3) - Slope at point where Mach is 2.32
SREF - Reference wing area, sq. ft.
SREFM - Reference wing area, sq. m.
XMAX - Length to maximum area, ft.
XMAXM - Length to maximum area, m.

Refer to the discussion of subroutine NDRAG for definitions of the symbols associated with data statements in that subroutine.

COMPUTER PROGRAM

Problem Description

Wave and friction drag increments were determined for a range of parametric nacelle shapes in reference 2. In order to determine drag increments for any nacelle shape of interest, values must be interpolated and/or extrapolated. A major part of the program is involved with the determination of the data points to use when calculating the drag associated with a given set of values of the independent variables. Once these data points are found, a cubic equation (reduces to a linear fit for two points) is fit, and the desired dependent variable is calculated. This sorting process and the resulting cubic fit occurs in a definite order and is repeated many times before the final answer is determined.

The numeric method for fitting a cubic is similar to Hermite interpolation in that the coefficients of the cubic are determined by two points and the derivatives of this cubic also satisfy the slopes evaluated at these two points. The derivatives are defined by passing parabolas through those points using a total of four points for the derivative evaluation. (A cubic is also defined using a total of three points with a modified definition for the two slopes). These points are chosen so that the desired independent variable is in the middle interval.

Method of Solution

There are four possible situations that must be handled by the program:

1. Given four points with the value of the independent variable in the middle interval,
2. When the desired value is in the last or first interval,
3. When there are only two values, and
4. When the value is outside the range of data.

Given four points with the desired value of the given independent variable in the middle interval, as shown in figure A-1, assume the equation

$$Z = AX^3 + BX^2 + CX + D \qquad (1)$$

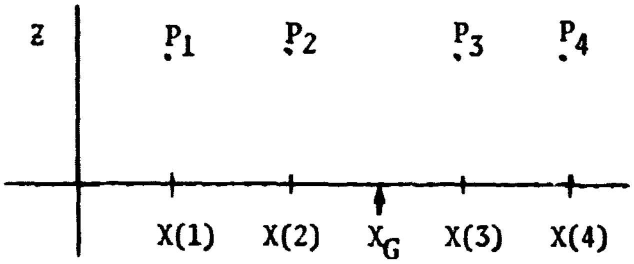

Figure A-1 - ILLUSTRATION OF PARAMETER RANGE will go through the points P_2 and P_3. Also, the derivative

$$Z' = 3AX^2 + 2BX + C = A^1 X^2 + B^1 X + C^1 \qquad (2)$$

is evaluated at P_2 using the points P_1, P_2 and P_3 for the calculation of the coefficients A^1, B^1 and C^1. It is also evaluated at P_3 using the points P_2, P_3 and P_4 so that equation (1) passes through points P_2 and P_3 and the derivation equation (2), also satisfies the slope at these two points. Therefore, four equations result to determine A, B, C, and D, in equation (1). This is the basic numeric method used by the program to determine the dependent variable Z given X_G. The detailed equations are contained in a following section.

When the desired value X_G is in the last interval, the cubic is defined by points P_3 and P_4, and the derivative at P_3 is determined by passing a quadratic through P_2, P_3, and P_4 while the derivative at P_4 is defined by passing a straight line through points P_3 and P_4. Similarly, when X_G is in the first interval, the cubic is defined at points P_1 and P_2. The slope at P_2 is derived by fitting a quadratic through P_1, P_2 and P_3. The slope at P_1 is the slope of the straight line passing through points P_1 and P_2. In both cases, only three points are used. In the event that only two points are defined, then linear interpolation is used. When constraints are violated, the process determines points as if the value of X_G is in the first or last interval. Then, a linear or cubic curve fit results in the calculation of an extrapolated value for Z.

Program Description

OPERATING ENVIRONMENT.- This program was written using standard Fortran statements using a IBM SYS370 model 168 computer with the operating system OS/VS2.

PROGRAM SPECIFICATIONS.- Source listings of the main program, NDRAG, and subroutine NDTLAE are at the end of the appendix; memory requirements are:

NDRAG - 9874 decimal bytes

NDTLAE - 3806 decimal bytes

The program uses 40K bytes including system subroutines, and no common is used.

PROGRAM MODULE DEFINITIONS.- The main program calls subroutine NDTLAE to initiate the interpolation for the total drag given values for the independent variables. Four calls are made in order to calculate the necessary quantities at each of two mach numbers.

Main Program Module (NDRAG): The main program performs the following functions:

(1) Setup of data for subroutine NDTLAE,
(2) Conversion of units,
(3) Calculation of the effect of Mach number on drag increments,
(4) Input and output and checks on independent parameter values,
(5) Setup of data in data statements.

A large portion of this module is involved in setting up the input data in the correct format for subroutine NDTLAE. The input variables required for this subroutine are

$\frac{X_{MAX}}{L}$, $\frac{A_N}{A_C}$, $\frac{A_{MAX}}{A_C}$, $\frac{L}{d_C}$, A_C and M. Here,

$d_C = \sqrt{\frac{4 * A_C}{\pi}}$ and these are set up and used in the English system of units. (Refer to figure A-2).

The main program also includes the conversion of data from English to International units (and vice-versa) for input-output convenience.

The calculations for the Mach number influence on total drag increment start at statement number 83. DER, the slope, is determined from the equation

$$DER = \frac{CD0232 \ - \ CD012}{2.32-1.2}$$

The slope at Mach 1.2 then has a value of 2.0 * DER, and the slope at Mach 2.32 is 0.35*DER. (These values for the end derivatives are estimated from a study of the basic shapes or trends inherent in curves such as Figure 61 on page 87 of reference 2). Using these two points and the two derivatives, a cubic is fit, and the total drag increment at any Mach number is determined.

Additional functions include the input and output of data and the necessary calculations to determine if a constraint has been violated. If this is the case, the value of the variable is printed out and the program extrapolates.

The ranges are:

Indep. var. #1 $.4 \leq \frac{X_{MAX}}{L} \leq 1.$

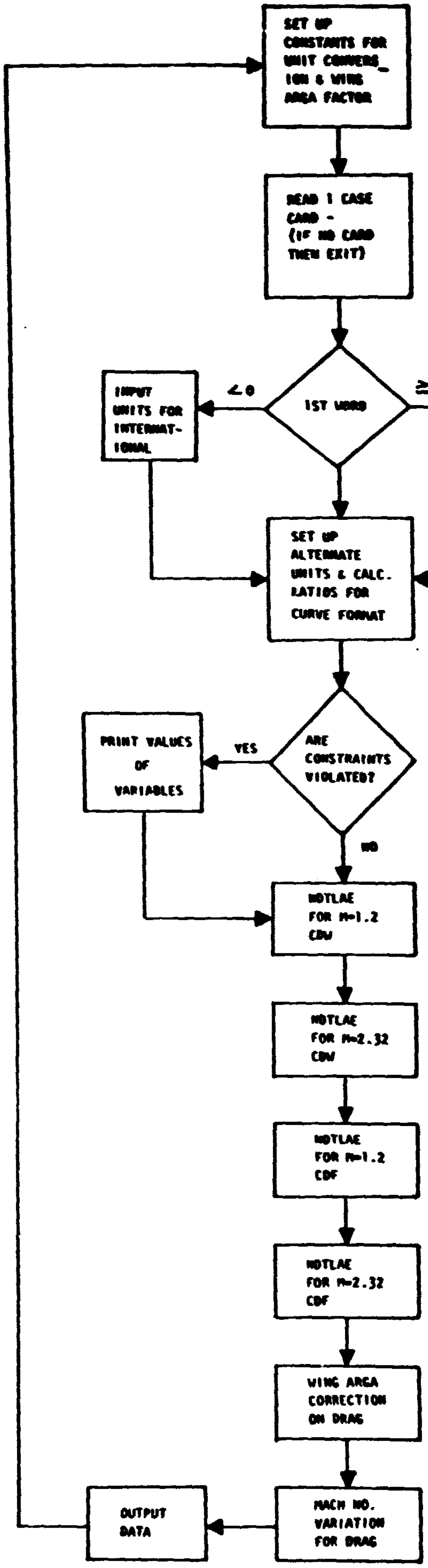

Figure A-2 - NDRAG FLOW CHART

Indep. var. #2 $1.0 \le \frac{A_N}{A_C} \le 2.0$

Indep. var. #3 $1.25 \le \frac{A_{MAX}}{A_C} \le 2.0$

Indep. var. #4 $5.5 \le \frac{L}{d_C} \le 7.0$

Indep. var. #5 $20. \le A_C \le 40.$

Indep. var. #6 $1.2 \le M \le 2.32$

Independent variables 3, 4, 5, and 6 are required for the calculation of friction drag.

Included in the first part of the module are several data statements. These contain values of the independent and dependent variables as determined from Figure 24 through 59 for wave drag and from Table XIII for friction drag of reference 2. Each array has a special definition and the order of the variables is specified by the interpolation method from subroutine NDTLAE.

Values of the independent variables are:

Indep. var. #1, $\frac{X_{MAX}}{L}$ = .4, .5, .6, .7, .75, .8, .85, .90, 95, 1.0

Indep. var. #2, $\frac{A_N}{A_C}$ = 1.0, 1.25, 1.50, 2.0

Indep. var. #3, $\frac{A_{MAX}}{A_C}$ = 1.25, 1.50, 2.0

Indep. var. #4, $\frac{L}{d_C}$ = 5.5, 7.0

Indep. var. #5, A_C = 20., 30., 40.

Indep. var. #6, M = 1.2 and 2.32

Each data statement array is defined below.

NX is the array of the number of values for each independent variable in the order as specified above.

X is the array of individual values of the independent variables in the order as specified above.

Z1 is the array of values of the dependent variables for friction drag from reference 2, Table XIII.

The order of these variables in the Z1 array will be described by using notation defining the independent variables used for the calculation of friction drag. Thus, variable X_3 has three values $X_3(1)$, $X_3(2)$ and $X_3(3)$; variable X_4 has two values $X_4(1)$ and $X_4(2)$; variable $X_5(1)$, $X_5(2)$ and $X_5(3)$; and the last variable X_6 has two values $X_6(1)$ and $X_6(2)$. The first variable in the Z1 array corresponds to the following order for the independent variables:

for Z1(1) use $X_3(1)$, $X_4(1)$, $X_5(1)$, $X_6(1)$,

Then, for the second element,

Z1(2) use $X_3(2)$, $X_4(1)$, $X_5(1)$, $X_6(1)$,

Z1(3) use $X_3(3)$, $X_4(1)$, $X_5(1)$, $X_6(1)$.

Then, for Z1(4), Z1(5), and Z1(6) repeat the first three lines with $X_4(1)$ replaced by $X_4(2)$. Now a total of six Z1 values are defined for Z1(1) through Z1(6). Values for Z1(7) through Z1(12) are obtained when these first six lines are repeated with $X_5(1)$ replaced by $X_5(2)$. In the first 6 lines replace $X_5(1)$ by $X_5(3)$ then Z1(13) through Z1(18) are determined. So far, 18 lines or values for Z1 have been defined using $X_6(1)$. If these 18 lines are repeated with $X_6(1)$ replaced by $X_6(2)$ then Z1(19) through Z1(36) are specified. These 36 lines represent the Z1 matrix for the friction drag. This is the definition of the data sequence required for the Z matrix as used in subroutine NDTLAE.

ARW1 through FRW1 are arrays of values of the dependent variable for wave drag, for Mach 1.2. The basic method for ordering the dependent variables is the same as for the friction drag array Z1, with two additional independent variables.

Arrays ARW2 through FRW2 are values of the dependent variables for wave drag for Mach 2.32. Again, the method for ordering is the same as for friction drag only with two additional independent variables.

Subroutine NDTLAE: The main function of this subroutine is to determine the value of the dependent variable Z for given values of the independent variables X(I). These points are contained in the DATA statements appearing in the main program.

The calling sequence for this subroutine is

CALL SUBROUTINE(NIV, X_G, X, Z, NX, RES, A, B, C, D)

where

NIV	Number of independent variables (4 or 6)
X_G	Array of given values of independent variables
X	Array of independent variables
Z	Array of dependent variables
NX	Array of number of values given for each independent variable
RES	Final required Z for given XG using X and Z arrays
A,B,C,D	Coefficients of the cubic fit to the data points thus defining Z values (In some cases this reduces to a linear fit with two coefficients C and D).

Initially, various arrays are defined for the purpose of determining the location of the first Z to be used from the Z array. The object is to determine which interval of input points in the X array will be used to calculate the Z array given X_G. After these subscripts and indicators have been set, the evaluation the necessary equations for the Z array can be made. The composition of this array, and the sequence of steps leading to the final Z value will be outlined here. (Refer to the section "Method of Solution" for a description of the number of intervals used given the X array and to the section "Equations For Curve Fitting" for the equations used for the curve fit.)

The procedure, for calculating the location of the first Z (LISTZ) to be used, starts with defining the ICF array where

ICF(I) = Number of values of each independent variable (I) to be used for curve fit (i.e. 2, 3, or 4)

Next, the IGAT(I) array is set to the following values, if

IGAT(I) = 1, X_G(I) is in one of the middle intervals

= 2, X_G(I) is in the first interval

= 3, X_G(I) is in the last interval.

At the same time, the LOC (I) array is defined as the location in the X array of the first value to be used for independent variable I. Thus, the subscripts for the X array for the polynomial curve fit are obtained.

The location of Z(I) given values of X(I) array are then determined. The equations to do this are contained between statement numbers 32 to 35 in the listings at the end of the appendix. The formula,

$$Z(I)\ \text{index} = LOC(1) + \sum_{k=1}^{NIV-1} NX(1)*NX(2)\ldots*NX(k)*[LOC\ (k+1)-1] \qquad (3)$$

specifies the location (or index) of the element number in the Z(I) array associated with each sequence of values for the independent variables X(I). (That is, an analytical gearing between the X and Z array is defined.)

Statement number 50, which sets LL, through statement number 2000, where the polynominal for the curve fit is evaluated, is described by a step by step analyses of the coding in the section "Step By Step Analysis of Subroutine NDTLE." That section also describes, by specific example, the evaluation of the LLCTR sequence at statement number 410. Thus, the location of the next Z to use is developed. Figure A-3 describes the flow within this subroutine with emphasis on control during the evaluation of the Z matrix. (Refer to listing of subrouting NDTLAF for complete symbol definition.)

An example of the use of equation 3 will be demonstrated with the friction drag data. For convenience, number the variables 1 through 4 (instead of 3 through 6) as described in the previous discussion of independent variables; therefore,

Variable #1 is $\frac{A_{MAX}}{A_C}$ with $NX_1 = 3$,

Variable #2 is $\frac{L}{d_C}$ with $NX_2 = 2$,

Variable #3 is A_C with $NX_3 = 3$,

Variable #4 is M with $NX_4 = 2$.

Let subscript refer to variable number:

Z(1) is dependent variable for	$X_1(1)$	$X_2(1)$	$X_3(1)$	$X_4(1)$
Z(2)	$X_1(2)$	$X_2(1)$	$X_3(1)$	$X_4(1)$
Z(7)	$X_1(1)$	$X_2(1)$	$X_3(2)$	$X_4(1)$
Z(21)	$X_1(3)$	$X_2(1)$	$X_3(1)$	$X_4(2)$

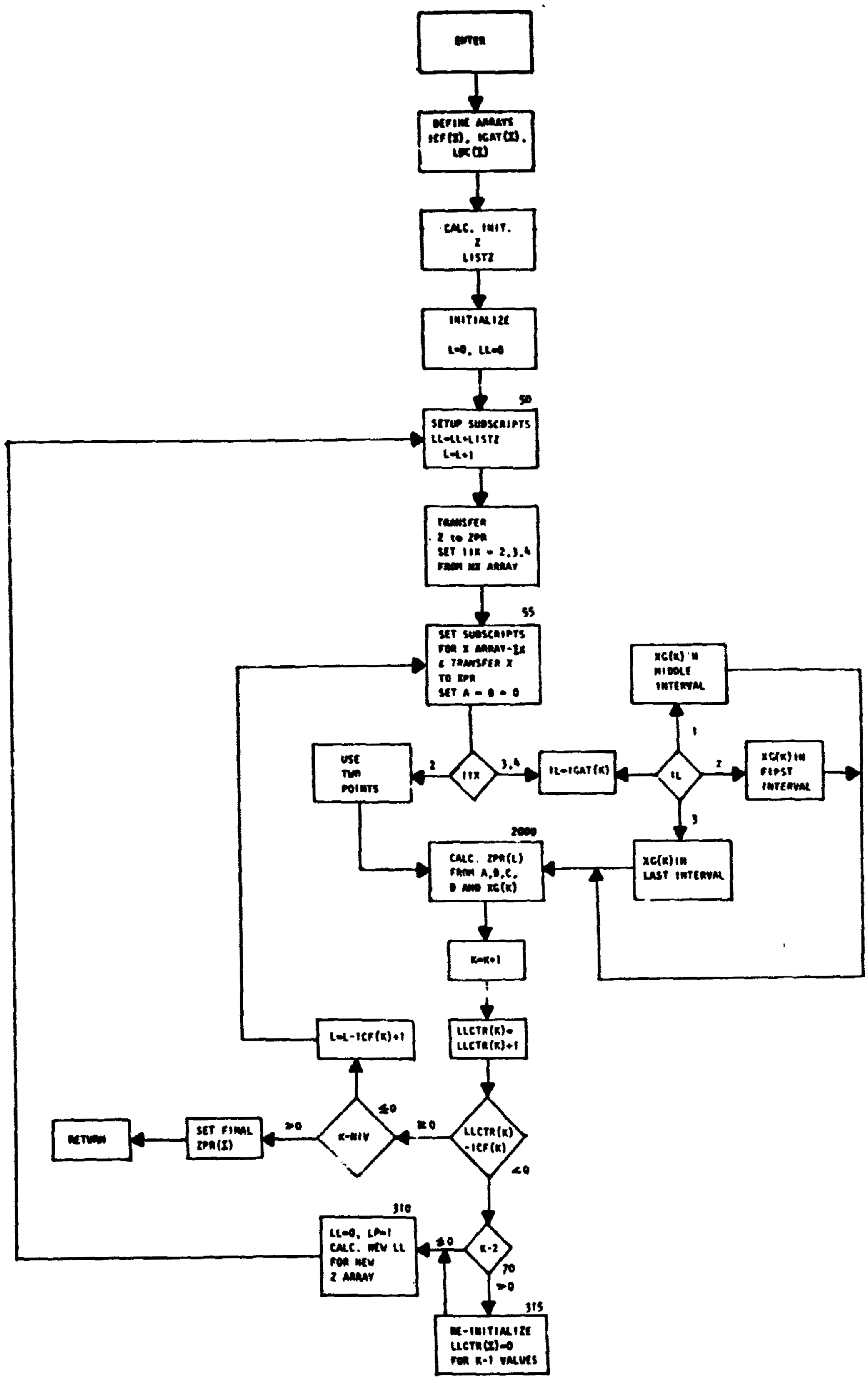

Figure A-3 - NDTLAE FLOW CHART

From equation (3) for Z(7) and for element 1121,

LØC(1) + 3 * [LØC(2)-1] + 3*2 [LØC(3)-1] + 3*2*3[LØC(4) - 1]

Then the element is:

1 + 0 + 6 + 0 = 7

For Z(21), values in equation (1) for element 3112 give the element

3 + 0 + 0 + 18 = 21

Because of the number of variables in each array, the value of equation (3) would always be 1, and new Z values are specified by LL arrays when modified by LLCTR values. That is, the LØC appearing in this example is modified by LL array.

PROGRAM LOGIC.- Figure A-4 shows a program flow during the calculation of the Z array. The last Z calculated is the final result. Note that in this figure the required number of Z values is determined by the number of values contained in the next array of independent variables. Figure A-5 shows in more detail the series of Z as calculated for the friction drag. ZGGG1 follows as a result of ten previous curve fits where three are linear and seven are cubic.

INPUT-OUTPUT SPECIFICATION.- Standard input-output functions are utilized to input case data and to output the calculated total drag for each mach number. The input data is printed out for identification purposes.

Input: A read tape 5 is used to read 1 case of 1 card containing seven numbers with a E10.6 format. In order,

		Card Column Identification
Word #1 - A_C	Capture area	(CC2-10)
Word #2 - A_{MAX}	Maximum area	(CC12-20)
Word #3 - A_N	Nozzle area	(CC22-30)
Word #4 - X_{MAX}	Length to maximum area	(CC32-40)
Word - L	Total length	(CC42-50)
Word #6 - SREF	Reference wing area	(CC52-60)
Word #7 - M	Mach number	(CC62-70)

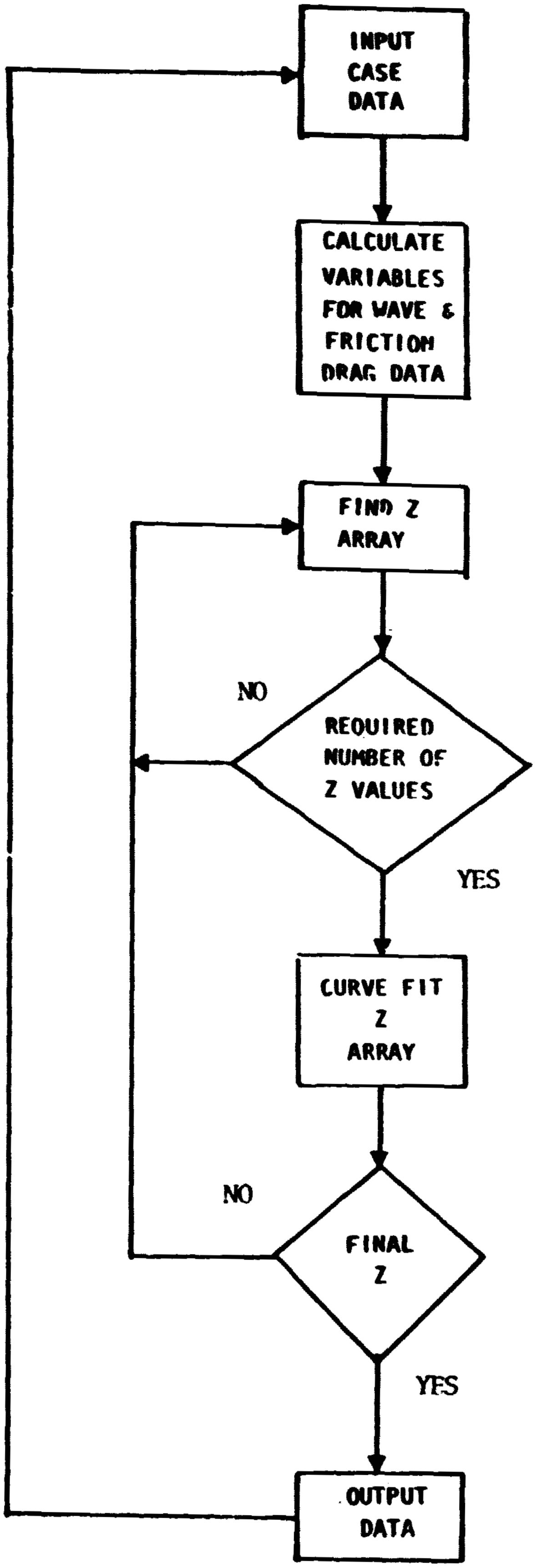

Figure A-4 - PROGRAM FLOW FOR Z ARRAY

Normal input is assumed to be in the English units with the basic length measured in feet. A minus sign in column 1 indicates the units are in the International units with the basic length measured in meters.

Output: A write tape 6 with an F format is used for printing data. The above input data and the friction drag, wave drag and total drag for Mach 1.2 and 2.32 are printed. Also printed is the total drag for an input Mach number.

RESTRICTIONS. - Each figure for wave drag in reference 2 contains values of A_N/A_C for a given value of A_{MAX}/A_C. Physically, A_N/A_C cannot exceed A_{MAX}/A_C, but in a mathematical sense a numerical value for the drag must be determined in order to sustain the interpolation process. In this case, when a limit is exceeded, the extrapolation assumes that the limiting values of drag are used for values of A_N/A_C greater than A_{MAX}/A_C. That is, on figure 24 (reference 2) with two curves for A_N/A_C of 1.0 and 1.25, drag values for the 1.50 and 2.0 curves are assumed to be identical to those for the 1.25 curve. The number of points used in the curve fit depends on where the desired value of A_N/A_C falls relative to the index values of 1.0, 1.25, 1.50 and 2.0. If $1.5 < A_N/A_C \leq 2.0$ then last three points would be used. When $1.25 < A_N/A_C \leq 1.50$, a total of four points would be used for the curve fit since this is the middle interval. When extrapolation for the other independent variables is required,no limiting values of the variables are substituted.

The terminal point for each wave drag value is specified by the condition that the boattail angle does not exceed 10°. In order to satisfy this requirement, the final drag value for each curve (i.e. each A_N/A_C value) is repeated in .05 increments for X_{MAX}/L until X_{MAX}/L is 1.0. Thus, the proper drag level as set by the maximum boattail angle will be meet.

DIAGNOSTICS.- When a desired value for an independent variable does not fall within the given data range, the variable and its value will be printed. The calculations will use this value for the extrapolation as described above.

Subroutine NDTLAE contains several tests to determine if calculated index values are set properly. The statement number of the test generating the diagnostic is printed out.

TEST CASES.- Cases 1 and 2 (tables A-I and A-II are presented herein and the values of CDO have been verified by comparing with values read directly from table XIII for friction drag (CDF) and figures 24 through 59 for wave drag (CDW) in reference 2. Cases 3 and 4 are presented for the NASA LTV nacelle, described in reference 3. These cases were checked by cross plotting the curve data. The parametric study is based on a nacelle that had straight line radius connections of the inlet face, maximum cross section and the nozzle exit. The NASA LTV nacelle deviates from these straight line connections and, therefore, it is necessary to simulate the nacelle with straight lines. Case 3 (table A-III) simulates the LTV nacelle using the inlet capture area, actual maximum area, and the nozzle exit area. A considerable difference in CDO may be noted. It has been determined that the best simulation is obtained by using the maximum cross-sectional area that occurs at the intersection of straight lines originating from the inlet and the nozzle and whose slopes nearly match the slopes of the actual nacelle as illustrated in figure 5. The maximum area deviation will be approximately 10%. Case 4 (table A-IV) represents the later simulation and the CDO's agree with the calculated CDO's. The difference in CDW is attributed to the following considerations:

1. The wing was resized from 10,996 sq.ft. for the reference configuration to 9819 sq.ft. for the parametric study.

2. The nacelles were relocated further inboard and forward in accordance with the ground rules of reference 1. (See figure 21 of reference 1).

The above discussion concerns only the 1.2 and 2.32 Mach number data points. The additional CDO at any specified Mach number is derived from a cubic curve fit described on page 5. The deviation of CDO may be as much as -.0002 between 1.3 Mach and 1.5 Mach due to the fact that the true drag coefficient as a function of Mach number does not necessarily follow a cubic.

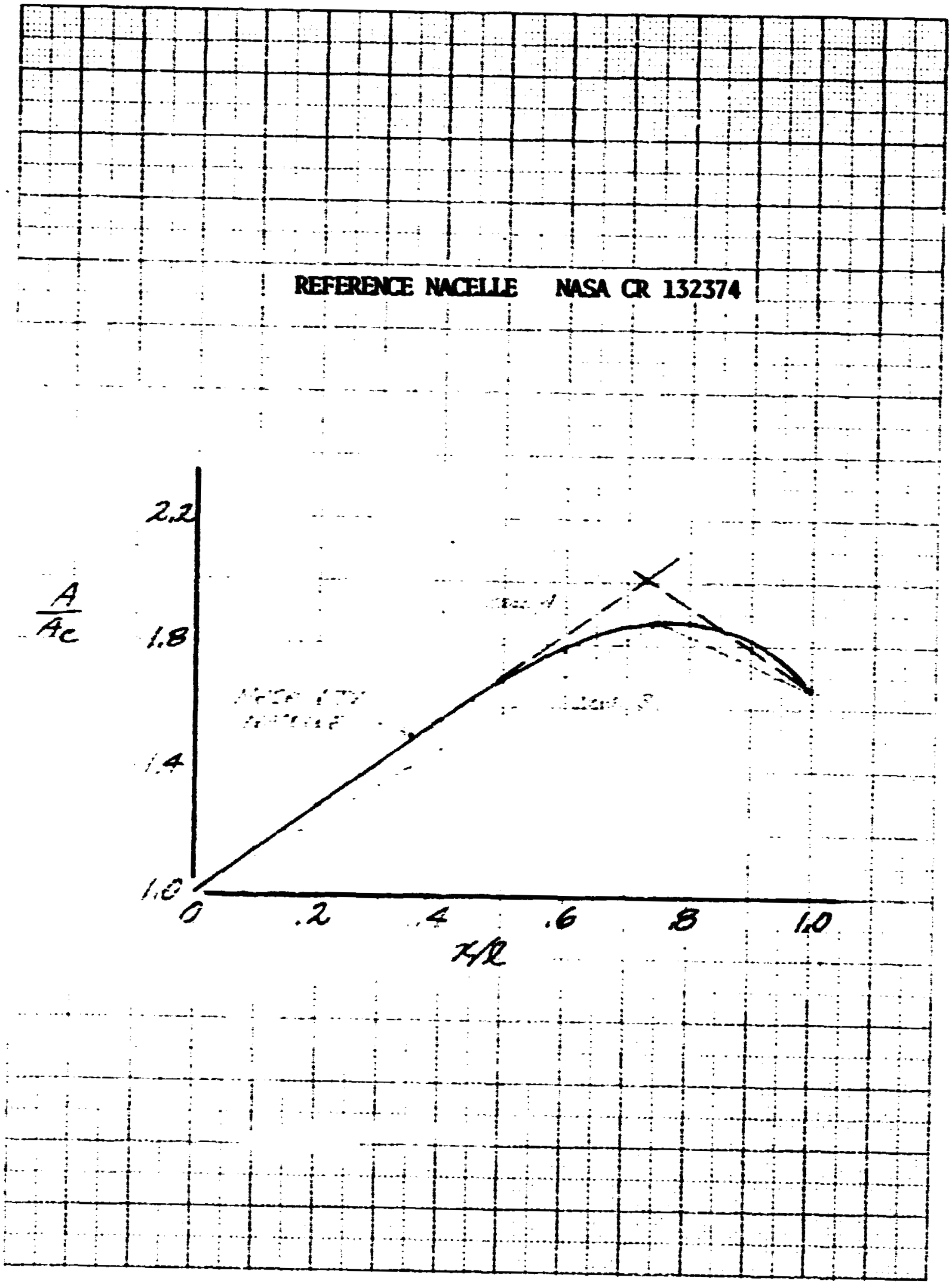

Figure A-5 NACELLE NORMALIZED CROSS-SECTIONAL AREA VARIATION

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OF POOR QUALITY

TABLE A-I.-Case 1 Output

```
NACELLE GEOMETRY

          CAPTURE AREA          2.79  SQ M   (     30.00  SQ FT)
          MAXIMUM AREA          4.18  SQ M   (     45.00  SQ FT)
          NOZZLE AREA           3.48  SQ M   (     37.50  SQ FT)
          LOC. OF MAX. AREA     6.22   M     (     20.40    FT )
          TOTAL LENGTH         10.36   M     (     33.99    FT )

WING REFERENCE AREA           929.03  SQ M   (  10000.00  SQ FT)

INCREMENTAL NACELLE DRAG COEFFICIENTS
          MACH 1.2     CDF=  0.00053   CDW=  0.00040    CDO=  0.00093
          MACH 2.32    CDF=  0.00047   CDW=  0.00007    CDO=  0.00054
          MACH 1.20                                     CDO=  0.00093

XMAX/L=    0.600    AN/AC=    1.250    AMAX/AC=    1.500    L/DC=    5.500

INCREMENTAL NACELLE DRAG COEFFICIENTS - LTV REFERENCE VEHICLE
          MACH 1.2     CDF=  0.00072   CDW= -0.00041    CDO=  0.00031
          MACH 2.32    CDF=  0.00060   CDW= -0.00018    CDO=  0.00042
          MACH 1.20                                     CDO=  0.00032
```

TABLE A-II.-Case 2 Outp t

```
NACELLE GEOMETRY

          CAPTURE AREA          3.72  SQ M   (     40.00  SQ FT)
          MAXIMUM AREA          7.43  SQ M   (     80.00  SQ FT)
          NOZZLE AREA           5.57  SQ M   (     60.00  SQ FT)
          LOC. OF MAX. AREA    12.94   M     (     42.46    FT )
          TOTAL LENGTH         15.23   M     (     49.96    FT )

WING REFERENCE AREA           929.03  SQ M   (  10000.00  SQ FT)

INCREMENTAL NACELLE DRAG COEFFICIENTS
          MACH 1.2     CDF=  0.00042   CDW=  0.00007    CDO=  0.00049
          MACH 2.32    CDF=  0.00061   CDW=  0.00005    CDO=  0.00066
          MACH 2.32                                     CDO=  0.00066

XMAX/L=    0.550    AN/AC=    1.500    AMAX/AC=    2.000    L/DC=    7.000

INCREMENTAL NACELLE DRAG COEFFICIENTS - LTV REFERENCE VEHICLE
          MACH 1.2     CDF=  0.00072   CDW= -0.00041    CDO=  0.00031
          MACH 2.32    CDF=  0.00060   CDW= -0.00018    CDO=  0.00042
          MACH 2.32                                     CDO=  0.00042
```

TABLE A-III.-Case 3 Output

```
NACELLE GEOMETRY

        CAPTURE AREA           2.57  SQ M   (      27.69  SQ FT)
        MAXIMUM AREA           4.83  SQ M   (      51.99  SQ FT)
        NOZZLE AREA            4.29  SQ M   (      46.13  SQ FT)
        LOC. OF MAX. AREA      9.59    M    (      31.48    FT )
        TOTAL LENGTH          12.81    M    (      42.03    FT )

WING REFERENCE AREA          929.03  SQ M   (  10000.00  SQ FT)

INCREMENTAL NACELLE DRAG COEFFICIENTS
        MACH 1.2     CDF=  0.00064   CDW= -0.00054   CDO=  0.00010
        MACH 2.32    CDF=  0.00056   CDW= -0.00021   CDO=  0.00035
        MACH 1.86                                    CDO=  0.00026

XMAX/L=    0.749   AN/AC=    1.669   AMAX/AC=    1.877   L/DC=    7.079


INCREMENTAL NACELLE DRAG COEFFICIENTS - LTV REFERENCE VEHICLE
        MACH 1.2     CDF=  0.00072   CDW= -0.00041   CDO=  0.00031
        MACH 2.32    CDF=  0.00060   CDW= -0.00018   CDO=  0.00042
        MACH 1.90                                    CDO=  0.00043
```

TABLE A-IV.-Case 4 Output.

```
NACELLE GEOMETRY

        CAPTURE AREA           2.57  SQ M   (      27.69  SQ FT)
        MAXIMUM AREA           5.17  SQ M   (      55.66  SQ FT)
        NOZZLE AREA            4.29  SQ M   (      46.13  SQ FT)
        LOC. OF MAX. AREA      9.35    M    (      30.68    FT )
        TOTAL LENGTH          12.81    M    (      42.03    FT )

WING REFERENCE AREA          929.03  SQ M   (  10000.00  SQ FT)

INCREMENTAL NACELLE DRAG COEFFICIENTS
        MACH 1.2     CDF=  0.00066   CDW= -0.00034   CDO=  0.00031
        MACH 2.32    CDF=  0.00057   CDW= -0.00014   CDO=  0.00043
        MACH 1.69                                    CDO=  0.00038

XMAX/L=    0.730   AN/AC=    1.669   AMAX/AC=    2.012   L/DC=    7.079


INCREMENTAL NACELLE DRAG COEFFICIENTS - LTV REFERENCE VEHICLE
        MACH 1.2     CDF=  0.00072   CDW= -0.00041   CDO=  0.00031
        MACH 2.32    CDF=  0.00060   CDW= -0.00018   CDO=  0.00042
        MACH 1.69                                    CDO=  0.00046
```

EQUATIONS FOR CURVE FITTING

1. Slope using parabolic fit

General equation of parabola

$$Z = aX^2 + bX + c \qquad (1)$$

Slope of parabola

$$Z' = 2aX + b \qquad (2)$$

If given three independent variable values with corresponding dependent variable values then:

$X_1, Z_1 \qquad X_2, Z_2 \qquad X_3, Z_3$

$$Z_1 = aX_1^2 + bX_1 + c \qquad (3)$$

$$Z_2 = aX_2^2 + bX_2 + c$$

$$Z_3 = aX_3^2 + bX_3 + c$$

Solving equation (3) for a and b

$$a = \frac{(Z_1-Z_2)\,(X_1-X_3) - (Z_1-Z_3)\,(X_1-X_2)}{(X_1^2-X_2^2)\,(X_1-X_3) - (X_1^2-X_3^2)\,(X_1-X_2)}$$

$$b = \frac{(X_1^2-X_2^2)\,(Z_1-Z_3) - (X_1^2-X_3^2)\,(Z_1-Z_2)}{(X_1^2-X_2^2)\,(X_1-X_3) - (X_1^2-X_3^2)\,(X_1-X_2)}$$

Then substituting in (2) above the slope at X_G is

$$S = 2aX_G + \frac{(Z_1-Z_2 - \left\{(X_1)^2 - (X_2)^2\right\} a)}{X_1 - X_2}$$

2. Derivation of coefficients for the cubic

General form of cubic

$$Z = aX^3 + bX^2 + cX + d$$

Slope of cubic

$$Z' = 3aX^2 + 2bX + c$$

To determine the cubic passing through two given points, (X_2, Z_2) and (X_3, Z_3), and having given slopes, S_2 and S_3, at these points, the following system of equations is solved for a, b, c, and d.

$$Z_2 = aX_2^3 + bX_2^2 + cX_2 + d \qquad (4)$$

$$Z_3 = aX_3^3 + bX_3^2 + cX_3 + d$$

$$S_2 = 3aX_2^2 + 2bX_2 + c$$

$S_3 = 3aX_3^2 + 2bX_3 + c$

Solving for the four unknowns:

$$a = \frac{-\{2(Z_3-Z_2) - (S_2+S_3)\ (X_3-X_2)\}}{(X_3 - X_2)^3}$$

$$b = \left\{\frac{Z_3-Z_2}{X_3-X_2} - S_2 - (X_3+2X_2)\ (X_3-X_2)*a\right\}\frac{1}{X_3-X_2}$$

$$c = S_2-2X_2\ b - 3X_2^2\ a$$

$$d = Z_2- aX_2^3 - bX_2^2 - cX_2$$

3. Final calculation of dependent variable

The dependent variable Z is then calculated using the coefficients a, b, c, d and the given value of x_G in the equation

$Z = aX_G^3 + bX_G^2 + cX_G + d$ or

$Z = d + X_G\ (c + X_G\ (b + X_G\ a))$

STEP BY STEP ANALYSIS OF SUBROUTINE NDTLAE

The sequence of steps to calculate the friction drag will be defined by reference to the program steps contained in subroutine NDTLAE. Primary emphasis of the following discussion is on setting values of counters and subscripts leading to the determination of the final interpolated value for Z.

Thus, refering to the section on subroutine NDTLAE for definition of independent variables,

NX(1) = 3, NX(2) = 2, NX(3) = 3, NX(4) = 2.

From statements starting at statement number 3,

ICF(1) = 3, ICF(2) = 2, ICF(3) = 3, ICF (4) = 2.

Program steps ending at statement number 23 define the LØC array as:

LØC(1) = 1, LØC(2) = 1, LØC(3) = 1, LØC(4) = 1.

Also, for IGAT assume IGAT(1) = 3, IGAT(2) is linear, IGAT(3) = 2, IGAT(4) = 3. Refer to equation (3) of this appendix for the location of ed, first Z to be used, i.e.

LISTZ = LØC(1) = 1

The basic logic for performing the calculations, starts at statement number 50.

NIV = 4

L = 0, LL = 0, LLCTR (I) = 0, I = 2, 3, 4, 5

50 LL = LIST Z = 1

K = 1

L = L+1 = 1

IC = ICF(1) = 3

For J = 1, 2, 3, and M = 1, 2, 3:

ZPR(1) = Z(1) = Z_{1111}, ZPR(2) = Z_{2111}, ZPR(3) = Z(3) = Z_{3111}

The derivative of X (XPR) with vaules from first X array are then determined:

XPR(1) = X_1(1), XPR(2) = X_1(2), XPR(3) = X_1(3) and IIX = NX_1 = 3.

Then, IL = IGAT(1) = 3 for XG_1 in last internal for variable X1; then go to 72.

At statement #72,

IPN = 1, IIN = L = 1, IS = 2, M = 3, IRX = 1 and go to 80

At statement number 80,

IN = IIN+IRX = 2, IP = IPN+IRX = 2

Calculate slopes S(2), S(3) and A, B, C, D and final ZPR(1) = AX^3+BX^2+CX+D for X = XG_1 (The equations for these quantities are defined in Appendix A)

Note that LLCTR(2) = 0 here

K = K+1 = 2

LLCTR(2) = LLCTR(2) + 1 = 1

Test LLCTR(2) - ICF(2) = 1-2< 0 and

K-2 = 0, go to 310 for next Z to be used from Z array

Find LL = LL+LLCTR(2) *LP where LP = LP*NX(1) = 3

Note that LLCTR(3) = 0, then

LL = 3

go to 50

Therefore, here Z_{G111} in ZPR(1) has been calculated and since LL = LL+LISTZ = LØC(1) + 3 = 4, the next cycle will calculate Z_{G211}. (Note LLCTR(2) = 1)

Reset, K = 1, L = L+1 = 2, IC = ICF(1) = 3

For ZPR, J=1, 2, 3, M=2, 3, 4 and

ZPR(2) = Z(4), ZPR(3)=Z(5), ZPR(4)=Z(6)

Again, for X array, IIX=3 and since k=1, IX=LØC (1)=1 so that

XPR(1) = X_1(1), XPR(2) = X_1(2), XPR(3) = X_1(3).

Again, IGAT(1)=3, go to 72 and calculate slopes, A, B, C, and D for fit so ZPR(2) is defined.

k=k+1=2

LLCTR(2) = LLCTR(2) + 1 = 2

LLCTR(2) = ICF(2), ICF(2) = 2

go to 301, K<NIV, go to 500

L=L + 1 - ICF(2) = 1

go to 55

Note that here Z_{G111} and Z_{G211} in ZPR(1) and ZPR(2) have been calculated and next is a linear interpolation with respect to X_2 values.

Subscripts for Z are defined in Figure 6.

At 55, IIX = NX(2) = 2 and since K > 1, go to 49 where

I=K-1=1 and IX=NX(1) + LØC (2) = 3 + 1 = 4

IXP = IX + J - 1 = 4, 5 for J = 1, 2 so that

XPR(1) = X_4(1), XPR(2) = X_4(2)

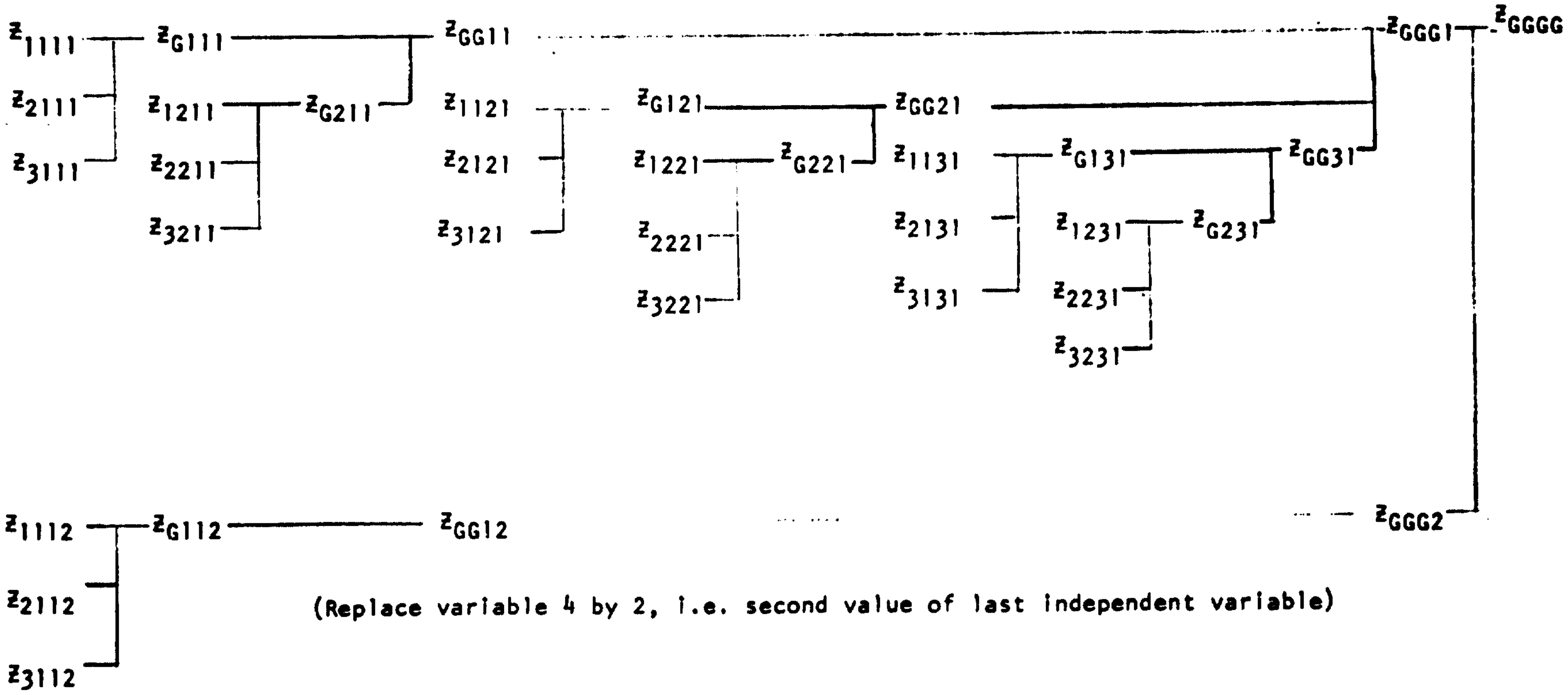
IIX=2 so go to statement number 64 for linear curve fit

for C & D and go to 2000 for ZPR(1) or Z_{GG11} calculation.

K=K+1=3, LLCTR(3) = LLCTR(3)+1+1, K>2, to to 315 and

Set KK=K-1+2, LLCTR(2)=0

Find next Z to be used from array, redefine LL where NX_1=3, NX_2=2



(Replace variable 4 by 2, i.e. second value of last independent variable)

Note: Subscripts refer to values of independent variable and G refers to the desired value of each independent variable. Thus z_{G211} means the z for X_G for variable #1, the second value for variable #2, the first value for variable #3 and the first value for variable #4.

Figure A-6. z CALCULATION FOR FRICTION DRAG

$LL=NX_1*NX_2=6$

go to 50

The next 6 elements of the Z matrix will be processed for Z_{G121} and Z_{G221} with the same logic as for the first six elements, but now LL=LL+LISTZ = 7 for Z the prime values. The X values are the same as for the first six lines.

The next series of calculations ends with the calculation of Z_{GG21} from Z_{G121} and Z_{G221}. Similarly, Z_{G131} and Z_{G231} are used to determine Z_{GG31}. Since three values of Z for variable number 3 have been determined a cubic can be fit and the resulting answer is Z_{GGG1}. Thus one value of Z has been determined corresponding to the first value for variable number 4.

Next, replace variable 4 by its second value and proceed through the calculations the same as above. This determines Z_{GGG2} and one more line interpolation produces Z_{GGGG} the desired value of the dependent variable given values of the independent variables.

SOURCE DECK LISTINGS FOR NCRAG AND NDTLAE

```
         ( JAN 75 )                    OS/360  FORTRAN H EXTENDED              DATE 76.162/15.04.43

REQUESTED OPTIONS: LIST,XREF,DECK

OPTIONS IN EFFECT: NAME(MAIN) OPTIMIZE(1) LINECOUNT(42) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC LIST DECK OBJECT MAP NOFORMAT GOSTMT XREF ALC NOANSF NOTERMINAL FLAG(I)

   ISN 0002          DIMENSION XG(6) ,X(24) ,Z(1440) ,NX(6) ,ARW1(140) ,BRW1(140) ,
                    1CRW1(140) , DRW1(140) ,ERW1(140) ,FRW1(20)  ,ARW2(120),BRW2(120),
                    2CRW2(120) ,DRW2(120) , ERW2(120) ,FRW2(120)
   ISN 0003          DIMENSION XG1(4) ,X1(10) ,Z1(36) , NX1(4)  ,XPR(2),  ZPR(2) ,S(3)
                    1,LW(7),MLT(7)
   ISN 0004          EQUIVALENCE (XG1(1),XG(3)) , (X1(1),X(15)) , (NX1(1),NX(3))
   ISN 0005          EQUIVALENCE (Z(1),ARW1(1)), (Z(141),BRW1(1)) , (Z(281) ,CRW1(1)),
                    1(Z(421),DRW1(1)) , (Z(561),ERW1(1)) , (Z(701),FRW1(1)) ,
                    2(Z(721),ARW2(1)) , (Z(841),BRW2(1)) , (Z(961),CRW2(1)) ,
                    3(Z(1081),DRW2(1)), (Z(1201),ERW2(1)) ,(Z(1321),FRW2(1))
   ISN 0006          REAL L,LM,MTF,M2TF2,M,LW,LP,MLT, LTVW,      LTVO
   ISN 0007          DATA LW /.00032,.00048,.00052,.00046,.00043,.00042,.00041/
   ISN 0008          DATA MLT /1.2,1.3,1.4,1.6,1.8,2.32,2.70/
   ISN 0009          DATA  NX /10,4,3,2,3,2 /
   ISN 0010          DATA    X /.4,.5,.6,.7,.75,.80,.85,.90,.95,1.0, 1.0,1.25,1.5,2.0,
                    11.25,1.5),2.0, 5.5,7.0 ,20.,30.,40., 1.2,2.32 /
   ISN 0011          DATA    Z1 /  .00034,.00036,.00039,.00042,.00044,.00048,         ZFR1-2 1
                    1.00050, .00053, .00057, .00061, .00065, .00070, .00060,          ZFR1-2 2
                    2.00069, .00075,  .00080,  .00085, .00092 , .00031, .00032 ,      ZFR1-2 3
                    3.00035,  .00038,  .00040,  .00043,  .00045,  .00047,  .00051,    ZFR1-2 4
                    4.00053,  .00056,  .00061,  .00056,  .00061,  .00066,  .00071,    ZFR1-2 5
                    5.00075,  .00081  /                                               ZFR1-2 6
   ISN 0012          DATA  ARW1 / .00038 ,.00043,.00046 ,.00048 ,.00049 ,.00049 ,     ARW10001
                    1.00048 ,.00047 ,.00046 ,.00046 ,-.00008 ,-.00010 ,-.00014 ,      ARW10002
                    2-.00017 ,-.00019 ,-.00022 ,-.00024 ,-.00026 ,-.000286,-.00030 ,  ARW10003
                    3-.00008 ,-.00010 ,-.00014 ,-.00017 ,-.00019,-.00022 ,-.00024 ,   ARW10004
                    4-.00026 ,-.000286,-.00030 ,-.00008 ,-.00010 ,-.00014 ,-.00017 ,  ARW10005
                    5-.00019 ,-.00022 ,-.00024 ,-.00026 ,-.000286,-.00030 ,           ARW10006
                    6.0010   ,.00108 ,.00115 ,.00123,.00128 ,.00133 ,.00137,.00140 ,  ARW10007
                    7.00140 ,.00140 ,.00149 ,.00047 ,.00045 ,.00040 ,.000377,.000345, ARW10008
                    8.000309,.00026 ,.00021 ,.00021 ,-.000034,-.000107,-.00019,-.00027,ARW10009
                    9-.00032 ,-.000362,-.000406,-.000455,-.000503,-.000545,-.000034,  ARW10010
                    1-.000107,-.00019,-.00027 ,-.00032 ,-.000362,-.000406,-.000455,   ARW10011
                    1-.000503,-.000545,.00318 ,.00318 ,.00324 ,.00347 ,.00368 ,.00385 ,ARW10012
                    2.00385 ,.00385 ,.00385 ,.00385 ,.00216 ,.00214 ,.00216 ,.00223 , ARW10013
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              3.00229 ,.00236 ,.00244 ,.00244 ,.00244 ,.00244 ,.0016 ,.0012 ,     ARW10014
              4.00128 ,.00126 ,.00123 ,.00118 ,.001099,.0010 ,.0010 ,.0010 ,     ARW10015
              5.00045 ,.00018 ,-.00006 ,-.00030 ,-.00042,-.00054 ,-.00065 ,     ARW10016
              6-.00074 ,-.00082 ,-.00091 ,.00013,.00023 ,.00004 ,-.00006 ,     ARW10017
              7-.00011 ,-.00015 ,-.00017 ,-.0002 ,-.00021 ,-.00023 ,-.00012 ,     ARW10018
              8-.00014 ,-.00018 ,-.00024 ,-.00025 ,-.00027 ,-.00028 ,-.00028 ,     ARW10019
              9-.00027 ,-.00026  /                                               ARW10020
         C
ISN 0013       DATA  BRW1  / -.00012 ,-.00014 ,-.00018 ,-.00024 ,-.00025 ,       BRW10021
              1-.00027 ,-.00026 ,-.00026 ,-.00027 ,-.00026 ,-.00012 ,-.00014 ,     BRW10022
              2-.00018 ,-.00024 ,-.00025 ,-.00027 ,-.00028 ,-.00028 ,-.00027 ,     BRW10023
              3-.00026 ,.00075 ,.00075 , .00066 , .00048 , .00040 ,.00032 ,       BRW10024
              4.00025 ,.00017 ,.00017 ,.00017 ,.00024 ,.00021 ,.0001 ,-.0001 ,     BRW10025
              5-.00015 ,-.00022 ,-.00026 ,-.00030 ,-.00032 ,-.00032 ,-.0001 ,     BRW10026
              6-.00022 ,-.00032 ,-.00045 ,-.00050 ,-.00053 ,-.00055 ,-.00055 ,     BRW10027
              7-.00053 ,-.00050 ,-.0001 ,-.00022 ,-.00032 ,-.00045 ,-.00050 ,     BRW10028
              8-.00053 ,-.00055 ,-.00055 ,-.00053 ,-.00050 ,                       BRW10029
              9.00223 ,.00215 ,.00205 ,.0019 ,.00185 ,.00176 ,.00169 ,.00169 ,     BRW10030
              1.00169 ,.00169 ,.0016 ,.00145 ,.00128 ,.00103 ,.0009 ,.00074 ,     BRW10031
              1.00058 ,.0005 ,.0005 ,.0005 ,.00105 ,.00065 ,.00060 ,.00030 ,       BRW10032
              2.00011 ,-.00008 ,-.0002 ,-.00027 ,-.0004 ,-.0003 ,.00015 ,          BRW10033
              3-.00015 ,-.00043 ,-.00070 ,-.00082 ,-.00094 ,-.001  ,-.00102 ,      BRW10034
              4-.00099 ,-.00088 ,.00060 ,.00056 ,.0005 ,.0004 ,.00032 ,.00025 ,   BRW10035
              5.00019 ,.00012 ,.00005 ,.00005 ,-.00013 ,-.00019 ,-.00025 ,         BRW10036
              6-.00033 ,-.00035 ,-.0004 ,-.00045 ,-.00045 ,-.00043 ,-.0004,        BRW10037
              7-.00013 ,-.00019 ,-.00025 ,-.0003 ,-.00035 ,-.0004 ,-.00045 ,       BRW10038
              8-.00045 ,-.00043 ,-.0004 ,-.00013 ,-.00019 ,-.00025 ,-.0003 ,       BRW10039
              9-.00035 ,-.0004 ,-.00045 ,-.00045 ,-.00043 ,-.0004  /               BRW10040
         C
ISN 0014       DATA   CRW1   / .00145 ,.00145 ,.0014 ,.00128 ,.0012 ,.0011 ,    CRW10041
              1.001 ,.00095 ,.00095 ,.00095 ,.00065 ,.00055 ,.0004  ,.00021,       CRW10042
              2.0001 ,-.00005 ,-.00018 ,-.0003 ,-.00035 ,-.00035 ,-.00032 ,        CRW10043
              3-.0002 ,-.00036 ,-.00055 ,-.00062 ,-.00072 ,-.00076 ,-.00079 ,      CRW10044
              4-.00077 ,-.00076 ,-.00002,-.0002 ,-.00036 ,-.00055 ,-.00062 ,       CRW10045
              5-.00070 ,-.00076 ,-.00079 ,-.00077 ,-.00076 ,.00451 ,.00445 ,       CRW10046
              6.0044 ,.00433 ,.00432 ,.00430 ,.00436 ,.0043, ,.0045  ,.00450 ,     CRW10047
              7.00338 ,.00312 ,.00285 ,.00255 ,.0024 ,.00224 ,.0021 ,.0021 ,       CRW10048
              8.0021 ,.0021 ,.00239 ,.0029 ,.0016 ,.00114 ,.0009 ,.00065 ,         CRW10049
              9.00046 ,.00033 ,.00033 ,.00033 ,.00081,.00025 ,-.00025 ,-.00074 , CRW10050
              1-.00094 ,-.0011 ,-.0012 ,-.00125 ,-.00125 ,-.00125 ,.00045 ,       CRW10051
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                  1.0024 ,.00032 ,.00018 ,.00005  ,-.0001 ,-.00016 ,-.00018 ,-.00014,CRW10052
                  2-.00012 ,-.0001 ,-.00017 ,-.00025 ,-.00032 ,-.00035 ,-.0004 ,      CRW10053
                  3-.00042 ,-.00041 ,-.0004 ,-.00034 ,-.0001 ,-.00017 ,-.00025 ,      CRW10054
                  4-.00032 ,-.00035 ,-.0004 ,-.00042 ,-.00041,-.0004 ,-.00034 ,       CRW10055
                  5-.0001 ,-.00017 ,-.00025 ,-.00032 ,-.00035 ,-.0004 ,-.00042 ,      CRW10056
                  6-.00041 ,-.0004 ,-.00034 ,.00119 ,.0011 ,.00095 ,.00066 ,.00051   ,CRW10057
                  7.0003 ,.00025 ,.00036 ,.00036 ,.00036 ,.00051 ,.00039 ,.00018 ,    CRW10058
                  8-.0001 ,-.00024 ,-.0004 ,-.00055 ,-.00056 ,-.00048 ,               CRW10059
                  9-.00048  /                                                         CRW10060
          C
ISN 0015           DATA   DRW1   / -.00005 ,-.00024 ,-.0004 ,-.0006 ,-.00065 ,        DRW10061
                  1-.00074 ,-.00079 ,-.00079 ,-.00074 ,-.0006 ,-.00035 ,-.00024 ,     DRW10062
                  2-.0004 ,-.0006 ,-.00065 ,-.00074 ,-.00079 ,-.00079 ,-.00074 ,      DRW10063
                  3-.0006 ,.00356 ,.0033 ,.00302 ,.00279 ,.00265 ,.00255 ,.00248 ,    DRW10064
                  4.00248 ,.00248 ,.00248 ,.00265 ,.00228 ,.00185 ,.00135 ,.0011 ,    DRW10065
                  5.00085 ,.00081 ,.00091 ,.00091 ,.00091 ,.00103 ,.0014 ,.00091 ,    DRW10066
                  6.00037 ,.00006 ,-.00024 ,-.00038 ,-.00035 ,-.00027 ,-.00027 ,      DRW10067
                  7.00055 ,.00003 ,-.00045 ,-.0009 ,-.0011 ,-.00123 ,-.00128 ,        DRW10068
                  8-.00127 ,-.0012 ,-.00103 ,.00015 ,.00032 ,.00036 ,.00023 ,         DRW10069
                  9.0001 , 0.   ,-.00005 ,-.00003 , 0.  , 0.   ,-.00017 ,-.0001 ,     DRW10070
                  1-.0001 ,-.0002 ,-.0003 ,-.00036 ,-.00037 ,-.00036 ,-.00035,        DRW10071
                  1-.00028,-.00017 ,-.0001  ,-.0001 ,-.0002 ,-.0003 ,-.00036 ,        DRW10072
                  2-.00037 ,-.00036 ,-.00035 ,-.00028 ,-.00017 ,-.0001 ,-.0001 ,      DRW10073
                  3-.0002 ,-.0003 ,-.00036 ,-.00037 ,-.00036 ,-.00035  ,-.00028 ,     DRW10074
                  4.0019 ,.0016 ,.00135 ,.00107 ,.00095  ,.00085 ,.00083 ,.00095 ,    DRW10075
                  5.00095 ,.00095  ,.0008 ,.0005 ,.00019 ,-.00012 ,-.00026 ,-.0004 ,  DRW10076
                  6-.00046 ,-.00045 ,-.00036 ,-.00036 ,  0.  ,-.0003 ,-.00058 ,       DRW10077
                  7-.00077 ,-.00085 ,-.00092 ,-.00095 ,-.00095 ,-.00090 ,-.00076 ,    DRW10078
                  8  0. ,-.0003  ,-.00058 ,-.00077 ,-.00085 , -.00092 ,               DRW10079
                  9-.00095 ,-.00095 ,  -.0009 , -.00076  /                            DRW10080
          C
ISN 0016           DATA   ERW1   / .00586 ,.00533 ,.00489 ,.00469 ,.00470 ,.00475 ,   ERW10081
                  1.00475 ,.00475 ,.00475 ,.00475 ,.00438 ,.00365 ,.00302 ,.00252 ,   ERW10082
                  2.00233 ,.00221 ,.00232 ,.00232 ,.00232 ,.00232 ,.00313 ,.0023 ,    ERW10083
                  3.00154 ,.00090 ,.00062 ,.00035 ,.00022 ,.00025 ,.00025 ,.00025 ,   ERW10084
                  4.00121 ,.00033 ,-.00045 ,-.00101 ,-.00121 ,-.0014 ,-.00145 ,       ERW10085
                  5-.00145 ,-.00138 ,-.00119 ,.00081 ,.00075 ,.00066 ,.00036 ,        ERW10086
                  6.00019 ,-.00005 ,-.00014 ,-.00011 ,.00003 ,.00003 ,.00004 ,        ERW10087
                  7-.0001 ,-.00023 ,-.00035 ,-.0004 ,-.00045 ,-.0005 ,-.00049 ,       ERW10088
                  8-.00045 ,-.00039 ,.00044 ,-.0001 ,-.00023 ,-.00035 ,-.0004 ,       ERW10089
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                    9-.00045 ,-.0005 ,-.00049 ,-.00045 ,-.00034 ,.00004,-.0001 ,        ERW10090
                    1-.00023 ,-.00035 ,-.0004 ,-.00045 ,-.0005 ,-.00049 ,-.00045 ,      ERW10091
                    1-.00039 ,.00207 ,.00193 ,.00166 ,.00125 ,.00095 ,.00064 ,.0005 ,   ERW10092
                    2.00092 ,.00092,.00092,.00111 ,.0009 ,.00059 ,.00018 ,-.0001 ,      ERW10093
                    3-.00037 ,-.0005 ,-.00125 ,.00034 ,.00034 ,-.00015 ,-.00019 ,       ERW10094
                    4-.00027 ,-.00049 ,-.00064 ,-.00082 ,-.00095 ,-.00103 ,-.0009 ,     ERW10095
                    5-.00069  ,-.00015 ,-.00019 ,.00027 ,-.00049 ,-.00064 ,-.00082 ,    ERW10096
                    6.00095 ,-.00103 , -.0009 ,-.00069 ,.00589 ,.0056 ,.0051 ,.00455 , ERW10097
                    7.00417 ,.00391 ,.0042 ,.0042 ,.0042 ,.0042 ,.00455 ,.00434 ,       ERW10098
                    8.00346 ,.0026 ,.00215  , .00177 , .00176 ,                         ERW10099
                    9.0021 ,.0021 ,.0021 /                                              ERW10100
               C
ISN 0017             DATA  FRW1  / .0034 ,.00278 ,.00202 ,.00117 ,.00069 ,.00022 ,      FRW10101
                    1.00007 ,.0002 ,.0003 ,.0003 , .0016 ,.0007 ,-.00005 ,-.0007 ,      FRW10102
                    2-.00098 ,-.00125 ,-.00140 ,-.00140 ,-.00134 ,-.0011   /            FRW10103
ISN 0018             DATA  ARW2 / .000115 , .0001 , .00008 ,.00007 , .00006 ,.000051 , ARW20001
                    1.000046 , .00004 , .000035 ,.000035  , -.000049 , -.000068 ,       ARW20002
                    2-.00008 , -.000091 , -.0001 , -.000103 , -.00011 , -.000112 ,      ARW20003
                    3-.000118 ,-.00012 , -.000149 ,-.000068 , -.00008 ,-.000091 ,       ARW20004
                    4-.0001 , -.000133 , -.00011 , -.000112 , -.000118 , -.00012 ,      ARW20005
                    5-.000049 , -.000068 , -.00008 , -.000091 , -.0001 , -.000103 ,     ARW20006
                    6-.00011 , -.000112 , -.000118 , -.00012 , .00031 ,.00028 ,         ARW20007
                    7.00026 , .00023 ..000215 , .0002 , .00018 , .00017 ,.00017 ,      ARW20008
                    8.00017 , .000105 , .00007 , .000032 , 0.0    , -.00002 , -.00003 , ARW20009
                    9-.00004 , -.00005 , -.00006 , -.00006 , -.00006 , -.0001 ,         ARW20010
                    1-.00013 , -.00016 , -.00017 , -.00018  , -.000186,-.00019  ,       ARW20011
                    1-.000197 , -.0002 , -.00006 , -.0001 , -.00013 , -.00016 ,-.00017,ARW20012
                    2-.00018 , -.000186 , -.00019 , -.000197 , -.0002    ,              ARW20013
                    3.000815 , .000825 , .000832 , .00084,.000837 , .000837 , .000837, ARW20014
                    4.000837 , .000837 , .000837 ,  .000615 , .00057 , .00051 ,         ARW20015
                    5.00044 , .0004 , .00036 , .00032 , .00032  ,.00032 ,.00032 ,       ARW20016
                    6.00038 , .000315 , .00025 , .00017 , .000125 , .000082 , .00004 , ARW20017
                    70.0    , 0.0   ,  0.0    , .000045  , -.00005 , -.00013 , -.0002 ,ARW20018
                    8-.00023 , -.00026 , -.00028 , -.0003 , -.00032 ,                   ARW20019
                    9 -.000332 /                                                        ARW20020
               C
ISN 0019             DATA  BRW2 / .000029 , .000018 , .00001 , -.000002, -.00001  ,     BRW20021
                    1-.000012 , -.000015  , -.00002 , -.000025 , -.000025  , -.000068 ,BRW20022
                    2-.00008 , -.00009 - -.000102  , -.00011 , -.000114, -.000118,      BRW20023
                    3-.00012 , -.00012 , -.00012  , -.000068 , -.00008 , -.00009 ,      BRW20024
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                  4-.000102 ,-.00011 , -.000114, -.000116, -.00012 , -.00012 ,       BRW20025
                  5-.00012 , -.000068 , -.00008 , -.00009 , -.000102 , -.00011 ,     BRW20026
                  6-.000114 ,-.000118 , -.00012 , -.00012  ,-.00012  ,  .00285 ,     BRW20027
                  7.00026 , .00023 ,  .000215 ,  .00019 , .00018  , .00017 ,         BRW20028
                  8.00016 , .00016 , .00016  , .00008 , .00004 , .00001 , -.000025 , BRW20029
                  9-.00004 , -.00005 , -.00006 , -.00007 , -.000078 , -.000076 ,     BRW20030
                  1-.00008 , -.000125 , -.00016 , -.000188 , -.0002 , -.000208 ,     BRW20031
                  1-.00021 , -.000215 , -.000214 , -.000212  , -.00018 , -.000125 ,  BRW20032
                  2-.00016 , -.000188 , -.0002 , -.000208 , -.00021 , -.000215 ,     BRW20033
                  3-.000214 , -.000212  , .00084 , .000808 , .000756 , .00069 ,      BRW20034
                  4.00065 , .00061 , .00058  , .00056  ,.00056 ,.00058  , .000588 ,  BRW20035
                  5.000507 , .000425 , .00034  , .000295 , .00026 , .00024 , .00024, BRW20036
                  6.00024 , .00024 , .00035 , .000255 , .00016 , .000075 , .00003 ,  BRW20037
                  7-.00001 , -.00003 , -.00004 , -.00004 ,-.00004 , 0.0   ,-.00013 , BRW20038
                  8-.00022 , -.000287 , -.000312, -.000338  , -.00035 , -.000362 ,   BRW20039
                  9-.00037  ,-.000369  /                                             BRW20040
         C
ISN 0020           DATA  CRW2 /  .000155 , .00014 , .000123 , .0001 , .00008 ,       CRW20041
                  1.00007 , .000062 , .000055 , .000051 , .000051 , -.0001 ,         CRW20042
                  2-.000128 , -.000149 , -.00016 , -.00017 ,  -.000172 , -.000178 ,  CRW20043
                  3-.00018 ,-.00018  ,-.00016  , -.0001 , -.000128 , -.000149 ,      CRW20044
                  4-.00016 , -.00017 , -.000172  ,-.000178 , -.00018 , -.00018 ,     CRW20045
                  5-.00018 , -.0001   , -.000128  , -.000149  , -.00016 , -.00017 ,  CRW20046
                  6-.000172  , -.000178  , -.00018  , -.00018  , -.00016 , .00048 ,  CRW20047
                  7.00046 , .000426 , .000375 , .000345 , .00032 , .00029 , .00028 , CRW20048
                  8.00028 , .00028 , .00017 , .00012 , .00007 , .000012 , -.00002 , CRW20049
                  9-.000049 , -.00007 , -.00008 ,  -.000078 , -.000078  ,-.00008 ,   CRW20050
                  1-.00014 , -.00019 , -.000232 , -.000255 , -.00027 , -.000288 ,    CRW20051
                  1-.000295 , -.000295 , -.00029 , -.00008 , -.00014 , -.00019 ,     CRW20052
                  2-.000232 , -.000255 , -.00027 , -.000288  ,-.000295 ,-.000295 ,   CRW20053
                  3-.00029 , .001214 , ,.001183 , .00115 , .00111 , .001092 ,        CRW20054
                  4.00107 , .00107 , .00107 , .00107 ,.00107  , .00082 , .00074 ,    CRW20055
                  5.00066 , .00058 , .00054 , .0005 , .00049  , .00049  ,.00049 ,    CRW20056
                  6.00049 , .000495 , .000385 , .000282 , .000175 , .000125 ,        CRW20057
                  7.000075 , .000032 , 0.   ,  0.   ,  0.  , .00002 , -.00011 ,      CRW20058
                  8-.00022 , -.000325  , -.00037 , -.00041 , -.000438 , -.00045 ,    CRW20059
                  9-.00046 , -.000469   /                                            CRW20060
         C
ISN 0021           DATA DRW2  / .000155 , .000136  , .00012 , .000092 , .000085 ,    DRW20061
                  1.000070 , .000060 , .000040 , .000023 ,.000023 , -.000075 ,       DRW20062
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                      2-.0001 , -.000123 , -.00014 , -.000147 , -.00015 , -.000154 ,        DRW20063
                      3-.000155 , -.000155 , -.000154  , -.000075 , -.0001 , -.000123 ,     DRW20064
                      4-.00014 , -.000147 , -.00015 , -.000154 , -.000155 , -.000155,       DRW20065
                      5-.000154 , -.000075 , -.0001 ,- .000123 , -.00014  -.000147 ,        DRW20066
                      6-.00015 , -.000154 , -.000155 , -.000155 , -.000154  , .000425 ,     DRW20067
                      7.00038 , .00034 , .0003 , .00028 , .00026 , .00024 , .00022 ,        DRW20068
                      8.00022  ,.00022 , .000150 , .000087 , .000030 , -.000020 ,           DRW20069
                      9-.000042 , -.000060 , -.000080 , -.0001 , -.000115  , -.000115 ,     DRW20070
                      1-.00008 , -.000150  , -.000207 , -.000245 , -.00026 , -.000274 ,     DRW20071
                      1-.000280 , -.000284 , -.000285 ,-.000280 , -.00008 , -.000150 ,      DRW20072
                      2-.000207 , -.000245 , -.00026 , -.000274 , -.000280 , -.000284 ,     DRW20073
                      3-.000285 , -.000280 , .001088 , .00103 , .00097 , .000905 ,          DRW20074
                      4.00087 , .00084 , .000815 , .000815 , .000815 , .000815 ,.00074 ,   DRW20075
                      5.000638 , .00053 , .00042  , .00036 , .000315 , .00031 , .00032 ,   DRW20076
                      6.00032 , .00032  , .00044 , .00031 , .000165 , .000065 ,.000005 ,   DRW20077
                      7-.00004 , -.00007 , -.00007 , -.00006 , -.00006 , -.00002 ,          DRW20078
                      8-.000175 , -.000295 , -.000385 , -.000425 ,-.00046  , -.00048 ,      DRW20079
                      9-.00049 ,  -.00049 , -.000465   /                                    DRW20080
                C
   ISN 0022            DATA ERW2 / .000102 , .00011 , .000114 , .00011 , .000105 ,          ERW20081
                      1.0001 , .000095 , .000084  , .000080 ,.000080  , -.000090 ,          ERW20082
                      2-.000082 , -.000085 , -.0001  , -.00011 , -.00012 , -.00013 ,        ERW20083
                      3-.000137 , -.000144 , -.000158 , -.000090 , -.000080 , -.000085 ,    ERW20084
                      4-.0001 , -.00011 , -.00012 , -.00013  , -.000137 , -.000144 ,        ERW20085
                      5-.000158  , -.000090  , -.000080 , -.000085 , -.0001 , -.00011 ,     ERW20086
                      6-.00012 , -.00013 , -.000137 , -.000144 ,-.000158  , .000472 ,       ERW20087
                      7.000433 , .00040, .000375 , .000367 , .00036 , .00037 , .000385 ,  ERW20088
                      8.000385 , .000385  , .00011 , .00005 , -.00001 , -.00005 ,           ERW20089
                      9-.000068 , -.00008  , -.00009 , -.0001 , -.00011 ,-.00011 ,          ERW20090
                      1-.000168 , -.000225 , -.00027  , -.00031 , -.000329 , -.00034 ,      ERW20091
                      1-.00035 , -.00036 , -.00036 , -.000357  , -.000168 , -.000225 ;      ERW20092
                      2-.00027 , -.00031 , -.000329 , -.00034  , -.00035 ,-.00036 ,         ERW20093
                      3-.00036 , -.000352 ,  .00154 , .001468 , .0014 , .001338 ,           ERW20094
                      4.001305  , .00128 , .00128 , .00128 ,.00128  ,.00128 , .001225 ,    ERW20095
                      5.0009 , .000760  , .00066 , .000635 , .00061 , .00065 ,.00065  ,     ERW20096
                      6.00065 ,.00065 , .00062 , .00046  , .000322 , .00014 , .00013 ,     ERW20097
                      7.000075 , .000055 , .000075 , .000075  ,.000075 , .00006 ,           ERW20098
                      8-.000115, -.000255 , -.00036 , -.000435 , -.00048 , -.00051 ,        ERW20099
                      9-.00053  , -.00053 , -.00052   /                                     ERW20100
                C
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ISN 0023            DATA  FRW2  / .000226 , .000202  , .000175 , .000146 ,  .000128 , FRW20101
                   1.00011 , .00009  , .00009  , .000102 ,.000102  , -.000067 ,        FRW20102
                   2-.000105 , -.000132 , -.000166 , -.000171 , -.000176 , -.000180 , FRW20103
                   3-.000182 , -.000182  , -.000181 , -.000167 , -.000155 , -.000132 ,FRW20104
                   4-.000160 , -.000170 , -.000175  , -.000180 , -.000182 , -.000182 ,FRW20105
                   5-.000181 , -.000067 , -.000105 , -.000132 , -.000160 , -.000175 , FRW20106
                   6-.000175 , -.000180 , -.000182 , -.000182 , -.000181 , .000575 ,  FRW20107
                   7.00054 , .00049 , .00043 , .000392 , .000355 , .00035 , .00041 ,  FRW20108
                   8.00041 ,.00041 , .00023 , .00016 , .000088 , .000015 , -.000025 , FRW20109
                   9-.00036 , -.00009  , -.000090,-.000060 , -.000060 , -.000125 ,    FRW20110
                   1-.000167 , -.00021 , -.00026 , -.000287 , -.000315 , -.00034 ,    FRW20111
                   1-.00036 , -.00036  , -.00033 ,-.000125 , -.000167 ,-.00021 ,      FRW20112
                   2-.00026 , -.000287 , -.000315 , -.00034 , -.00036 , -.00036 ,     FRW20113
                   3-.00033 , .00163 , .00155 , .001465 , .00136 , .00130 , .001242 , FRW20114
                   4.00127 ,.00127 , .00127 ,.00127 , .00117 , .00103 , .00088 ,      FRW20115
                   5.00073 , .00065 ,  .000575 , .000565 , .00062 ,.00062  ,.00062 ,  FRW20116
                   6.00078 , .000595 ,  .00042 , .00024  , .000165 , .000080 ,        FRW20117
                   7.000050 , .000080 , .00012 ,.00012 , .0002 , -.000015 , -.0002 ,  FRW20118
                   8-.00035 , -.000415 , -.00047 , -.000515 ,  -.00054 ,              FRW20119
                   9-.00054 , -.00052  /                                              FRW2 120
ISN 0024            PI=3.141593
ISN 0025            FTM = .3048
ISN 0026            F2TM2 =.092903
ISN 0027            MTF = 3.28084
ISN 0028            M2TF2 =10.76391
ISN 0029            S1=10000.
ISN 0030          1 READ (5,10)  AC,AMAX,AN,XMAX,L,SREF,M
ISN 0031         10 FORMAT(7E10.6)
ISN 0032            IF (AC)  5,7,7
ISN 0033          5 SREF=SREF*M2TF2
ISN 0034          7 CDF12=0.
ISN 0035            CDW12=0.
ISN 0036            CD012=0.
ISN 0037            CDF232=0.
ISN 0038            CDW232=0.
ISN 0039            CD0232=0.
ISN 0040            CDOM=0.
ISN 0041            SRATIO =S1/SREF
ISN 0042            XG(1)=XMAX/L
ISN 0043            XG(2)=AN/ABS(AC)
```

```
ISN 0044            XG(3)=AMAX/ABS(AC)
ISN 0045            DC=SQRT(4*ABS(AC)/ PI)
ISN 0046            XG(4)=L/DC
ISN 0047            IF (AC) 15,17,17
ISN 0048         15 ACM=ABS(AC)
ISN 0049            AC=ACM * M2TF2
ISN 0050            AC1=AC
ISN 0051            AMAXM=AMAX
ISN 0052            AMAX=AMAX * M2TF2
ISN 0053            ANM =AN
ISN 0054            AN =AN * M2TF2
ISN 0055            XMAXM =XMAX
ISN 0056            XMAX =XMAX * MTF
ISN 0057            LM =L
ISN 0058            L=L * MTF
ISN 0059            SREFM=SREF*F2TM2
ISN 0060            GO TO 20
ISN 0061         17 ACM=AC*F2TM2
ISN 0062            AMAXM =AMAX * F2TM2
ISN 0063            ANM = AN * F2TM2
ISN 0064            XMAXM= XMAX * FTM
ISN 0065            LM= L* FTM
ISN 0066            SREFM = SREF * F2TM2
ISN 0067         20 XG(5)=ABS(AC)
ISN 0068            IF (XG(1).LT..4 .OR. XG(1).GT.1.)GO TO 25
ISN 0070            GO TO 30
ISN 0071         25 WRITE (6,101) XG(1)
ISN 0072         30 IF (XG(2).LT.1. .OR. XG(2).GT.2.) GO TO 35
ISN 0074            GO TO 40
ISN 0075         35 WRITE (6,102) XG(2)
ISN 0076         40 IF (XG(3).LT.1.25 .OR. XG(3).GT.2.) GO TO 45
ISN 0078            GO TO 50
ISN 0079         45 WRITE (6,103) XG(3)
ISN 0080         50 IF (XG(4).LT.5.5 .OR. XG(4).GT.7.) GO TO 55
ISN 0082            GO TO 60
ISN 0083         55 WRITE (6,104) XG(4)
ISN 0084         60 IF (XG(5).LT.20. .OR. XG(5).GT.40.)  GO TO 70
ISN 0086         65 GO TO 75
ISN 0087         70 WRITE(6,105) XG(5)
ISN 0088         75 XG(6)=1.2
```

```
                C ... CDW AT 1.2M
  ISN 0089            CALL NDTLAE(6 ,XG,X,Z,NX,CDW12,A,B,C,D)
                C ... CDW AT 2.32M
  ISN 0090            XG(6)=2.32
  ISN 0091            CALL NDTLAE(6 ,XG,X,Z,NX,CDW232,A,B,C,D)
                C ... CDF AT 1.2M
  ISN 0092            XG(6)=1.2
  ISN 0093            CALL NDTLAE(4 ,XG1,X1,Z1,NX1,CDF12,A,B,C,D)
                C ... CDF AT 2.32M
  ISN 0094            XG(6)=2.32
  ISN 0095            CALL NDTLAE(4 ,XG1,X1,Z1,NX1,CDF232,A,B,C,D)
  ISN 0096            CDF12=CDF12 * SRATIO
  ISN 0097            CDW12=CDW12 * SRATIO
  ISN 0098            CDF232=CDF232 * SRATIO
  ISN 0099            CDW232= CDW232 * SRATIO
  ISN 0100            CD012=CDF12 + CDW12
  ISN 0101            CD0232=CDF232 + CDW232
                C . . . CDO AT INPUT MACH NO.
  ISN 0102            IF (M)  83,95,83
  ISN 0103         83 DER=(CD0232-CD012)/1.12
  ISN 0104            S(2)=2.*DER
  ISN 0105            S(3)=.35* DER
  ISN 0106            LIPN=2
  ISN 0107            IP=1
  ISN 0108            ZPR(1)=CD012
  ISN 0109            ZPR(2)=CD0232
  ISN 0110            XPR(1)=1.2
  ISN 0111            XPR(2)=2.32
  ISN 0112            A = -(2.*(ZPR(LIPN) - ZPR(LIPN - 1))     - (S(3) + S(2))*(XPR(IP   NDT00281
                     2+ 1)- XPR(IP )))/(XPR(IP   + 1) - XPR(IP ))**3                 NDT00282
  ISN 0113            B = (((ZPR(LIPN)     - ZPR(LIPN - 1))    / (XPR(IP   + 1) - XPR(IP ))NDT00283
                     2) - S(2)- (XPR(IP   + 1) + 2.*XPR(IP ))*(XPR(IP   + 1) - XPR(IP ))*ANDT00284
                     3)/(XPR(IP   + 1) - XPR(IP ))                                      NDT00285
  ISN 0114            C = S(2) - 2.*XPR(IP )*B - 3.*XPR(IP )**2*A                        NDT00286
  ISN 0115            D = ZPR(LIPN - 1)   - XPR(IP )*(C + XPR(IP )*(B + XPR(IP )*A))    NDT00287
  ISN 0116            CDOM=D+M*(C+M*(B+M*A))
  ISN 0117         95 WRITE (6,100)  ACM ,AC , AMAXM , AMAX , ANM ,AN , XMAXM , XMAX ,
                     1LM  ,  L    , SREFM ,SREF , CDF12 ,CDW12 ,CD012 , CDF232 ,CDW232 ,
                     2CD0232
  ISN 0118        100 FORMAT (1H1 20X, 16HNACELLE GEOMETRY//1H 20X,19HCAPTURE AREA
```

```
                   1 F6.2,2X,12HSQ M    (     F6.2,2X,6HSQ FT),/ 1H  26X,19HMAXIMUM AREA
                   2         F6.2,2X,12HSQ M    (     F6.2,2X,6HSQ FT)/ 1H  26X,19HNOZZLE
                   3AREA          F6.2,2X,12HSQ M    (     F6.2,2X,6HSQ FT)/ 1H  26X,19HLO
                   4C. OF MAX. AREA  F6.2,4X,10HM     (     F6.2,4X,4HFT )/ 1H  26X,19HT
                   5OTAL LENGTH       F6.2,4X,10HM     (     F6.2,4X,4HFT )//1H 26X,22HW
                   6ING REFERENCE AREA   F9.2,2X,9HSQ M    ( F9.2,2X,6HSQ FT)//1H 20X,3
                   77HINCREMENTAL NACELLE DRAG COEFFICIENTS/ 1H 26X,17HMACH 1.2    CDF
                   8= F8.5,3X,5HCDW= F8.5,3X,5HCDO= F8.5/ 1H  26X,17HMACH 2.32   CDF=
                   9F8.5,3X,5HCDW= F8.5,3X,5HCDO= F8.5)
ISN 0119            IF  (M)  109,112,109
ISN 0120        109 WRITE (6,110)  M,CDOM
ISN 0121        110 FORMAT ( 1H 26X,4HMACH F5.2,35X,5HCDO= F8.5)
ISN 0122        112 WRITE (6,115)  XG(1),XG(2),XG(3),XG(4)
ISN 0123        115 FORMAT (/1H 20X, 8HXMAX/L= F7.3,3X, 7HAN/AC= F7.3,3X, 9HAMAX/AC= F
                   17.3,3X, 6HL/DC= F7.3)
ISN 0124            WRITE(6,140)
ISN 0125        140 FORMAT (//1H 20X,61HINCREMENTAL NACELLE DRAG COEFFICIENTS - LTV RE
                   1FERENCE VEHICLE/1H 26X,25HMACH 1.2    CDF=  0.00672,3X,13HCDW= -0.
                   200041,3X,13HCDO=  0.00031/1H 26X,25HMACH 2.32   CDF=  0.00060,3X,1
                   33HCDW= -0.00018,3X,13HCDO=  0.00042)
ISN 0126            IF (M) 201,310,201
              C LTV REFERENCE VEHICLE NACELLE WAVE AND FRICTION DRAGS
ISN 0127        201 IF (M-1.4)  204,204,206
ISN 0128        204 I=1
ISN 0129            GO TO 220
ISN 0130        206 IF (M-1.8)  208,208,210
ISN 0131        208 I=3
ISN 0132            GO TO 220
ISN 0133        210 I=5
ISN 0134        220 LTVW=(M-MLT(I+1))*(M-MLT(I+2))/((MLT(I)-MLT(I+1))*(MLT(I)-MLT(I+2)
                   1))*LW(I)  +(M-MLT(I))*(M-MLT(I+2))/((MLT(I+1)-MLT(I))*(MLT(I+1)-MLT
                   2(I+2)))*LW(I+1) +(M-MLT(I))*(M-  MLT(I+1))/((MLT(I+2)-MLT(I))*(MLT
                   3(I+2)-MLT(I+1))) *LW(I+2)
ISN 0135            LTVO=LTVW
ISN 0136        230 WRITE (6,145)   M,LTVO
ISN 0137        145 FORMAT(1H 26X,4HMACH F5.2,33X,7H  CDO= F8.5)
ISN 0138        101 FORMAT (1H1 20X, 22HXMAX/L OUTSIDE RANGE =F6.2)
ISN 0139        102 FORMAT (1H1 20X, 21HAN/AC OUTSIDE RANGE =F6.2)
ISN 0140        103 FORMAT (1H1 20X, 23HAMAX/AC OUTSIDE RANGE =F6.2)
ISN 0141        104 FORMAT (1H1 20X, 20HL/DC OUTSIDE RANGE =F6.2)
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ISN 0142        105 FORMAT (1H1 20X, 18HAC OUTSIDE RANGE =F6.2)
ISN 0143        310 GO TO 1
ISN 0144            END
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REQUESTED OPTIONS: LIST,XREF,DECK

OPTIONS IN EFFECT: NAME(MAIN) OPTIMIZE(1) LINECOUNT(42) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC LIST DECK OBJECT MAP NOFORMAT GOSTMT XREF ALC NOANSF NOTERMINAL FLAG(I)

  ISN 0002            SUBROUTINE NDTLAF(NIV, XG, X, Z, NX, RES, A, B, C, D)         NDT00010
              C                                                                     NDT00020
              C                                                                     NDT00030
              C          NOMENCLATURE                                               NDT00040
              C               NIV     = NUMBER OF INDEPENDENT VARIABLES             NDT00050
              C               XG      = ARRAY OF GIVEN VALUES OF INDEPENDENT VARIABLES NDT00060
              C               X       = ARRAY OF INDEPENDENT VARIABLES              NDT00070
              C               Z       = ARRAY OF DEPENDENT VARIABLES                NDT00080
              C               NX      = ARRAY OF NUMBER OF VALUES GIVEN FOR EACH    NDT00090
              C                         INDEPENDENT VARIABLE                        NDT00100
              C               RES     = FINAL INTERPOLATED VALUE OF Z AT X1 GIVEN, X2  NDT00110
              C                         GIVEN, .......XNIV GIVEN                    NDT00120
              C               A,B,C,D = COEFFICIENTS OF THE CUBIC DEFINING THE Z VALUESNDT00130
              C               ICF     = ARRAY OF NUMBER OF POINTS TO BE USED FOR CURVE NDT00140
              C                         FIT FOR EACH INDEPENDENT VARIABLE           NDT00150
              C               XXG     = ARRAY OF GIVEN VALUES OF INDEPENDENT VARIABLES NDT00160
              C                         UNLESS VALUE WAS OUTSIDE RANGE.  IN THIS CASE  NDT00170
              C                         CLOSEST VALUE IN THE TABLE IS ASSIGNED XXG  NDT00180
              C               IGAT    = ARRAY OF INDICATORS OF LOCATIONS OF X GIVEN IN NDT00190
              C                         X ARRAY                                     NDT00200
              C                         1, IF XG IS IN ONE OF THE MIDDLE INTERVALS  NDT00210
              C                         2, IF XG IS IN THE FIRST INTERVAL           NDT00220
              C                         3, IF XG IS IN THE LAST INTERVAL            NDT00230
              C               LOC     = ARRAY OF LOCATION IN X ARRAY OF FIRST VALUE TO NDT00240
              C                         BE USED FOR EACH INDEPENDENT VARIABLE .     NDT00250
              C               XPR     = TEMPORARY ARRAY FOR X VALUES BEING USED     NDT00260
              C               ZPR     = TEMPORARY ARRAY FOR Z VALUES BEING USED     NDT00270
              C               LISTZ   = LOCATION OF FIRST VALUE USED IN THE Z ARRAY NDT00280
              C               LLCTR   = COUNTERS FOR THE ZS WITHIN A SUBSET         NDT00290
              C               L       = SUBSCRIPT FOR Z-PRIME                       NDT00300
              C               LL      = SUBSCRIPT FOR Z                             NDT00310
              C               K       = SUBSCRIPT INDICATING THE SUBSET             NDT00320
              C                                                                     NDT00330
              C                                                                     NDT00340
              C       DIMENSION NX(1), LOC(NIV), XG(1),X(1), Z(1), ZPR(4 + 3*(NIV - 2)),NDT00350
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                 C      XPR(4), S(3), XXG(NIV), IGAT(NIV), ICF(NIV), LLCTR(NIV + 1)       NDT00360
                 C                                                                        NDT00370
                 C                                                                        NDT00380
ISN 0003                DIMENSION NX(1), LOC(10), XG(1), X(1), Z(1), ZPR(28), XPR(4), S(3)NDT00390
                       1, XXG(10), IGAT(10), ICF(10), LLCTR(11)                           NDT00400
ISN 0004                DO 1 I = 1, NIV                                                   NDT00410
                 C                                                                        NDT00420
                 C      TEST TO SEE IF EACH VARIABLE HAS MORE THAN ONE POINT              NDT00430
                 C                                                                        NDT00440
ISN 0005                IF(NX(I)-1) 2, 2, 3                                               NDT00450
                 C                                                                        NDT00460
                 C      VARIABLE I ONLY HAS ONE POINT, THEREFORE PROGRAM CANNOT CONTINUE  NDT00470
                 C                                                                        NDT00480
ISN 0006              2 WRITE(6,100) I,NX(I)                                              NDT00490
ISN 0007            100 FORMAT(13H1   VARIABLE I3,10H ONLY HAS  I2,41H POINT, THEREFORE PRNDT00500
                       2OGRAM CANNOT CONTINUE)                                            NDT00510
ISN 0008                STOP                                                              NDT00520
                 C                                                                        NDT00530
                 C      SET UP ARRAY ICF WHICH IS THE NUMBER OF POINTS REQUIRED FOR CURVE NDT00540
                 C      FIT                                                               NDT00550
                 C                                                                        NDT00560
ISN 0009              3 IF(NX(I) - 3) 4, 4, 5                                             NDT00570
ISN 0010              4 ICF(I) = NX(I)                                                    NDT00580
ISN 0011                GO TO 1                                                           NDT00590
ISN 0012              5 ICF(I) = 4                                                        NDT00600
ISN 0013              1 CONTINUE                                                          NDT00610
                 C                                                                        NDT00620
                 C      ICF(NIV + 1) IS ARTIFICIAL VALUE TO CONCLUDE CURVE FITTING FOR    NDT00630
                 C      ENTIRE ROUTINE                                                    NDT00640
                 C                                                                        NDT00650
ISN 0014                ICF(NIV + 1) = 1                                                  NDT00660
ISN 0015                IT = 0                                                            NDT00670
                 C                                                                        NDT00680
                 C      FIND LOCATIONS OF INTERVALS CONTAINING GIVEN INDEPENDENT VARIABLESNDT00690
                 C      THUS FORMING THE LOC ARRAY.                                       NDT00700
                 C                                                                        NDT00710
ISN 0016                DO 6 I = 1, NIV                                                   NDT00720
ISN 0017                XXG(I) = XG(I)                                                    NDT00730
ISN 0018                IL = IT + 1                                                       NDT00740
ISN 0019                IIX = IL                                                          NDT00750
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ISN 0020            IT = IT + NX(I)                                          NDT00760
ISN 0021            IGAT(I) = 1                                              NDT00770
ISN 0022         19 IF(IIX - IT) 7, 8, 9                                     NDT00780
              C                                                              NDT00790
              C     ERROR OCCURRED                                           NDT00800
              C                                                              NDT00810
ISN 0023          9 IERR = 19                                                NDT00820
ISN 0024            GO TO 5000                                               NDT00830
              C                                                              NDT00840
              C     COMPARE GIVEN VALUE WITH X ARRAY FOR A PARTICULAR INDEPENDENT NDT00850
              C     VARIABLE                                                 NDT00860
              C                                                              NDT00870
ISN 0025          7 IF(XXG(I) - X(IIX)) 12, 11, 10                           NDT00880
ISN 0026         10 IF(XXG(I) - X(IIX +1)) 14, 14, 13                        NDT00890
ISN 0027         13 IF(IIX + 1 - IT) 15, 16, 17                              NDT00900
ISN 0028         17 IERR = 13                                                NDT00910
              C                                                              NDT00920
              C     ERROR OCCURRED                                           NDT00930
              C                                                              NDT00940
ISN 0029            GO TO 5000                                               NDT00950
ISN 0030         15 IIX = IIX + 1                                            NDT00960
ISN 0031            GO TO 10                                                 NDT00970
              C                                                              NDT00980
              C                                                              NDT00990
ISN 0032         16 GO TO 20                                                 NDT01000
ISN 0033         14 IF(IIX - IL) 18, 11, 20                                  NDT01010
ISN 0034         18 IERR = 14                                                NDT01020
              C                                                              NDT01030
              C     ERROR OCCURRED                                           NDT01040
              C                                                              NDT01050
ISN 0035            GO TO 5000                                               NDT01060
ISN 0036         12 GO TO 11                                                 NDT01070
ISN 0037         11 IGAT(I) = 2                                              NDT01080
              C                                                              NDT01090
              C     X GIVEN IN FIRST INTERVAL                                NDT01100
              C                                                              NDT01110
ISN 0038          8 IIX = IIX + 1                                            NDT01120
ISN 0039            GO TO 23                                                 NDT01130
ISN 0040         20 IF(NX(I) - 3) 8, 24, 24                                  NDT01140
ISN 0041         24 IF(IIX + 1 - IT) 23, 25, 26                              NDT01150
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ISN 0042          26 IERR = 24                                                          NDT01160
             C                                                                          NDT01170
             C       ERROR OCCURRED                                                     NDT01180
             C                                                                          NDT01190
ISN 0043             GO TO 5000                                                         NDT01200
ISN 0044          25 IGAT(I) = 3                                                        NDT01210
             C                                                                          NDT01220
             C       X GIVEN IN LAST INTERVAL                                           NDT01230
             C                                                                          NDT01240
             C       DETERMINE LOCATION OF FIRST VARIABLE TO BE USED FOR CURVE FIT      NDT01250
             C                                                                          NDT01260
ISN 0045          23 LOC(I) = IIX - IL                                                  NDT01270
ISN 0046           6 CONTINUE                                                           NDT01280
ISN 0047             LISTZ = LOC(1)                                                     NDT01290
ISN 0048          33 IF(NIV - 1) 30, 31, 32                                             NDT01300
ISN 0049          30 IERR = 33                                                          NDT01310
             C                                                                          NDT01320
             C       ERROR OCCURRED                                                     NDT01330
             C                                                                          NDT01340
ISN 0050             GO TO 5000                                                         NDT01350
             C                                                                          NDT01360
             C       FIND LOCATION OF FIRST Z IN ARRAY                                  NDT01370
             C                                                                          NDT01380
ISN 0051          32 DO 35 I = 2, NIV                                                   NDT01390
ISN 0052             IPROD = 1                                                          NDT01400
ISN 0053             IO = I - 1                                                         NDT01410
ISN 0054             DO 36 IXP = 1, IO                                                  NDT01420
ISN 0055          36 IPROD = IPROD*NX(IXP)                                              NDT01430
ISN 0056             IPROD = IPROD*(LOC(I) - 1)                                         NDT01440
ISN 0057          35 LISTZ = LISTZ + IPROD                                              NDT01450
ISN 0058          31 NC = NIV + 1                                                       NDT01460
             C                                                                          NDT01470
             C       INITIALIZE COUNTER TO BE USED FOR Z VALUES                         NDT01480
             C                                                                          NDT01490
ISN 0059             DO 37 I = 2, NC                                                    NDT01500
ISN 0060          37 LLCTR(I) = 0                                                       NDT01510
             C                                                                          NDT01520
             C       INITIALIZE SUBSCRIPTS FOR Z AND ZPRIME                             NDT01530
             C                                                                          NDT01540
ISN 0061             L = 0                                                              NDT01550
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ISN 0062              LL = 0                                                          NDT01560
ISN 0063           50 LL = LL + LIST2                                                 NDT01570
               C                                                                      NDT01580
               C      SET UP SUBSCRIPTS - K FOR VARIABLE, L FOR ZPRIME, AND LL FOR Z  NDT01590
               C                                                                      NDT01600
ISN 0064              K = 1                                                           NDT01610
ISN 0065              L = L + 1                                                       NDT01620
ISN 0066              IC = ICF(1)                                                     NDT01630
               C                                                                      NDT01640
               C      MOVE Z TO ZPRIME                                                NDT01650
               C                                                                      NDT01660
ISN 0067              DO 42 J = 1, IC                                                 NDT01670
ISN 0068              M = L + J - 1                                                   NDT01680
ISN 0069              ZPR(M) = Z(LL)                                                  NDT01690
ISN 0070           42 LL = LL + 1                                                     NDT01700
ISN 0071           55 IX = 0                                                          NDT01710
ISN 0072              IIX = 4                                                         NDT01720
ISN 0073              IF(NX(K) - 3) 44, 44, 45                                        NDT01730
ISN 0074           44 IIX = NX(K)                                                     NDT01740
ISN 0075           45 IF(K - 1) 47, 48, 49                                            NDT01750
ISN 0076           47 IERR = 45                                                       NDT01760
               C                                                                      NDT01770
               C      ERROR OCCURRED                                                  NDT01780
               C                                                                      NDT01790
ISN 0077              GO TO 5000                                                      NDT01800
ISN 0078           49 J = K - 1                                                       NDT01810
               C                                                                      NDT01820
               C      SET UP SUBSCRIPTS FOR X VALUES                                  NDT01830
               C                                                                      NDT01840
ISN 0079              DO 60 J1 = 1, J                                                 NDT01850
ISN 0080           60 IX = IX + NX(J1)                                                NDT01860
ISN 0081           48 IX = IX + LOC(K)                                                NDT01870
               C                                                                      NDT01880
               C      MOVE X TO XPRIME                                                NDT01890
               C                                                                      NDT01900
ISN 0082              DO 61 J = 1, IIX                                                NDT01910
ISN 0083              IXP = IX + J - 1                                                NDT01920
ISN 0084           61 XPR(J) = X(IXP)                                                 NDT01930
ISN 0085              A = 0.0                                                         NDT01940
ISN 0086              B = 0.0                                                         NDT01950
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                C                                                                      NDT01960
                C     TEST NUMBER OF POINTS                                            NDT01970
                C                                                                      NDT01980
 ISN 0087             IF(IIX - 2) 63, 64, 65                                           NDT01990
 ISN 0088          63 C = 0.0                                                          NDT02000
 ISN 0089             GO TO 66                                                         NDT02010
 ISN 0090          64 C = (ZPR(L+1) - ZPR(L))/(XPR(2) -XPR(1))                         NDT02020
 ISN 0091          66 D = ZPR(L) - C*XPR(1)                                            NDT02030
 ISN 0092             GO TO 2000                                                       NDT02040
 ISN 0093          65 IL = IGAT(K)                                                     NDT02050
                C                                                                      NDT02060
                C     DETERMINE WHAT INTERVAL X GIVEN IS IN                            NDT02070
                C                                                                      NDT02080
 ISN 0094             IF(IL.LT.1 .OR. IL.GT.3) GO TO 68                                NDT02090
 ISN 0096             GO TO (70, 71, 72), IL                                           NDT02100
 ISN 0097          68 WRITE(6,4000)                                                    NDT02110
 ISN 0098        4000 FORMAT('     IN VALID INDEX FOR COMPUTED GO TO          ')       NDT02120
 ISN 0099             STOP                                                             NDT02130
                C                                                                      NDT02140
                C     X GIVEN IN FIRST INTERVAL                                        NDT02150
                C     ONLY FIRST THREE POINTS WILL BE USED FOR CURVE FIT               NDT02160
                C                                                                      NDT02170
 ISN 0100          71 IS = 3                                                           NDT02180
 ISN 0101             IPN = 1                                                          NDT02190
 ISN 0102             IIN = L                                                          NDT02200
 ISN 0103             M = 2                                                            NDT02210
 ISN 0104             IRX = 0                                                          NDT02220
 ISN 0105          80 IN = IIN + IRX                                                   NDT02230
 ISN 0106             IP = IPN + IRX                                                   NDT02240
                C                                                                      NDT02250
                C     CALCULATE THE SLOPE OF STRAIGHT LINE                             NDT02260
                C                                                                      NDT02270
 ISN 0107             S(M) = (ZPR(IN + 1) - ZPR(IN))/(XPR(IP + 1) - XPR(IP))           NDT02280
 ISN 0108             IG = 1                                                           NDT02290
 ISN 0109             GO TO 1050                                                       NDT02300
                C                                                                      NDT02310
                C     X GIVEN IN LAST INTERVAL                                         NDT02320
                C     ONLY THREE POINTS WILL BE USED                                   NDT02330
                C                                                                      NDT02340
 ISN 0110          72 IPN = 1                                                          NDT02350
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ISN 0111              IIN = L                                                          NDT02360
ISN 0112              IS = 2                                                           NDT02370
ISN 0113              M = 3                                                            NDT02380
ISN 0114              IRX = 1                                                          NDT02390
ISN 0115              GO TO 80                                                         NDT02400
                C                                                                      NDT02410
                C     X GIVEN IN MIDDLE INTERVAL                                       NDT02420
                C     FOUR POINTS WILL BE USED FOR CURVE FIT                           NDT02430
                C                                                                      NDT02440
ISN 0116           70 IS = 2                                                           NDT02450
ISN 0117              IPN = 1                                                          NDT02460
ISN 0118              IIN = L                                                          NDT02470
ISN 0119              IG = 2                                                           NDT02480
                C                                                                      NDT02490
                C     CALCULATE SLOPE USING PARABOLIC FIT                              NDT02500
                C                                                                      NDT02510
ISN 0120         1050 AP = ((ZPR(IIN) - ZPR(IIN + 1))*(XPR(IPN) - XPR(IIN + 2)) - (ZPR  NDT02520
                     2(IIN) - ZPR(IIN + 2))*(XPR(IPN) -XPR(IPN+1)))/(((XPR(IPN))**2 - (XNDT02530
                     3PR(IPN+1))**2)*(XPR(IPN) - XPR(IPN + 2)) - ((XPR(IPN))**2 - (XPR(INDT02540
                     4PN + 2))**2)*(XPR(IPN) - XPR(IPN + 1)))                          NDT02550
ISN 0121              S(IS) = 2.*AP*XPR(IPN + 1) + (ZPR(IIN) - ZPR(IIN + 1) - (XPR(IPN)*NDT02560
                     2*2 - XPR(IPN + 1)**2)*AP)/(XPR(IPN) - XPR(IPN + 1))              NDT02570
ISN 0122              IF (IG.LT.1 .OR. IG.GT.3)  GO TO 1052                            NDT02580
ISN 0124              GO TO (90, 92,92), IG                                            NDT02590
ISN 0125         1052 WRITE(6,5001)                                                    NDT02600
ISN 0126         5001 FORMAT('       INVALID  INDEX FOR   IG        ')                 NDT02610
ISN 0127              STOP                                                             NDT02620
ISN 0128           92 IS = 3                                                           NDT02630
ISN 0129              IPN = 2                                                          NDT02640
ISN 0130              IIN = L + 1                                                      NDT02650
ISN 0131              IG = 1                                                           NDT02660
ISN 0132              IP = 2                                                           NDT02670
ISN 0133              GO TO 1050                                                       NDT02680
                C                                                                      NDT02690
                C     CALCULATE COEFFICIENTS                                           NDT02700
                C                                                                      NDT02710
ISN 0134           90 LIPN = L + IP                                                    NDT02720
ISN 0135              A = -(2.*(ZPR(LIPN) - ZPR(LIPN - 1))      - (S(1) + S(2))*(XPR(IP  NDT02730
                     2+ 1)- XPR(IP )))/(XPR(IP   + 1) - XPR(IP ))**3                   NDT02740
ISN 0136              B = (((ZPR(LIPN)     - ZPR(LIPN - 1))    / (XPR(IP   + 1) - XPR(IP ))NDT02750
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                 2) - S(2)- (XPR(IP   + 1) + 2.*XPR(IP ))*(XPR(IP   + 1) - XPR(IP ))*ANDT02760
                 3)/(XPR(IP   + 1) - XPR(IP ))                                        NDT02770
 ISN 0137         C = S(2) - 2.*XPR(IP )*B - 3.*XPR(IP )**2*A                         NDT02780
 ISN 0138         D = ZPR(LIPN - 1)    - XPR(IP )*(C + XPR(IP )*(B + XPR(IP )*A))     NDT02790
            C                                                                         NDT02800
            C     CALCULATE  Z                                                        NDT02810
            C                                                                         NDT02820
 ISN 0139     2000 ZPR(L) = D +XXG(K)*(C +XXG(K)*(B +XXG(K)*A))                       NDT02830
 ISN 0140         K = K + 1                                                           NDT02840
 ISN 0141         LLCTR(K) = LLCTR(K) + 1                                             NDT02850
            C                                                                         NDT02860
            C     TEST Z COUNTER WITH NUMBER OF POINTS REQUIRED FOR CURVE FIT         NDT02870
            C                                                                         NDT02880
 ISN 0142         IF(LLCTR(K) - ICF(K)) 300, 301, 301                                 NDT02890
 ISN 0143      300 IF(K - 2) 310, 310, 315                                            NDT02900
 ISN 0144      315 KK = K - 1                                                         NDT02910
            C                                                                         NDT02920
            C     RE-INITIALIZE PREVIOUS COUNTERS                                     NDT02930
            C                                                                         NDT02940
 ISN 0145         DO 320 I = 2, KK                                                    NDT02950
 ISN 0146      320 LLCTR(I) = 0                                                       NDT02960
 ISN 0147      310 LL = 0                                                             NDT02970
 ISN 0148         LP = 1                                                              NDT02980
            C                                                                         NDT02990
            C     FIND NEXT Z TO BE USED FROM ARRAY                                   NDT03000
            C                                                                         NDT03010
 ISN 0149         DO 400 I = 2, NIV                                                   NDT03020
 ISN 0150         IJ = I - 1                                                          NDT03030
 ISN 0151         DO 410 J = 1, IJ                                                    NDT03040
 ISN 0152      410 LP = LP*NX(J)                                                      NDT03050
 ISN 0153         LL = LL + LLCTR(I)*LP                                               NDT03060
 ISN 0154      400 LP = 1                                                             NDT03070
 ISN 0155         GO TO 50                                                            NDT03080
 ISN 0156      301 IF(K - NIV) 500, 500, 600                                          NDT03090
            C                                                                         NDT03100
            C     FIND SUBSCRIPT OF NEXT ZPR ELEMENT                                  NDT03110
            C                                                                         NDT03120
 ISN 0157      500 L = L - ICF(K) + 1                                                 NDT03130
 ISN 0158         GO TO 55                                                            NDT03140
            C                                                                         NDT03150
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               C      FINAL Z VALUE                                                  NDT03160
               C                                                                     NDT03170
ISN 0159         600 RES = ZPR(1)                                                    NDT03180
ISN 0160             RETURN                                                          NDT03190
ISN 0161        5000 WRITE              (6, 111) IERR                                NDT03200
ISN 0162         111 FORMAT(30H1 ERROR OCCURRED AT STATEMENT  I2)                    NDT03210
ISN 0163             STOP                                                            NDT03220
ISN 0164             END                                                             NDT03230
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