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EXPERIMENTAL PERFORMANCE EVALUATION OF A RADIAL-INFLOW TURBINE OVER A RANGE OF SPECIFIC SPEEDS

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SUMMARY

An experimental investigation was made to determine the effect of specific speed on efficiency for a 4.59-inch radial-inflow turbine. The range of specific speeds investigated (72 to 108) at equivalent design speed and pressure ratio was obtained by changing volume flow, based on rotor exit conditions. Changes in volume flow were accomplished by the use of stators having throat areas nominally 50, 75, 100, and 125 percent of design. The turbine was operated with air as the working fluid.

Maximum total and static efficiencies were obtained over the specific speed range of about 80 to 90. The peak total and static efficiencies were 0.91 and 0.87, respectively, for the 75-percent configuration.

An understanding of the losses which contributed to the variation of turbine performance with specific speed at design blade-jet speed ratio was made possible by an analysis which determined the magnitude of the various losses for each configuration. Stator loss was the predominant contributor to the decrease in efficiency as specific speed was reduced from a value of 86. Rotor incidence and viscous losses were the primary contributors to the decrease in performance when specific speed was increased above the value of 90. Stator exit static-pressure measurements showed that, at equivalent design speed and pressure ratio, rotor reaction increased as specific speed increased.

Rotor exit total-pressure and flow angle surveys indicated that low losses were obtained near the hub region of the rotor for all configurations at equivalent design speed and pressure ratio. Comparatively high losses were obtained near the outer wall. These increased losses may have resulted from tip leakage effects with blade unloading, as well as from centrifugation of low-momentum fluid to this region.

INTRODUCTION

The current Brayton-cycle space-power technology program at the Lewis Research Center includes the experimental investigation of factors which influence the performance of small radial-inflow turbines. One such factor is the specific speed parameter, which relates the operating variables of turbine rotative speed, volume flow based on exit conditions, and ideal specific work to turbine geometry and aerodynamic performance.

Reference 1 shows specific speed - efficiency correlations for a number of radial-inflow turbines of various sizes and for a wide range of inlet conditions. This reference shows that high efficiency is attainable for a specific speed range from 65 to 105, with a significant reduction in efficiency outside this range. However, turbine size, rotor tip clearance, and Reynolds number effects are present in the specific speed - efficiency correlations but are not examined separately. Therefore, the experimental investigation described herein was conducted to determine the specific speed effect on performance for a particular turbine size with rotor tip clearance and Reynolds number held constant.

Two approaches were considered to achieve the range of specific speeds. One was to design and fabricate an optimized stator and rotor configuration for each specific speed point, and the other was to use several stators with one rotor configuration. The second approach was chosen because it would minimize time and cost of the program; however, less than optimum turbine configurations may have resulted, especially at the extremes of the specific speed range.

The 4.59-inch-tip-diameter radial-inflow turbine of reference 2 was chosen as the research turbine. The design specific speed for this turbine is 95.6. Three additional stators having throat areas nominally 50, 75, and 125 percent of design were fabricated. The four configurations cover a specific speed range of 68 to 107 at equivalent design speed and pressure ratio. Each configuration was investigated over a range of turbine pressure ratios at equivalent design speed.

This report presents the performance of the subject turbine for each configuration and shows the specific speed effect on turbine efficiency. Results are presented in terms of equivalent weight flow and efficiency at equivalent design speed over a range of pressure ratios. Internal flow characteristics are presented in terms of static pressure variation through the turbine and radial variation of exit flow angle and loss distribution at the rotor exit.

SYMBOLS

g	gravitational constant, 32.174 ft/sec^2
H'	isentropic specific work based on total-pressure ratio, ft-lb/lb

Δh	specific work, Btu/lb
J	mechanical equivalent of heat, 778.029 ft-lb/Btu
N	turbine speed, rpm
N_s	specific speed, $NQ^{1/2}/(H')^{3/4}$, $ft^{3/4}/(min)(sec^{1/2})$
p	pressure, psia
Q	volume flow (based on exit conditions), cu ft/sec
Re	Reynolds number, $w/\mu r_t$
r	radius, ft
U	blade velocity, ft/sec
V	absolute gas velocity, ft/sec
V_j	ideal jet-speed corresponding to total- to static-pressure ratio across turbine, $\left(2gJ\,\Delta h_{id}\right)^{1/2}$, ft/sec
W	relative gas velocity, ft/sec
w	weight flow, lb/sec
α	absolute rotor exit gas flow angle measured from axial direction, deg
γ	ratio of specific heats
δ	ratio of inlet total pressure to U. S. standard sea-level pressure, p'_1/p^*
ϵ	function of γ used in relating parameters to that using air inlet conditions at U. S. standard sea-level conditions, $\frac{0.740}{\gamma}\left(\frac{\gamma+1}{2}\right)^{\gamma/\gamma-1}$
η_s	static efficiency (based on total- to static-pressure ratio across turbine)
η_{tot}	total efficiency (based on total- to total-pressure ratio across turbine)
θ_{cr}	squared ratio of critical velocity at turbine inlet to critical velocity at U. S. standard sea-level temperature, $(V_{cr,1}/V^*_{cr})^2$
μ	gas viscosity, lb/(ft)(sec)
ν	blade-jet speed ratio (based on rotor inlet tip speed), U_t/V_j

Subscripts:

cr	condition corresponding to Mach number of unity
id	ideal
w	outer wall

t tip

1 station at turbine inlet

2 station at stator exit

3 station at turbine exit

Superscripts:

' absolute total state

* U. S. standard sea-level conditions (temperature equal to 518.67° R and pressure equal to 14.696 psia)

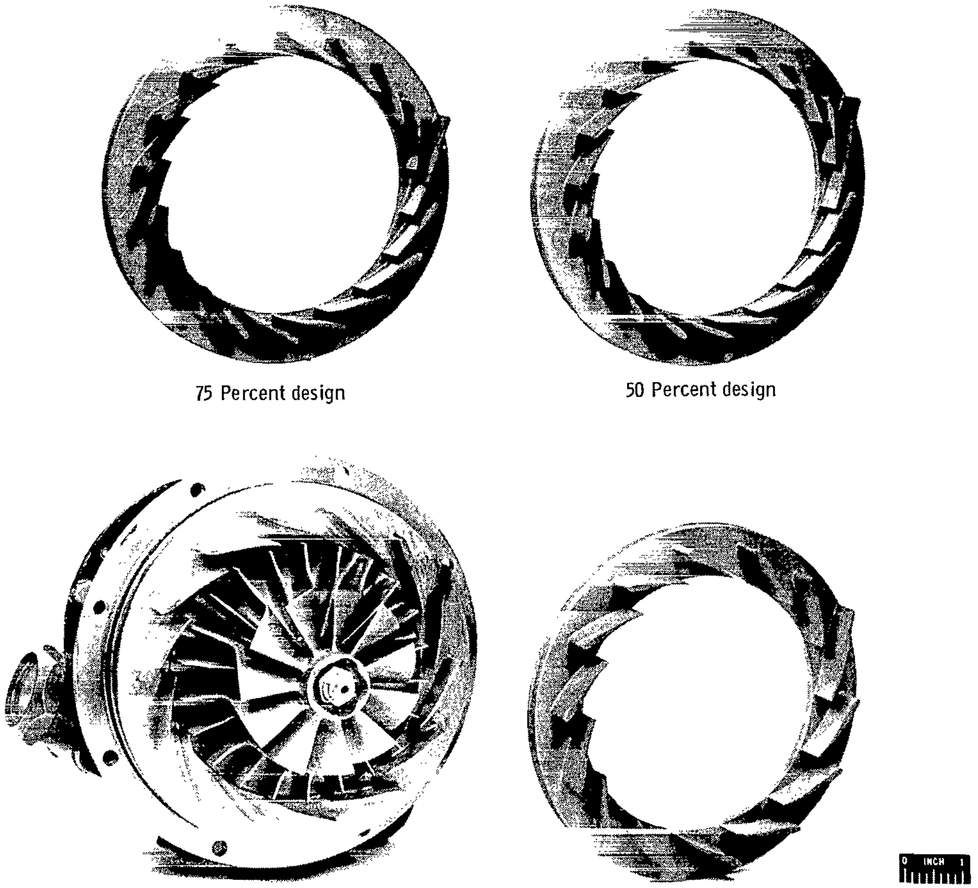
TURBINE DESCRIPTION

The 4.59-inch-tip-diameter radial-inflow turbine described in reference 2 was selected for this investigation. Air equivalent design values are as follows:

Equivalent weight flow, $w\epsilon\sqrt{\theta_{cr}}/\delta$, lb/sec	0.616
Equivalent specific work, $\Delta h/\theta_{cr}$, Btu/lb	11.9
Equivalent speed, $N/\sqrt{\theta_{cr}}$, rpm	29 550
Equivalent total- to static-pressure ratio, p_1'/p_3	1.540
Total to total efficiency, η_{tot}	0.880
Total to static efficiency, η_s	0.824
Blade-jet speed ratio, ν	0.697
Specific speed, N_s, $NQ^{1/2}/(H')^{3/4}$, $ft^{3/4}/(min)(sec^{1/2})$	95.6

The range of specific speeds at equivalent design speed and pressure ratio was obtained by changing volume flow by using stators with different throat areas. This was done by essentially changing the stator blade angle. Three additional stators having nominal throat areas of 50, 75, and 125 percent of design were used to obtain nominal specific speeds of 68, 83, and 107.

Figure 1 shows the four stators and the rotor used in the investigation. The measured stator throat areas were 49.6, 75.3, 96.1, and 126.1 percent of design. Hereafter, each stator and rotor combination will be referred to as the 50-, 75-, 100-, and 125-percent configuration. One stator blade of each configuration had an elongated leading edge to block the flow from entering the small area end of the inlet scroll. A description of the 100-percent configuration including velocity diagrams is given in reference 2. The 100- and 125-percent stators each have 14 blades, whereas the 50- and 75-percent stators have 18 blades each. In order to maintain acceptable stator-blade



75 Percent design

50 Percent design

100 Percent design

125 Percent design

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Figure 1. - Turbine rotor and four stators.

surface velocities, the 50-, 75-, and 125-percent stators have slightly different shapes than the 100-percent stator.

It may be noted that, although the throat area of the 100-percent stator was 3.9 percent smaller than design, results (as reported in ref. 2) showed that equivalent design weight flow was obtained at equivalent design speed and pressure ratio. Attainment of equivalent design weight flow results from the flow check procedure, in which the rotor throat area is increased by cutting back rotor trailing edges until equivalent design weight flow is obtained.

The rotor has 11 blades and 11 splitter vanes. These splitter vanes are used over the initial third of the rotor, thereby increasing the solidity in this region. The resultant decrease in loading was required at the hub to prevent low blade pressure-surface gas velocities.

APPARATUS, INSTRUMENTATION, AND METHODS

The test facility, instrumentation, and method of calculating performance parameters were the same as those described in reference 2, except that air was used as the working fluid. Figure 2 shows a cross-sectional sketch of the turbine test section and the instrument measuring stations. A varying area scroll was used to obtain uniform inlet conditions at the stator inlet. A center body was used at the rotor exit to obtain measurement of exit static pressure at the hub and at the outer wall. Radial surveys of total pressure, total temperature, and flow angle were made at the rotor exit.

The 100-percent configuration was tested at nominal inlet conditions of 16.0 pounds per square inch absolute and 540° R and resulted in a weight flow of 0.657 pound per second at equivalent design speed and pressure ratio. A nominal Reynolds number of 277 000 was calculated from this result; Reynolds number is defined herein as $Re = w/\mu r_t$. In order to eliminate the effects of changes in Reynolds number on turbine efficiency, this parameter was held constant for all configurations at equivalent design speed and pressure ratio. Thus, the inlet total pressure was adjusted for the other configurations until a weight flow of approximately 0.657 pound per second was obtained. Table I shows the values of inlet total pressure and temperature and the pressure ratio

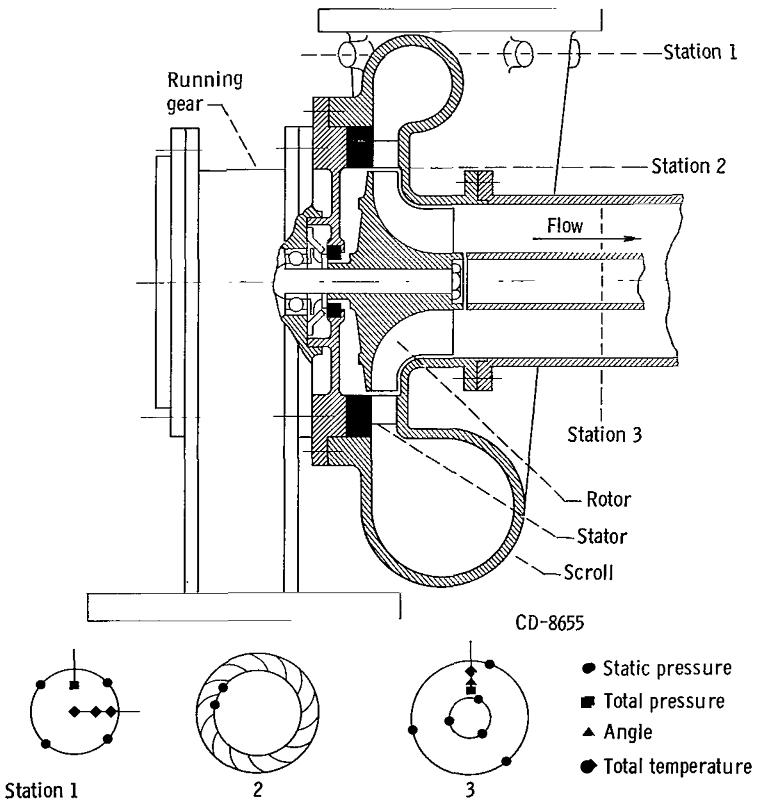

Figure 2. - Turbine test section and instrumentation.

TABLE I. - EXPERIMENTAL OPERATING CONDITIONS

Configuration, percent design	Inlet total pressure, psia	Inlet total temperature, $^{\circ}R$	Pressure-ratio range
125	13.0	536	1.28 to 2.13
100	16.0	540	1.30 to 2.16
75	19.2	540	1.29 to 2.26
50	27.2	542	1.31 to 2.32

range over which the turbine was investigated for each configuration.

The turbine was rated on the basis of both total and static efficiency. Turbine inlet and exit total pressures were calculated from weight flow, static pressure, total temperature, and flow angle. In the calculations of turbine inlet total pressure, the flow was assumed to be normal to the plane defined by station 1. The exit total temperature was determined from turbine power measurements.

RESULTS AND DISCUSSION

The results of this investigation are presented in two sections. The first section includes overall results in terms of equivalent weight flow and efficiency for a range of pressure ratios at equivalent design speed with cold air as the working fluid. The effect of specific speed on turbine efficiency is then shown. The second section discusses the internal flow characteristics of the turbine as determined from exit radial surveys of angle and total- and static-pressure measurements through the turbine at equivalent design speed and pressure ratio.

Turbine Performance

Weight flow. - Figure 3 shows the variation of equivalent weight flow $w\epsilon\sqrt{\theta_{cr}}/\delta$ with inlet total- to exit static-pressure ratio at equivalent design speed. Equivalent weight flows of 0.752, 0.615, 0.519, and 0.367 pound per second were obtained for the 125-, 100-, 75-, and 50-percent configurations at the equivalent design pressure ratio of 1.54. The variation of weight flow with increasing pressure ratio indicated that the flow was subsonic over the entire range of pressure ratios covered. The figure also shows that near choked flow conditions were obtained for the 50-percent configuration at the pressure ratio of 2.32. The combination of near choked flow conditions obtained for the 50-percent configuration and the flattening of the weight-flow curves with decreasing stator-throat area indicates that the velocity level through the stator blade row was increasing with decreasing stator throat area.

Figure 4 presents the variation of equivalent weight flow with stator throat area for equivalent design speed and pressure ratio. Equivalent weight flow is expressed as

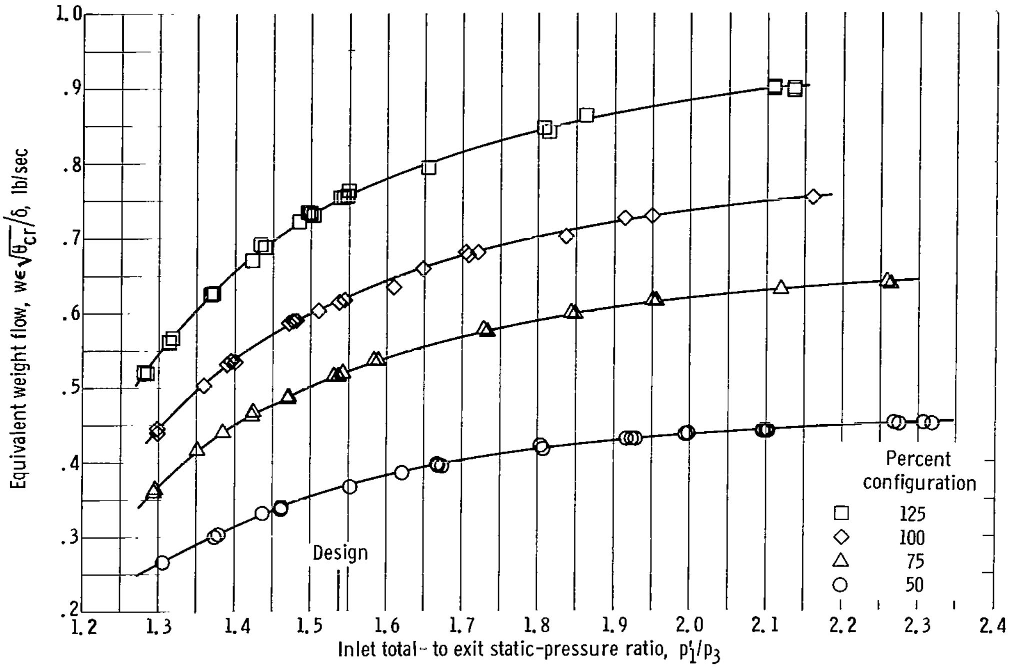

Figure 3. - Variation of weight flow with pressure ratio and stator throat area at equivalent design speed.

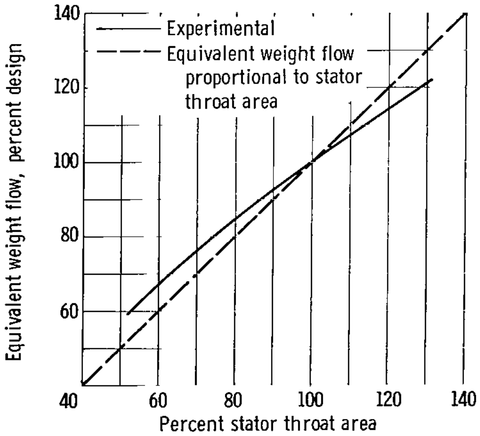

Figure 4. - Variation of weight flow with stator throat area at equivalent design speed and pressure ratio. (Based on measured throat area of 100-percent stator.)

a percentage of the experimental equivalent weight flow obtained with the 100-percent configuration. The dashed line shown on the figure represents the case where equivalent weight flow is directly proportional to stator throat area. Comparison of the experimental curve with the ideal case shows that the weight flow increases at a lower rate than the rate of area increase. This indicates that the stator pressure ratio p_2/p'_1 increased with increasing stator throat area and, therefore, rotor reaction increased. This change in rotor reaction resulted from the variation of stator to rotor throat area ratios of the four configurations. The change in rotor reaction among the four configurations is discussed further in the section Internal Flow Characteristics.

Efficiency. - Figure 5 shows the variation of total and static efficiency with blade-jet speed ratio for each configuration. The highest efficiencies, at design blade-jet speed ratio, were obtained with the 75-percent configuration. Total and static

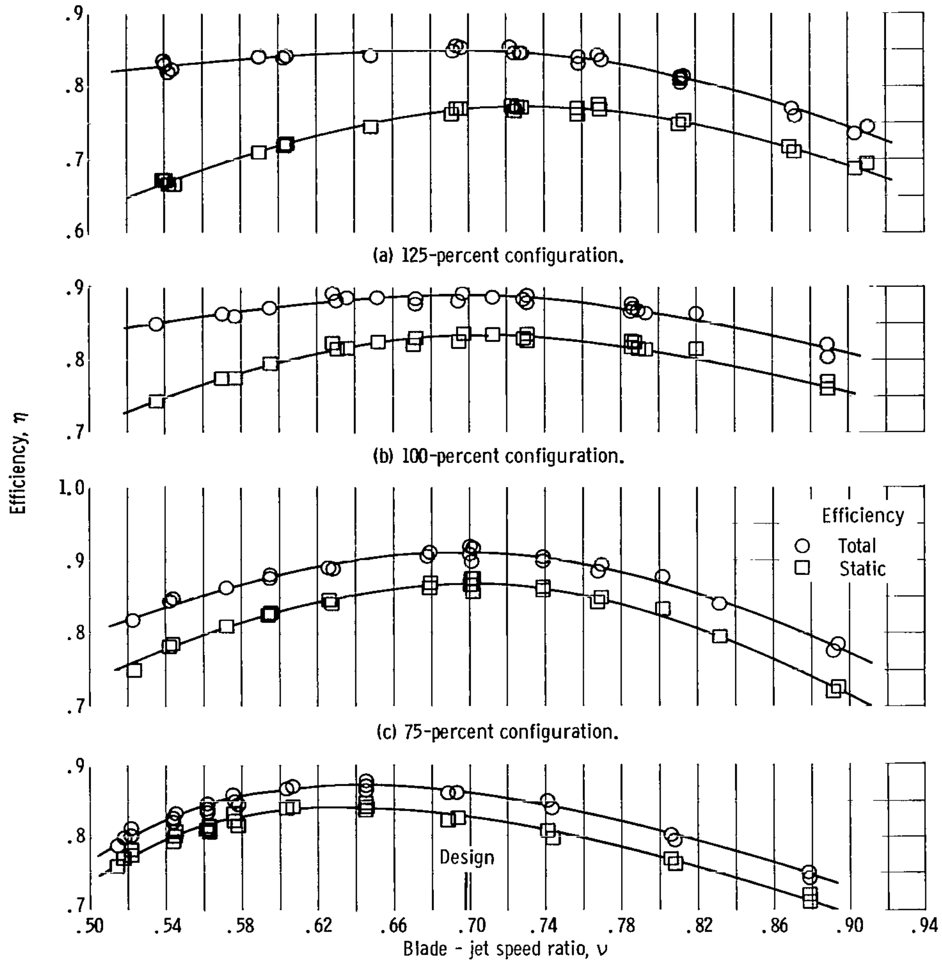

Figure 5. - Variation of efficiency with blade - jet speed ratio at equivalent design speed.

efficiencies were 0.91 and 0.87, respectively, for this configuration. These values are significantly higher than the total and static efficiencies of 0.89 and 0.83 obtained with the 100-percent configuration. At design blade-jet speed ratio, the lowest efficiencies, total and static, were obtained with the 125-percent configuration. These values were 0.85 and 0.77 for the total and static efficiencies, respectively.

The level of rotor exit velocity, as indicated by the difference between total and static efficiency, decreases with decreasing stator throat area. For example, at the design blade-jet speed ratio of 0.697, approximately 8 points in efficiency are attributed to rotor kinetic energy for the 125-percent configuration, while only 3.0 points in efficiency are attributed to rotor exit kinetic energy for the 50-percent configuration. This decrease in rotor exit velocity with decreasing stator throat area results from the change in the stator to rotor throat area ratio among the four configurations. The figure also indicates the variation of rotor exit kinetic energy with blade-jet speed ratio. Comparison of figures 5(a) and (d) shows that there was a greater rate of change in exit kinetic energy with increasing blade-jet speed ratio (decreasing turbine pressure ratio p_1'/p_3) for the 125-percent configuration than for the 50-percent configuration. This effect results from the larger variation of weight flow with pressure ratio for the 125-percent configuration than for the other configurations, as shown in figure 3 (p. 8).

Figure 6 shows the variation of total and static efficiency with specific speed for all four configurations investigated. The dashed line representes the variation of efficiency with specific speed at the design blade-jet speed ratio of 0.697. The upper plot in figure 6 shows that the highest total efficiency value of 0.91 was obtained at a specific speed of approximately 86. This efficiency value is 2.0 points higher than the efficiency of 0.89, which was obtained at the design specific speed value of 95.6 for the 100-percent or reference turbine configuration. It may be noted that the design blade-jet speed ratio curve (dashed line) passes through the peak efficiency point for all but the 50-percent configuration. The heavy curve shown in the figure represents the envelope of the efficiency curves for all configurations. This curve shows that maximum total efficiency is obtained in the specific speed range of about 80 to 90.

The lower plot in figure 6 shows the variation of static efficiency with specific speed for the four configurations. The highest efficiency value of 0.87 was also obtained at a specific speed of approximately 86. This value of efficiency is about 3.0 points higher than that obtained for the 100-percent or reference turbine configuration at the design specific speed of 95.6. The lowest peak static efficiency of 0.77 was obtained at a

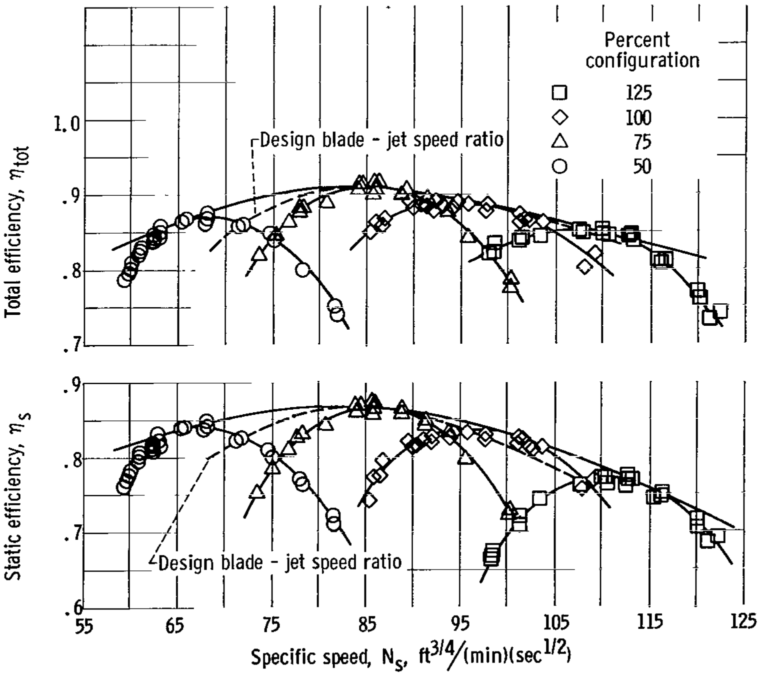

Figure 6. - Variation of efficiency with specific speed at equivalent design speed.

specific speed of 111. It should be pointed out, however, that part of this decrease in static efficiency results from using the same rotor with each stator. Since the 125-percent configuration passes the largest volume flow of the four configurations, the rotor exit kinetic energy would be expected to be higher for this configuration.

The variation of static efficiency with specific speed for design blade-jet speed ratio (dashed line) shows the same trend as the envelope curve represented by the heavy line. The highest efficiency of 0.87 was obtained at a specific speed of 86, and the lowest efficiency of 0.77 was obtained at a specific speed of 108. It may be noted that both total and static efficiencies obtained at design blade-jet speed ratio occur at or very close to the peak efficiency points for the 75- and 100-percent configurations and at lower values of efficiency for the other configurations. From these results, it appears that radial-inflow turbines should be designed for a specific speed range of about 80 to 90 for the attainment of high efficiency.

Loss distribution. - In order to obtain an understanding of the losses which contributed to the variation of turbine performance with specific speed at design blade-jet speed ratio, an analysis was made to determine the magnitude of the various losses for each configuration. The method used involved the determination of velocity diagrams for each configuration from measured turbine work, weight flow, inlet conditions of pressure and temperature, speed, stator throat area, and results of rotor exit surveys of total pressure and flow angle. Design loss distribution between the stator and rotor was used to proportion the measured overall turbine loss for the 100-percent configuration. Stator losses for the other configurations were then assumed to vary in proportion to the average of inlet and outlet kinetic energy as determined from the velocity diagrams.

Rotor incidence losses were determined through adjustment of the actual incidence angle, which resulted in an effective relative whirl velocity different from the velocity diagram value. The adjustment depends upon the blade speed, the number of blades, the rotor diameter, and the volume flow at the rotor inlet. The use of the effective relative whirl velocity is analogous to the use of the slip factor for centrifugal impellers. The remaining losses were attributed to rotor viscous losses. Figure 7 shows the results of these calculations. The various losses, expressed in terms of efficiency, are shown as a function of specific speed. The magnitude of the exit kinetic-energy loss is shown by the difference between total and static efficiency values obtained from figure 5 (p. 9) at design blade-jet speed ratio.

Figure 7 shows that rotor incidence loss increases as specific speed increases above 90. This increase in rotor incidence loss results from an increase in the stator exit flow angle (as measured from tangential) and a decrease in the stator exit velocity with increasing specific speed. Rotor viscous losses also increase substantially with increasing specific speed. The increase in rotor loss results from the increased relative velocity level through the rotor. Part of the increase in rotor viscous loss can be attributed to the manner in which the range of specific speeds was obtained. Figure 7

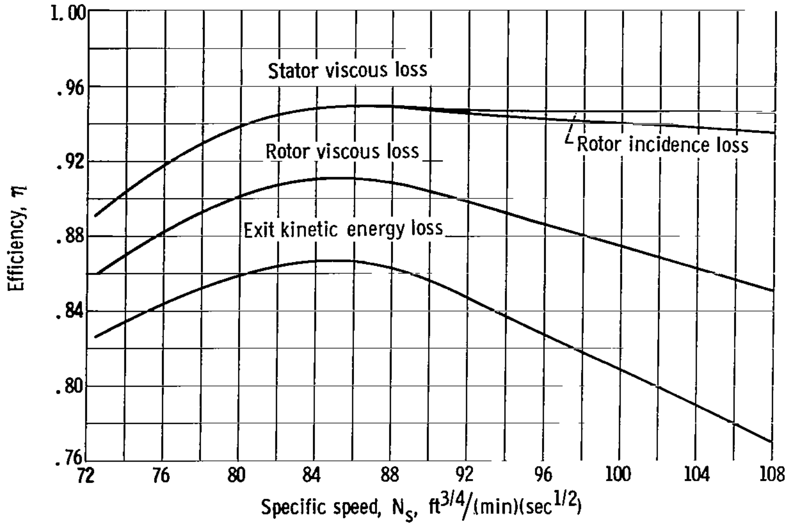

Figure 7. - Variation of turbine losses with specific speed at equivalent design speed and pressure ratio.

shows that there is no significant change in stator viscous losses as the specific speed is increased above a value of 86. This would indicate that the combined losses resulting from the velocity level through the stators and the boundary-layer blockage did not change to any large degree.

Decreasing specific speed below a value of 86 results in an increase in stator viscous losses. The figure shows that the losses increase from about 5.0 points in terms of efficiency at a specific speed of 86 to about 11.0 points at a specific speed of approximately 72. These losses may be associated with the increased velocity level through the stator and the increased boundary-layer blockage due to a larger ratio of wetted area to flow area.

Calculations also indicated that rotor incidence losses were insignificant below a specific speed of 90. Rotor viscous and exit kinetic-energy losses decreased with decreasing specific speed, since specific speed is proportional to the square root of the exit velocity when rotative speed, rotor throat area, and pressure ratio are constant.

Internal Flow Characteristics

The determination of turbine internal-flow characteristics for each configuration was based on the measured static-pressure distribution through the turbine, together with the results of a radial survey of turbine exit total pressure and flow angle.

Figure 8 shows the variation in stator exit static pressure with design stator throat area at equivalent design speed and pressure ratio for the four configurations investigated. Rotor reaction decreases and stator exit velocity increases with decreasing stator throat area, as was noted in the discussion of equivalent weight flow.

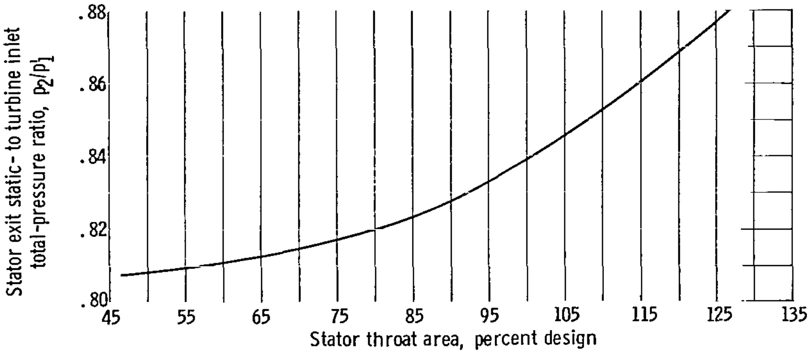

Figure 8. - Variation of stator exit static pressure with stator throat area at equivalent design speed and pressure ratio.

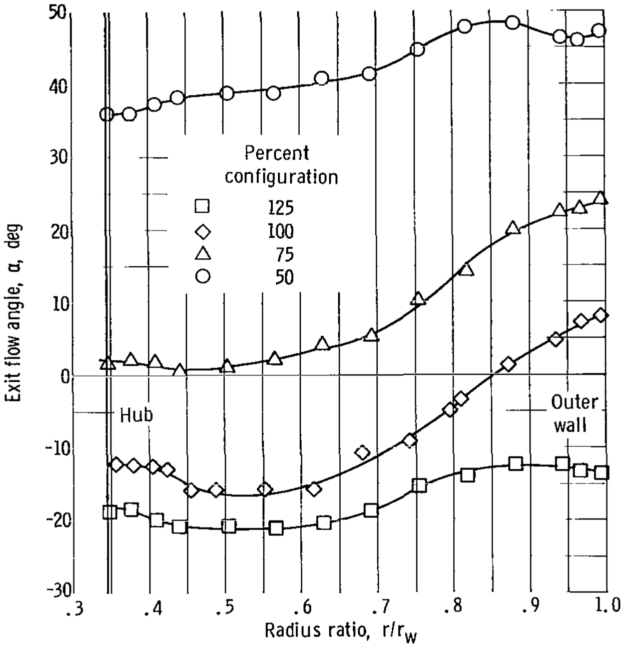

Figure 9. - Variation of turbine exit flow angle with radius ratio at equivalent design speed and pressure ratio.

The results of a radial survey of exit flow angle taken at equivalent design speed and pressure ratio are presented in figure 9 for the four configurations investigated. It may be noted that, as the stator throat area was reduced, the exit flow angle changed from predominately overturning (as denoted by negative angles) to underturning over the entire passage height. This trend in exit flow angle with configuration is to be expected since the rotor exit relative velocity decreases with decreasing stator throat area.

The variation of exit flow angle and exit total and static pressure with radius ratio indicated that there was a nonuniform work distribution from hub to outer wall for all four configurations, with minimum work occurring along the outer wall. This may be due to blade unloading which results from tip leakage and from centrifugation of low momentum fluid to this region.

Local values of total efficiency were calculated on the basis of the change in tangential momentum through the rotor and the radial distribution of total pressure at the rotor exit. These results are plotted in figure 10 in terms of turbine loss $(1.0 - \eta_{tot})$ as a function of radius ratio. The figure shows that the largest radial variation in loss or efficiency is obtained with the 75- and 100-percent configurations. However, the magnitudes of the losses for these two configurations are substantially lower than those for the other two configurations. The curves show low losses along the hub region and comparatively high losses in the region near the outer wall for all configurations.

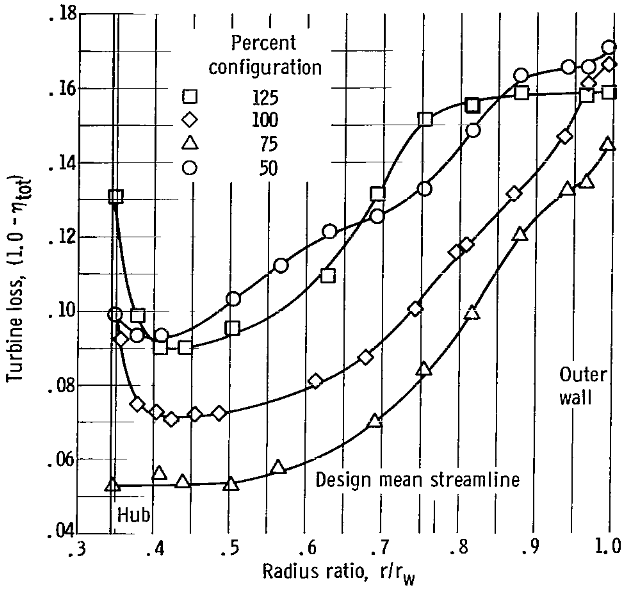

Figure 10. - Variation of turbine loss with radius ratio at equivalent design speed and pressure ratio.

Calculations were made from experimental results to determine the radius ratio at which the weight flow was divided into equal parts. A radius ratio of approximately 0.77 was calculated for all configurations. This coincides with the design mean stream line, as shown in figure 10. At the mean stream line the calculated local loss is approximately equal to the experimental value as obtained from overall performance for each configuration.

SUMMARY OF RESULTS

An experimental investigation was made to determine the specific speed effect on performance for a 4.59-inch-tip-diameter radial-inflow turbine at equivalent design speed over a range of pressure ratios. Results are presented for operation at a nominally constant Reynolds number of 277 000 at equivalent design speed and pressure ratio. The effect of turbine size on performance was eliminated by use of the same rotor for each configuration. The range of specific speed values investigated at equivalent design speed and pressure ratio was obtained by changing volume flow through the use of stators having throat areas nominally 50, 75, 100, and 125 percent of design. From this investigation the following results were obtained:

1. Comparison of actual equivalent weight flow with an equivalent weight flow, which is directly proportional to stator throat area, showed that there was a deficiency in

weight flow for the 125-percent configuration and a surplus of weight flow for the 50- and 75-percent configurations at equivalent design speed and pressure ratio. This difference in weight flows was attributed to the corresponding changes in rotor reaction which result from the use of the same rotor for each configuration.

2. Maximum total and static efficiencies were obtained in the specific speed range of about 80 to 90. In this range, peak total and static efficiencies of 0.91 and 0.87 were obtained with the 75-percent configuration at a specific speed of 86. The lowest peak value of efficiency was obtained with the 125-percent configuration. For this case, the total efficiency was 0.85 at a specific speed of approximately 108. The corresponding static efficiency was 0.77 at a specific speed of 111.

3. An analysis of stator and rotor losses over the range of specific speeds investigated at equivalent design speed and pressure ratio showed the following:

(a) Turbine losses were at a minimum for the specific speed range of about 80 to 90.

(b) Stator viscous losses were the predominant factor in the decrease in total efficiency as the specific speed was decreased from a value of 86.

(c) Rotor incidence and viscous losses were the predominant factors in the decrease in total efficiency as specific speed was increased from 90.

4. Stator-exit static-pressure measurements obtained at equivalent-design speed and pressure ratio indicated that the highest rotor reaction was obtained for the 125-percent configuration. Rotor reaction decreased with decreasing stator throat area.

5. Radial surveys of rotor exit total pressure and flow angle at equivalent design speed and pressure ratio indicated that minimum losses occurred near the hub region and the losses increased substantially near the outer wall. These increased losses may have resulted from tip leakage effects with blade unloading and from centrifugation of low-momentum fluid toward the outer wall. Comparison of losses between configurations showed that minimum losses were obtained from hub to outer wall for the 75-percent configuration.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 26, 1966,
120-27-03-13-22.

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NASA-Langley, 1966 E-3470

m_i	mass of i^{th} perturbating body, sun mass units
m_r	mass of reference body plus m, sun mass units
N_M	Mach number
P	atmospheric pressure, newtons/m^2
$\vec{P}$	$\vec{V}' \times \vec{A}$ (appendix B)
P_w	power, w
p	semilatus rectum, m
q	dynamic pressure, $\frac{1}{2}\rho(V')^2$, newtons/m^2
R_r	radius of reference body, m
r	radius from origin to object, m
r_i	radius from origin to i^{th} perturbating body, m
S	aerodynamic reference area, m^2
T	temperature, $^{\circ}K$
t	time, sec
U	gravitational potential
U_x,U_y,U_z	x,y,z accelerations due to gravity, m/sec^2
V	absolute velocity, m/sec
V'	relative velocity, m/sec
v	true anomaly, radians
X	forces acting on object other than gravity, thrust, lift, drag, and perturbations due to perturbating bodies
x,y,z	components of r, m
α	angle between thrust and velocity vectors (sketch (a)), deg
β	angle of rotation of thrust out of orbit plane (sketch (a)), deg
η	power efficiency factor
μ	$k^2 m_r$
ρ	atmospheric density, kg/m^3

ω	argument of pericenter, radians
Ω	equatorial longitude of ascending node, radians

Subscript:

0	initial value

APPENDIX B

VECTOR RESOLUTION

Relative Velocity

The relative velocity is defined as the velocity of the object with respect to the origin body. If the origin body is assumed to rotate about the z-axis, this velocity is given by

$$\vec{V}' = \vec{V} - \vec{\omega} \times \vec{r} \tag{B1}$$

In x,y,z component form,

$$V_x' = V_x + \omega y \tag{B2a}$$

$$V_y' = V_y - \omega x \tag{B2b}$$

$$V_z' = V_z \tag{B2c}$$

In the following sections, the atmosphere of the origin body is assumed to rotate as a solid body at the rate $\vec{\omega}$.

Thrust Resolution Along x,y,z Axes

The thrust direction is specified with respect to the relative velocity vector $\vec{V}'$ by the angles α and β, as shown in sketch (a) (p. 4). For resolution of thrust vector into x,y,z components, it is convenient to define vectors $\vec{A}$ and $\vec{P}$ normal to and within the $\vec{r},\vec{V}'$ plane, respectively, such that $\vec{V}'$, $\vec{A}$, and $\vec{P}$ form an orthogonal set. Thus,

$$\vec{A} \equiv \vec{r} \times \vec{V}' = \text{relative angular momentum per unit mass} \tag{B3}$$

$$\vec{P} \equiv \vec{V}' \times \vec{A} \tag{B4}$$

The thrust vector can then be resolved in the $\vec{V}',\vec{A},\vec{P}$ set as:

$$\vec{F} \cdot \vec{V}' = FV' \cos \alpha \tag{B5a}$$

$$\vec{F} \cdot \vec{A} = FA \sin \alpha \sin \beta \tag{B5b}$$

$$\vec{F} \cdot \vec{P} = FP \sin \alpha \cos \beta \tag{B5c}$$

Solving for $\vec{F}$ yields

$$\vec{F} = \frac{F}{P^2}\left(V' \cos \alpha\, \vec{A} \times \vec{P} + A \sin \alpha \sin \beta\, \vec{P} \times \vec{V}' + P \sin \alpha \cos \beta\, \vec{P}\right) \tag{B6}$$

or, in x,y,z component form,

$$F_x = \frac{F}{P^2}\left[V' \cos \alpha(A_yP_z - A_zP_y) + A \sin \alpha \sin \beta(P_yV_z' - P_zV_y') + P \sin \alpha \cos \beta\ P_x\right] \tag{B7a}$$

$$F_y = \frac{F}{P^2}\left[V' \cos \alpha(A_zP_x - A_xP_z) + A \sin \alpha \sin \beta(P_zV_x' - P_xV_z') + P \sin \alpha \cos \beta\ P_y\right] \tag{B7b}$$

$$F_z = \frac{F}{P^2}\left[V' \cos \alpha(A_xP_y - A_yP_x) + A \sin \alpha \sin \beta(P_xV_y' - P_yV_x') + P \sin \alpha \cos \beta\ P_z\right] \tag{B7c}$$

Aerodynamic Lift and Drag Resolution Along x,y,z Axes

The drag vector $\vec{D}$ is alined with the relative velocity vector $\vec{V}'$ and is therefore given in x,y,z components as

$$\vec{D} = -D\frac{V_x'}{V'} - D\frac{V_y'}{V'} - D\frac{V_z'}{V'} \tag{B8}$$

The lift vector $\vec{L}$ may be resolved into components along the previously defined orthogonal set $\vec{V}'$, $\vec{A}$, and $\vec{P}$ by the following relations:

$$\vec{L} \cdot \vec{V}' = 0 \tag{B9a}$$

$$\vec{L} \cdot \vec{A} = LA \sin \beta \tag{B9b}$$

$$\vec{L} \cdot \vec{P} = LP \cos \beta \tag{B9c}$$

Solving for $\vec{L}$ yields

$$\vec{L} = \frac{L}{P^2}(A \sin \beta\ \vec{P} \times \vec{V}' + P \cos \beta\ \vec{P}) \tag{B10}$$

or, in x,y,z component form,

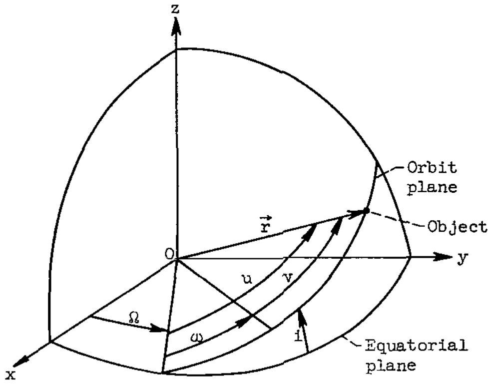
$$L_x = \frac{L}{P^2}\left[A \sin \beta(P_yV_z' - P_zV_y') + P \cos \beta\ P_x\right] \tag{B11a}$$

$$L_y = \frac{L}{P^2}\left[A \sin \beta(P_zV_x' - P_xV_z') + P \cos \beta\ P_y\right] \tag{B11b}$$

$$L_z = \frac{L}{P^2}\left[A \sin \beta(P_xV_y' - P_yV_x') + P \cos \beta\ P_z\right] \tag{B11c}$$

APPENDIX C

TRANSFORMATION EQUATIONS FROM ORBIT ELEMENTS TO RECTANGULAR COORDINATES



(c)

From spherical trigonometry used in reference to the celestial sphere shown in sketch (c), the following relations may be derived for the position coordinates:

$$x = r(\cos \Omega \cos u - \sin \Omega \sin u \cos i) \tag{C1a}$$

$$y = r(\sin \Omega \cos u + \cos \Omega \sin u \cos i) \tag{C1b}$$

$$z = r(\sin u \sin i) \tag{C1c}$$

where

$$r = \frac{p}{1 + e \cos v} \tag{C2a}$$

$$u = \omega + v \tag{C2b}$$

and v can be obtained from

$$\cos v = \frac{\cos E - e}{1 - e \cos E} \tag{C2c}$$

and

$$M = E - e \sin E \tag{C2d}$$

The velocity components may be obtained by differentiating the position equations using the two-body relations $\dot{u} = \dot{v} = \frac{\sqrt{\mu p}}{r^2}$ and $\dot{r} = \sqrt{\frac{\mu}{p}}\, e \sin v$:

$$\dot{x} = -\sqrt{\frac{\mu}{p}}\,(N \cos i \sin \Omega + Q \cos \Omega) \tag{C3a}$$

$$\dot{y} = \sqrt{\frac{\mu}{p}}\,(N \cos i \cos \Omega - Q \sin \Omega) \tag{C3b}$$

$$\dot{z} = \sqrt{\frac{\mu}{p}}\,(N \sin i) \tag{C3c}$$

where

$$N = e \cos \omega + \cos u \tag{C4a}$$

$$Q = e \sin \omega + \sin u \tag{C4b}$$

APPENDIX D

RUNGE-KUTTA AND LOW-ORDER INTEGRATION SCHEMES WITH ERROR CONTROL

The Runge-Kutta formula used is of fourth-order accuracy in step size h. It is of the form

$$X\Big]_1^2 \equiv X_2 - X_1 = \frac{1}{6}\left(k_1 + 2k_2 + 2k_3 + k_4\right) \tag{D1}$$

where

X = a dependent variable

$X\Big]_1^2$ = increment in the dependent variable

h_2 = increment in the independent variable t

$$k_1 = h_2\dot{X}_2(t_1, X_1)$$

$$k_2 = h_2\dot{X}_2\left(t_1 + \frac{h_2}{2},\ X_1 + \frac{k_1}{2}\right)$$

$$k_3 = h_2\dot{X}_2\left(t_1 + \frac{h_2}{2},\ X_1 + \frac{k_2}{2}\right)$$

$$k_4 = h_2\dot{X}_2(t_1 + h_2,\ X_1 + k_3)$$

A lower-order formula may be found by utilizing the three derivatives at $t = t_0$, t_1, and t_2. If $h_1 = t_1 - t_0$ and $h_2 = t_2 - t_1$, the following Lagrangian interpolation formula gives the derivative at any time $t_0 \leq t \leq t_2$:

$$\dot{X} \equiv \dot{X}_0 \frac{(t - t_1)(t - t_2)}{h_1(h_1 + h_2)} - \dot{X}_1 \frac{(t - t_0)(t - t_2)}{h_1 h_2} + \dot{X}_2 \frac{(t - t_0)(t - t_1)}{h_2(h_1 + h_2)} \tag{D2}$$

Integration of this equation from t_1 to t_2 yields

$$X'\Big]_1^2 = \frac{1}{6}\left[\left(\frac{h_2}{h_1}\right)^2\left(\frac{-h_2}{1 + \frac{h_2}{h_1}}\right)\dot{X}_0 + \frac{h_2}{h_1}\left(h_2 + 3h_1\right)\dot{X}_1 + \left(2h_2 + \frac{h_2}{1 + \frac{h_2}{h_1}}\right)\dot{X}_2\right] \tag{D3}$$

The difference in the increments over the interval h_2 between the Runge-Kutta scheme and the low-order scheme may be divided by a nominal value of the dependent variable $\overline{X}$ to obtain the relative error δ_2. Thus,

$$\delta_2 = \left| \frac{X'\Big]_1^2 - X\Big]_1^2}{\overline{X}} \right| \tag{D4}$$

The error is expected to vary as approximately the fifth power of h, which leads to

$$\delta = Ah^5 \tag{D5a}$$

(where A is a suitable coefficient) or in the logarithmic form

$$\log \delta = A' + 5 \log h \tag{D5b}$$

where

$$A' = \log A \tag{D6a}$$

Let it be assumed that A' will vary linearly with t, the variable of integration. Then A' at a time corresponding to t_3 can be found from A' at two previous points t_1 and t_2 as

$$A_3' = A_2' + \frac{A_2' - A_1'}{t_2 - t_1} (t_3 - t_2) \tag{D6b}$$

and if $h_3 = (t_3 - t_2)$ and $h_2 = (t_2 - t_1)$,

$$A_3' = A_2' + (A_2' - A_1') \frac{h_3}{h_2} \tag{D6c}$$

and on this basis δ_3 would be predicted to be

$$\log \delta_3 = A_3' + 5 \log h_3 \tag{D7}$$

It is desired that δ_3 should approximate $\overline{\delta}$, the reference error; therefore,

$$\log h_3 = \frac{1}{5} (\log \overline{\delta} - A_3') \tag{D8}$$

Each dependent variable has an associated relative error and would lead to computation of a different step size for each variable; however, the maximum relative error of all variables may be selected for δ. Obviously, inaccurate predictions of step size can occur when the maximum relative error shifts from one variable to another or when any sudden change occurs. When a step size produces an excessively large error ($\delta > \delta_{limit}$), a reduced step size must be used. It may be obtained from the reference error $\bar{\delta}$ as

$$h_3 = \exp\left[\frac{1}{5} (\log \bar{\delta} - A_2^1)\right] \qquad \text{(D9)}$$

Starting the integration. - The Runge-Kutta scheme is simple to start, since integration from X_n to X_{n+1} requires no knowledge of X less than X_n. Since the error control coefficient A has no value at $t = 0$, a prediction of the second step size is difficult. To overcome this difficulty, two equal size first steps may be made before checking the error. The A for the first step may be arbitrarily set equal to the A for the second step so that h_3 may be predicted. The low-order integration scheme equation in this case becomes, with $h_2 = h_1$,

$$X'\Big]_1^2 = \frac{h_1}{3} (\dot{X}_0 + 4\dot{X}_1 + \dot{X}_2) \qquad \text{(D10)}$$

Failures. - Should two consecutive predictions of the same step fail to produce an error δ less than δ_{limit}, a return to the starting procedure will be made with a third prediction on step size, which is no larger than one-half of the second estimate. The step-size control described here will operate stably with nearly constant error per step only for a well-behaved function. For most problems it will repeat a step occasionally to reduce a large error, and on sharp corners it will restart. This action is not regarded as objectionable. The objective is to attain a desired level of accuracy with a minimum total number of steps.

APPENDIX E

GLOSSARY OF VARIABLES

VARIABLE	COMMON LOCATION	DEFINITION
A (700)	C(11)	ARRAY CONTAINING THE INITIAL DATA AND THE PROGRAM CONTROL VARIABLES
A1	B(10)	ERROR CONTROL PARAMETER DEFINED BY EQ. (D6A) AT T(1)
A2	B(11)	ERROR CONTROL PARAMETER DEFINED BY EQ. (D6A) AT T(2)
ACOEF1	B(12)	INTERPOLATION POLYNOMIAL COEFFICIENT FOR VARIABLE STEP SIZE, EQ. (D3)
ACOEF2	B(13)	INTERPOLATION POLYNOMIAL COEFFICIENT FOR VARIABLE STEP SIZE, EQ. (D3)
ACOEF3	B(14)	INTERPOLATION POLYNOMIAL COEFFICIENT FOR VARIABLE STEP SIZE, EQ. (D3)
AEXIT1 (10)	A(103)	ENGINE EXIT AREAS FOR AT MOST 10 STAGES, M**2
AEXIT	B(3)	AEXIT1(NSTAGE)
AK (3)	A(51)	RUNGE KUTTA COEFFICIENTS,SET IN STDATA
ALPHA	A(49)	ANGLE BETWEEN VELOCITY AND THRUST VECTORS,SEE SKETCH (A)
ALT	A(4)	VEHICLE ALTITUDE ABOVE EARTH, M
AM	B(90)	TOTAL VEHICLE ANGULAR MOMENTUM PER UNIT MASS, M**2/ SEC
AMASS (30)	A(347)	PERMANENT LIST OF BODY MASSES IN ORDER OF PNAME LIST, SET IN STDATA,MASSES FROM ELIPS DATA BEGIN AT AMASS (21), SUN MASS UNITS
AMC (3)	B(87)	X,Y,Z COMPONENTS OF ANGULAR MOMENTUM PER UNIT MASS, **2)/SEC
AMSQRD	B(91)	SQUARE OF TOTAL ANGULAR MOMENTUM PER UNIT MASS,M**4/ SEC**2
AREA1 (10)	A(113)	AERODYNAMIC REFERENCE AREAS FOR AT MOST 10 STAGES, M**2
AREA	B(6)	AREA1(NSTAGE)
ASYMPT	A(7)	SEE TABLE II
ATMN	A(21)	SEE TABLE II
AU	A(29)	ASTRONOMICAL UNIT,M
AW (4)	A(55)	RUNGE KUTTA COEFFICIENTS,SET IN STDATA
AZI	A(35)	INITIAL AZIMUTH ANGLE,USED WHEN IMODE = 4, SEE SKETCH (B),DEGREES

B (800)	C(1111)	ARRAY CONTAINING INTERNAL PARAMETERS NOT UNDER USER CONTROL
BETA	A(50)	ANGLE BETWEEN VELOCITY-THRUST PLANE AND ORBIT PLANE, SEE SKETCH(A)
BMASS (8)	B(137)	BODY MASSES SELECTED FROM AMASS LIST IN SEQUENCE CORRESPONDING TO BNAME LIST
BNAME (8)	B(122)	ORDERED LIST OF BCD BODY NAMES
BODYCD (10)	A(143)	ORIGINAL UNORDERED LIST OF BCD BODY NAMES READ IN AT INPUT
BODYL (10)	B(153)	AUXILIARY ORDERED LIST OF BCD BODY NAMES
CD	A(165)	TOTAL DRAG COEFFICIENT
CDI	A(163)	INDUCED DRAG COEFFICIENT
CHAMP	B(25)	SMALLEST CRITICAL RADIUS (RBCRIT(J)) WITHIN WHICH OBJECT LIES
CINCL	B(55)	COSINE OF INCLINATION
CIRCUM	B(82)	CIRCUMFERENTIAL COMPONENT OF TOTAL PERTURBATIVE ACCELERATION,M/SEC**2
CL	A(164)	LIFT COEFFICIENT
CLEAR	C(3)	SEE TABLE II
COEFN (192)	A(407)	STORAGE ARRAY FOR COEFFICIENTS USED TO COMPUTE ALPHA, CL,CDI,CD OR OTHER PARAMETERS
COMPA (3)	B(63)	COMPONENTS OF TOTAL PERTURBATIVE ACCELERATION ALONG X ,Y,Z AXES.
CONSU	A(31)	SEE TABLE II
CONSTU	A(32)	SEE TABLE II
COSALF	B(48)	COSINE OF ALPHA
COSBET	B(49)	COSINE OF BETA
COSTRU	B(53)	COSINE OF TRU
COSV	B(57)	COSINE OF THE ARGUMENT OF LATITUDE
D (1100)	C(2111)	ARRAY WHERE SAVED DATA IS STORED FOR LATER USE. ARRAYS A,XPRIM,AND XPRIMB MAY BE SAVED.
DELMAX	A(19)	SEE TABLE II
DEL	A(43)	OUTPUT CONTROL PARAMETER USED IN STEP
DELT1 (10)	A(133)	INITIAL STEP SIZES FOR AT MOST 10 STAGES,SEC
DELT	B(1)	DELT1(NSTAGE)
DNSITY	B(29)	ATMOSPHERIC DENSITY,KG/M**3
DONE	B(39)	CONTROL PARAMETER FROM STEP WHICH INFORMS NBODY TO STOP INTEGRATING

DRAG (3)	B(69)	X,Y,Z COMPONENTS OF THE DRAG ACCELERATION,M/SEC**2
DTOFFJ	A(23)	JULIAN DATE OF TAKEOFF
E2	B(18)	LARGEST OF THE RELATIVE ERRORS BETWEEN R-K AND LOW-ORDER INTEGRATION METHODS,EQ. (D4)
EFMRS (7)	B(130)	LIST OF BCD BODY NAMES WHOSE POSITIONS ARE TO BE DETERMINED FROM TAPE DATA
ELEV	A(36)	INITIAL ELEVATION ANGLE,USED WHEN IMODE=4, SKETCH(B), DEGREES
ELIPS (12,10)	A(167)	ELLIPSE DATA FOR PERTURBATING BODIES,READ FROM CARDS, 12 PIECES OF DATA PER BODY
EMONE	B(28)	ECCENTRICITY -1
END	A(5)	SEE TABLE II
EPAR	B(26)	SQUARE ROOT OF (ECCENTRICITY SQUARED -1)
EREF	A(13)	SEE TABLE II
ERLIMT	A(14)	SEE TABLE II
ERLOG	B(17)	NATURAL LOGARITHM OF EREF
ETOL	A(30)	SEE TABLE II
EXITA	B(392)	AEXIT(NSTAGE)/100, NEWTONS/MB
EXMODE	B(27)	ECCENTRICITY CALCULATED WHEN IMODE=3
FILE	B(22)	SEE TABLE II
FLOW1 (10)	A(83)	RATE OF PROPELLENT FLOW, KG/SEC
FLOW	B(5)	FLOW1(NSTAGE)
FORCE (3)	B(66)	X,Y,Z COMPONENTS OF THRUST ACCELERATION, M/SEC**2
GASFAC	A(46)	DEFINED IN SUBROUTINE AERO, SET IN STDATA
GEOH	B(32)	GEOPOTENTIAL, M
GK2M	B(36)	GRAVITATIONAL CONSTANT,MU,OF THE SYSTEM,M**3/SEC**2
GKM	B(37)	SQUARE ROOT OF GK2M
H2	B(15)	VALUE OF DELT FOR PREVIOUS STEP
IBODY (8)	B(177)	DEFINED IN SUBROUTINE ORDER
ICC (10)	A(153)	SEE TABLE II
IDENT (10)	A(123)	INPUT IDENTIFICATION NUMBERS ASSOCIATED WITH EACH STAGE
IMODE	A(1)	SEE TABLE II
IND (3)	A(60)	SET OF INDICES, SET IN STDATA
INDERR	B(51)	NUMBER OF SETS OF ERROR DATA, SET IN ERRORZ FOR USE IN NBODY

INLOOK	A(599)	INPUT IDENTIFICATION NUMBER FOR INPUT AFTER FINDING C (LOOKX) = XLOOK
KSUB	B(19)	INDEX OF RUNGE-KUTTA SUBINTERVALS
LAT	A(33)	INITIAL GEOCENTRIC LATITUDE, USED WHEN IMODE=4,SKETCH (8), DEGREES
LONG	A(34)	INITIAL LONGITUDE RELATIVE TO GREENWICH, USED WHEN IMODE=4, SKETCH(8), DEGREES
LOOKX	A(8)	SEE TABLE II
LOOKSW	A(9)	SEE TABLE II
LSTAGE	A(38)	TOTAL NUMBER OF STAGES INTEGRATED BEFORE RETURNING TO THE MAIN PROGRAM
MBODYS	B(42)	NUMBER OF PERTURBATING BODIES (NBODYS-1)
MODOUT	A(20)	SEE TABLE II
NBODYS	B(41)	TOTAL NUMBER OF BODIES, EXCLUDING THE VEHICLE
NCASES	A(600)	SAVED VALUE OF NCASE
NCASE	C(1)	CASE NUMBER, RAISED ONCE EACH TIME CONTROL PASSES THROUGH THE MAIN PROGRAM
NEFMRS (8)	B(185)	DEFINED IN SUBROUTINE ORDER
NEQ	A(2)	NUMBER OF EQUATIONS TO BE INTEGRATED, SET TO 8 IN STDATA
NSAVE	C(4)	SEE TABLE II
NSTAGE	A(3)	THE INDEX INDICATING THE PARTICULAR STAGE CURRENTLY BEING INTEGRATED
NSTART	B(24)	INTERNAL CONTROL IN NBODY AND EQUATE
OBLATJ	A(26)	OBLATENESS COEFFICIENT OF SECOND HARMONIC
OBLATD	A(27)	OBLATENESS COEFFICIENT OF FOURTH HARMONIC
OBLATH	A(28)	OBLATENESS COEFFICIENT OF THIRD HARMONIC
OBLATN	A(40)	SEE TABLE II
OBLAT (3)	B(75)	X,Y,Z COMPONENTS OF OBLATENESS ACCELERATION, M/SEC**2
OLDDEL	B(9)	VALUE OF DELT FOR PREVIOUS GOOD STEP
ORBELS (6)	B(116)	ARRAY OF OUTPUT VARIABLES,EITHER RECTANGULAR OR ORBIT ELEMENTS
OUTPOT	B(399)	CAUSES ABSENCE OF OUTPUT WHEN NONZERO
P (3)	B(84)	DEFINED IN EQ. (B4)

PAR (3)	B(60)	DEFINED BY EQUATIONS IN SUBROUTINE THRUST
PMAGN	B(50)	DEFINED IN EQUATION FORM BY SUBROUTINE THRUST
PNAME (30)	A(287)	PERMANENT LIST OF BODY NAMES MADE FROM PNAA LIST IN SUBROUTINE ORDER, ELIPS NAMES BEGIN AT PNAME(21)
PRESS	B(33)	ATMOSPHERIC PRESSURE, MB
PSI	B(30)	PATH ANGLE, ANGLE BETWEEN PATH AND LOCAL HORIZONTAL, DEGREES
PSIR	B(398)	RELATIVE PATH ANGLE, TAKEN RELATIVE TO A ROTATING ORIGIN BODY, DEG
PUSH	A(166)	THRUST FORCE, NEWTONS
PUSHO	B(391)	VACUUM THRUST FORCE, NEWTONS
Q	B(59)	DYNAMIC PRESSURE, NEWTONS/M**2
QMAX	B(44)	MAXIMUM VALUE OF Q DEVELOPED DURING A SINGLE TRAJECTORY (SET TO ZERO WHEN CONTROL PASSES THROUGH SUBROUTINE EXTRA)
QX (3)	B(78)	X,Y,Z COMPONENTS OF PERTURBATIVE ACCELERATION DUE TO PERTURBATING BODIES, M/SEC**2
R (8)	B(102)	DISTANCES OF ALL BODIES FROM OBJECT, IN ORDER OF BNAME LIST, M
RADIAL	B(81)	RADIAL COMPONENT OF TOTAL PERTURBATIVE ACCELERATION, POSITIVE OUTWARD, M/SEC**2
RAMC (5)	B(393)	RELATIVE ANGULAR MOMENTUM PER UNIT MASS COMPONENTS, TOTAL RELATIVE ANGULAR MOMENTUM PER UNIT MASS, AND ITS SQUARE, M**2/SEC
RATM	A(22)	RADIUS OF ATMOSPHERE,M
RATMOS	B(23)	SET EQUAL TO RATM WHEN ATMN EQUALS THE REFERENCE BODY NAME, BNAME(1)
RATIO	B(58)	RATIO OF ADJACENT STEP SIZES, DELT
RB (3,8)	B(193)	X,Y,Z COMPONENTS OF DISTANCE FROM ALL BODIES TO THE OBJECT,M
RBCRIT (8)	B(145)	LIST OF SPHERE-OF-INFLUENCE RADII OF ALL BODIES IN BNAME LIST, M
RCRIT (30)	A(377)	PERMANENT LIST OF SPHERE-OF-INFLUENCE RADII CORRESPONDING TO PNAME LIST OF BODY NAMES. RADII FROM ELIPS DATA BEGIN AT RCRIT(21), M
RE	A(25)	RADIUS OF EARTH EQUATOR, M
RECALL	C(5)	SEE TABLE II
REFER (30)	A(317)	LIST OF REFERENCE BODIES CORRESPONDING TO PNAME LIST, REFERENCE BODIES FROM ELIPS DATA BEGIN AT REFER(21)
RESQRD	B(7)	SQUARE OF RE
RETURN	B(400)	CAUSES CONTROL NOT TO RETURN TO MAIN PROG. IF NONZERO

REVS	A(48)	REVOLUTION COUNTER, USED ONLY FOR OUTPUT
REVOLV	B(21)	ROTATION RATE OF REFERENCE BODY WHEN ATMN=BNAME(1), RAD/SEC
RMASS1 (10)	A(73)	INITIAL MASSES FOR AT MOST 10 STAGES,KG
ROTATE	A(39)	ROTATION RATE OF A REFERENCE BODY, RAD/SEC
RSQRD	B(45)	RADIUS SQUARED OF OBJECT TO ORIGIN, M**2
SIGNAL	B(31)	SEE TABLE II
SIMP1 (10)	A(93)	SPECIFIC IMPULSES FOR AT MOST 10 STAGES, SEC
SIMP	B(2)	SIMP1(NSTAGE)
SINALF	B(46)	SINE OF ALPHA
SINBET	B(47)	SINE OF BETA
SINTRU	B(52)	SINE OF TRU
SINCL	B(54)	SINE OF INCLINATION
SINV	B(56)	SINE OF THE ARGUMENT OF LATITUDE
SPACES	B(16)	NUMBER OF EQUAL TIME UNITS UNTIL NEXT OUTPUT
SPD	A(44)	SECONDS PER DAY, SET IN STDATA, SEC/DAY
SQRDK1	A(47)	GRAVITATIONAL CONSTANT OF THE SUN, AU**3/DAY**2
SQRDK	B(35)	GRAVITATIONAL CONSTANT OF THE SUN, M**3/SEC**2
STEPMX	A(16)	SEE TABLE II
STEPS	A(17)	SEE TABLE II
STEPGO	A(41)	COUNT OF SUCCESSFUL INTEGRATION STEPS
STEPNO	A(42)	COUNT OF UNSUCCESSFUL INTEGRATION STEPS (THOSE WHICH DO NOT PASS ERROR CONTROL TEST)
SWLOOK	A(10)	SEE TABLE II
TABLT	B(20)	TIME MEASURED RELATIVE TO THE JULIAN DATE OF TAKEOFF, DAYS
TABLE (200)	C(1911)	ARRAY OF INPUT PARAMETERS AND THEIR COMMON STORE LOCATIONS
TAPE3	C(2)	SEE TABLE II
TB (10)	A(63)	FLIGHT TIMES FOR AT MOST 10 STAGES, SEC

TDATA (6,3,7)	B(265)	COEFFICIENTS FROM EPHEMERIDES TAPE TO BE USED IN DETERMINING POSITIONS AND POSSIBLY VELOCITIES OF PERTURBATING BODIES, ONE SET FOR EACH OF 7 BODIES
TDEL (7)	B(170)	ONE-HALF OF TIME SPACING BETWEEN TWO ADJACENT ENTRIES OF LIKE BODY NAME ON EPHEMERIDES TAPE, READ FROM TAPE FOR EACH BODY
TFILE	A(6)	SEE TABLE II
TIM (7)	B(163)	TIME FOR SET OF EPHEMERIS DATA, READ FROM EPHEMERIDES TAPE, ONE FOR EACH BODY
TKICK	A(15)	INITIAL STEP SIZE OF A TRAJECTORY TO BE COMPUTED IN CLOSED-FORM, FOR USE WHEN IMODE=4, WHICH FACILITATES STARTING OF SOME TYPES OF TRAJECTORIES
TM	B(34)	ATMOSPHERIC TEMPERATURE TIMES THE RATIO OF MOLECULAR TO ACTUAL MOLECULAR WEIGHT, DEGREES KELVIN
TMAX	B(4)	SEE TABLE II
TMIN	A(18)	SEE TABLE II
TOFFT	A(24)	FRACTIONAL PART OF JULIAN DATE OF TAKEOFF, DAYS
TRSFER	B(8)	SEE TABLE II
TRU	B(40)	TRUE ANOMALY, RAD
TTEST	A(54)	SEE TABLE II
TTOL	A(45)	TIME TOLERANCE WITHIN WHICH PROBLEM TIME MINUS TMAX MUST LIE TO END STAGE
U	A(59)	ECCENTRIC ANOMALY, RAD
V	B(95)	VELOCITY OF OBJECT RELATIVE TO THE ORIGIN, M/SEC
VATM (3)	B(97)	X,Y,Z COMPONENTS OF THE RELATIVE VELOCITY, VQ,M/SEC
VEFM (3,8)	B(241)	X,Y,Z COMPONENTS OF OBJECT VELOCITY RELATIVE TO ALL BODIES, M/SEC
VEL	A(37)	INITIAL RELATIVE VELOCITY, USED WHEN IMODE=4, SKETCH (B), M/SEC
VMACH	B(38)	MACH NUMBER OF OBJECT
VQ	B(100)	VELOCITY OF OBJECT RELATIVE TO ATMOSPHERE, M/SEC
VQSQRD	B(101)	SQUARE OF VQ, M**2/SEC**2
VSQRD	B(96)	SQUARE OF V, M**2/SEC**2
VX	B(92)	X COMPONENT OF VELOCITY, M/SEC
VY	B(93)	Y COMPONENT OF VELOCITY, M/SEC
VZ	B(94)	Z COMPONENT OF VELOCITY, M/SEC
X (100)	B(401)	WORKING SET OF INTEGRATION VARIABLES
XDOT (100)	B(501)	TIME DERIVATIVES OF THE SET X

XIFT (3)	B(72)	X,Y,Z COMPONENTS OF LIFT ACCELERATION, M/SEC**2
XINC (100)	B(601)	INCREMENTS OF THE INTEGRATION VARIABLES PER STEP
XLOOK	A(12)	SEE TABLE II
XP (3,8)	B(217)	X,Y,Z COMPONENTS OF PERTURBATING BODY POSITIONS RELATIVE TO ORIGIN
XPRIM (100,2)	C(711)	TWO 100-ELEMENT SETS, THE FIRST SET CONTAINS VALUES OF THE INTEGRATION VARIABLES AT THE PREVIOUS GOOD STEP,THE SECOND SET IS UNDER THE INTEGRATION PROCESS, SEE TABLE V
XPRIMB (100,2)	C(911)	LEAST SIGNIFICANT HALF OF DOUBLE PRECISION INTEGRATION VARIABLES XPRIM
XTOL	A(11)	TOLERANCE ON THE DISCIMINATION C(LOOKX)-XLOOK TO BE SATISFIED
XWHOLE (6)	B(110)	RECTANGULAR COORDINATES AND VELOCITIES, SET ASIDE FOR USE IN ORIGIN TRANSLATIONS
ZN	B(43)	MEAN ANGULAR MOTION OF OBJECT, RAD/SEC
ZORMAL	B(83)	Z COMPONENT OF TOTAL PERTURBATIVE ACCELERATION, M/SEC**2

APPENDIX F

LEWIS RESEARCH CENTER EPHEMERIS

General Description

The ephemeris data initially available on magnetic tape were from the Themis code prepared by the Livermore Laboratory, evidently from U.S. Naval Observatory data. Later, an ephemeris was obtained from the Jet Propulsion Laboratory assembled as a joint project of the Jet Propulsion Laboratory and the Space Technology Laboratory. These data are given relative to the mean vernal equinox and equator of 1950.0 and are tabulated with ephemeris time as the argument.

An ephemeris was desired for certain uses in connection with the IBM 7090 computer that would be shorter than the original ephemeris tapes mentioned and would be as accurate as possible consistent with the length. A short investigation of the various possibilities led to adoption of fitted equations. In particular, fifth-order polynomials were simultaneously fitted to the position and velocities of a body at three points. This procedure provides continuity of position and velocity from one fit to the next, because the exterior points are common to adjacent fits. Polynomials were selected rather than another type of function, because they are easy to evaluate. Three separate polynomials are used for the x, y, and z coordinates, respectively.

Procedure Used to Fit Data

The process of computing the fitting equations is as follows:

(1) A group of 50 sets of the components of planetary position was read into the machine memory for a single planet together with differences as they existed on the original magnetic tape. The differences were verified by computation (in double precision because some data required it); and any errors were investigated, corrected, and verified. Published ephemeris data were adequate to correct all errors found.

(2) The components of velocity v_x, v_y, and v_z were computed and stored in the memory for each of the 50 positions by means of a numerical differentiation formula using ninth differences; namely,

$$\dot{x} = (T_1 - T_{-1})\left[\frac{\Delta I_{-1} + \Delta I_{+1}}{2} - \frac{\Delta III_{-1} + \Delta III_{+1}}{12} + \frac{\Delta V_{-1} + \Delta V_{+1}}{60} - \frac{\Delta VII_{-1} + \Delta VII_{+1}}{280} + \frac{\Delta IX_{-1} + \Delta IX_{+1}}{1260}\right] \tag{F1}$$

(See ref. 11, pp. 42 and 99 for notation.) Double-precision arithmetic was used for differences, but velocities were tabulated with single precision.

(3) Coefficients C, D, E, and F in the fifth-order polynomial

$$X = X_0 + \dot{X}_0(T - T_0) + C(T - T_0)^2 + D(T - T_0)^3 + E(T - T_0)^4 + F(T - T_0)^5 \qquad \text{(F2)}$$

and its derivative

$$\dot{X} = \dot{X}_0 + 2C(T - T_0) + 3D(T - T_0)^2 + 4E(T - T_0)^3 + 5F(T - T_0)^4 \qquad \text{(F3)}$$

were found to fit a first point (which was far enough from the beginning point to have all differences computed) and two equally spaced points for each component of position and velocity. (The initial spacing is not important, as will be seen later.) Spacing is defined as the number of original data points fitted by one equation. Single-precision arithmetic was used.

(4) The coefficients C, D, E, and F in step (3) were then used in equations (F2) and (F3) to calculate components of all positions and velocities given in the original data and lying within the interval fitted. These values were checked with the original data. Radius R and velocity V were computed at the times tabulated in the original data. If any component of the position differed from the original data by more than $R \times 10^{-7}$ or if any velocity differed from the original by more than $V \times 10^{-6}$, the fit was considered unsatisfactory.

(5) If the fit was considered unsatisfactory, this fact was recorded, and the spacing was reduced by two data points. Steps 2 to 4 were then repeated. If the fit was considered satisfactory, this fact was recorded, and the spacing was increased by two spaces. Steps 2 to 4 were repeated. The largest satisfactory fit was identified when a certain spacing was satisfactory and the next larger fit was not satisfactory.

(6) The coefficients that corresponded to the largest satisfactory fit were recorded on tape in binary mode as follows:

Word number	Data	Mode	Definitions and/or units
1	Planet name	BCD	Six characters (first six)
2	Julian date	Floating point	Date of midpoint of fit, Julian date
3	Delta T	↓	Number of days on each side of midpoint
4	F_x		[a]AU/day^5
5	E_x		[a]AU/day^4
6	D_x		[a]AU/day^3
7	C_x		[a]AU/day^2
8	$\dot{x}$		[a]AU/day
9	x		[a]AU
10	F_y		[a]AU/day^5
11	E_y		[a]AU/day^4
12	D_y		[a]AU/day^3
13	C_y		[a]AU/day^2
14	$\dot{y}$		[a]AU/day
15	y		[a]AU
16	F_z		[a]AU/day^5
17	E_z		[a]AU/day^4
18	D_z		[a]AU/day^3
19	C_z		[a]AU/day^2
20	$\dot{z}$		[a]AU/day
21	z		[a]AU

[a] Except for Moon data, which are in Earth radii and days.

(7) As soon as a set of coefficients was selected for an interval, additional data were read from the source ephemeris tape and used to replace the points already fitted (except the last point). These data were processed as described in steps 1 and 2 so that the next 50 points were ready to be fitted. Steps 3 to 6 were then used to find the next set of coefficients, and steps 1 to 6 were repeated until all data for all planets were fitted.

Data Treated

The preceding process was applied to all data available at the time. For the Moon, the technique usually led to the use of every point in the fitted interval (i.e., only three points were fitted). Thus, a check of accuracy was not available. The error in the attempt to fit the next greater interval (five points) was not excessive, however, and it is judged that the accuracy obtained from these fits is about equal to that held on the other bodies.

Merged Ephemeris Tape

Once all the positions and velocities of all the bodies then available were fitted, the coefficients were merged in order of the starting date of each fit. The resulting tape was written in binary mode with 12 sets of fits per record.

The detail of this record is as follows:

1st word: FORTRAN compatible
2nd word: file number, fixed point in decrement

Set 1
3rd word: planet name, code in BCD, first six characters
4th word: Julian date, floating point
- etc., according to list in paragraph 6
- 21 words
23rd word: z

Set 2
24th word: planet name, code in BCD, first six characters
25th word: Julian date, floating point
-
-
44th word: z

Successive sets follow one another with a total of 12 sets.

Set 12 (last set)
234th word: planet name
235th word: Julian date, floating point
254th word: z
End-of-record gap

One record contains 254 words, the first is for FORTRAN compatibility, the second is a file number used for identification in the system. It is a fixed point 2. The third is the beginning of the first set of data, and 12 sets follow each with 21 words. The last word is the 254th word (counting the FORTRAN compatible word) followed by an end-of-record gap. The remaining records are compiled in the same manner with an end-of-file recorded as a terminating mark.

Because of the merging operation, all bodies are given in one list in a random order according to the starting date of the interval. The starting date is the Julian day (word 2) minus the half interval (word 3) (see procedure, paragraph 6). The entire ephemeris occupies about one-seventh reel of tape. A summary of data is given in table VII.

APPENDIX G

INPUT-DATA REQUIREMENTS

The procedure needed to run actual problems with the aid of this routine is described herein. It is intended to permit the user with a specific problem in mind to make a complete list of data required and to select desirable operating alternatives from those available. The details of this procedure are contained in the following instructions:

(1) Provision has been made for two types of ephemeris data to specify the locations of celestial bodies that perturb the vehicle. They are ellipse data and ephemeris-tape data. If the problem does not involve perturbing bodies (except a reference body) or if elliptic data are used for all the perturbing bodies, skip to instruction 5.

(2) If the perturbing-body data are to be taken from an ephemeris tape, list the names of the ephemerides and Julian dates to be covered along with the following auxiliary information:

1st card: $DATA = 300, $TABLE, 2 = TAPE 3, 17 = ELIST, 29 = TBEGIN, 30 = TEND/

Other cards: TAPE 3 = 0

TBEGIN = ephemeris beginning Julian date

TEND = ephemeris ending Julian date

ELIST = (names of perturbing bodies in "ALF" format, see example in text)

The ephemerides of all planets except Earth bear the name of the planet. The ephemeris giving the distance from Earth to the Sun is called "sun," as is astronomical practice.

(3) If successive files on the ephemeris tape are to be made, punch the corresponding sets as follows:

$DATA = 300, TAPE 3 = 0, TBEGIN = , TEND = , ELIST =

As many similar sets as are needed may be appended.

(4) If ellipse data are to be loaded from cards, they are prepared later under instruction 11.

(5) On the first execution after loading the routine, the common area is cleared whether an ephemeris tape is constructed or not. It is now necessary to load a table of variable names. Once loaded, this table will not be cleared again (except if the control variable TAPE 3 is set equal to zero). These names are for use on the input cards. If a different name is desirable for any

variable, it may be changed in the table and where it appears on the input card (ref. 7). The cards are:

```
$DATA=1,$TABLE, 33=DTOFFJ, 34=TOFFT, 711=TIME, 716=X, 717=Y, 718=Z,
713=VX, 714=VY, 715=VZ, 11.=IMODE, 713=E, 714=OMEGA, 715=NODES,
716=INCL, 717=MA, 718=P, 43=LAT, 44=LONG, 45=AZI, 46=ELEV, 14=ALT,
47=VEL, 16=TFILE, 28=TMIN, 153=BODYCD, 177=ELIPS, 30.=MODOUT,
27=STEPS, 29=DELMAX, 26=STEPMX, 23=EREF, 24=ERLIMT, 4.=NSAVE,
5=RECALL, 3=CLEAR, 18.=LOOKX, 22=XLOOK, 19.=LOOKSW, 20=SWLOOK,
609.=INLOOK, 15=END, 31=ATMN, 32=RATM, 49=ROTATE, 417=COEFN,
163.=ICC, 60=BETA, 50=OBLATN, 73=TB, 93=FLOW, 103=SIMP, 123=AREA,
143=DELT, 83=RMASS, 113=AEXIT, 133.=IDENT, 48.=LSTAGE, 25=TKICK /
```

(6) The initial position and velocity of the vehicle may be given in any one of the three coordinate systems. If the initial data are given in orbit elements, skip to instruction (8). If the initial data are given in rectangular coordinates, skip to instruction (7). If the initial data are given in Earth-centered spherical coordinates, the following variables should be punched:

LAT = latitude, deg, positive north of equator

LONG = longitude, relative to Greenwich, deg

ALT = altitude above sea level, m

AZI = azimuth angle, east from north, deg

ELEV = elevation angle, horizontal to path, deg

VEL = initial relative velocity, m/sec

TKICK = size of initial vertical, nondrag step to facilitate starting, sec

If the Earth is assumed to be rotating but aerodynamic forces are not to be considered, set
ROTATE = Earth rotation rate, 7.29211585×10^{-5} radian/sec

If integration in rectangular coordinates is desired set
IMODE = 4
or else if integration in orbit elements is desired set
IMODE = -4

Skip to instruction (9).

(7) If the initial data are in rectangular coordinates, set the following variables:

X = x-component of position in x,y,z coordinate system, m

Y = y-component of position in x,y,z coordinate system, m

Z = z-component of position in x,y,z coordinate system, m

VX = x-component of velocity in x,y,z coordinate system, m/sec

VY = y-component of velocity in x,y,z coordinate system, m/sec

VZ = z-component of velocity in x,y,z coordinate system, m/sec

If integration in rectangular coordinates is desired set
IMODE = 2
or else, if integration in orbit elements is desired set
IMODE = -2

Skip to instruction (9).

(8) If the initial data are in orbit elements, set the following variables:

E = eccentricity

OMEGA = argument of pericenter, radians

NODES = longitude of ascending node (to mean vernal equinox of 1950.0), radians

INCL = orbit inclination to mean equator of 1950.0, radians

MA = mean anomaly, radians

P = semilatus rectum, m

If integration in orbit elements is desired set
IMODE = 1
or else, if integration in rectangular coordinates is desired set
IMODE = -1

(9) To specify takeoff time, set the following variables:

DTOFFJ = Julian day number

TOFFT = fraction of day

TIME = time from previously set Julian date, sec

Takeoff occurs at the instant (ephemeris time) corresponding to the sum of the last three quantities. If a specific date or time is not required, these variables may be skipped. In that case, the SUBROUTINE STDATA sets DTOFFJ to 2440 000.

(10) To specify the origin and any perturbing bodies, list them as BODYCD = (list of body names in "ALF" format, see text example). The first body in the list is taken to be the reference body. The distances between the bodies in

this list must be computable from either ellipse data (instruction (11)) or ephemeris-tape data (instruction (2)). There may be no more than eight names in the list. Also, if the ephemeris tape is being used, the correct file must be found on it. For this purpose, set TFILE = desired ephemeris-tape file. The ephemeris files were numbered in sequence when written in instruction (2). If TFILE is not given, it will be set equal to 1.0 by the SUBROUTINE STDATA.

(11) For each body whose path is represented by an ellipse, a 12-element set of data must be loaded. A 12-element set consists of:

1. Body name in "ALF" format (maximum of six characters)
2. Reference body name in "ALF" format (maximum of six characters)
3. Mass of body, sun mass units
4. Radius of sphere of influence, m
5. Semilatus rectum, AU
6. Eccentricity
7. Argument of pericenter, radians
8. Longitude of ascending node (to mean vernal equinox of 1950.0), radians
9. Orbit inclination (to mean equator of 1950.0), radians
10. Julian day at perihelion
11. Fraction of day at perihelion
12. Period, mean solar days

It is convenient to punch a 12-element set in sequence and to separate the elements by commas on as many cards as are required. Several sets may then be loaded consecutively. The order of the sets is immaterial. Ellipse data, if present, take precedence over ephemeris-tape data. The sets are loaded consecutively, in any order, as follows:

ELIPS = set 1, set 2, set 3, . . ., set n; $n \leq 10$ (see example in appendix I)

(12) If oblateness effects of the Earth are to be included, set

OBLATN = (ALF5)EARTH

(13) Provision has been made to fly multistage vehicles with up to 10 stages. At least one stage must be loaded. There are eight parameters for each stage with provision for input-controlled modifications of other variables. The 10 values of each parameter are stored in an array corresponding to the

10 stages. Input cards are as follows:

TB = burning time for 1st stage, 2nd stage, etc., sec

FLOW = propellant flow rate for 1st stage, 2nd stage, etc., kg/sec

SIMP = vacuum specific impulse of 1st stage, 2nd stage, etc., sec

AREA = aerodynamic reference area of 1st stage, 2nd stage, etc., m^2

AEXIT = engine exit area for 1st stage, 2nd stage, etc., m^2

RMASS = initial mass or jettison mass for 1st stage, 2nd stage, etc., kg

DELT = initial integration step size for 1st stage, 2nd stage, etc., sec

IDENT = input identification number 1st stage, 2nd stage, etc.

TB must be loaded for as many stages as are to be flown. Others may be omitted if zero is appropriate. If RMASS(i) is not positive, the i^{th} stage begins with the final mass of the previous stage reduced by the fixed amount RMASS(i). In the case of DELT, zero will result in use of TB/100. IDENT of a nonzero value will cause any data cards of that identification number to be read in after the stage is set up and before integration begins. This permits the user to make almost any change desired. The order of data cards is discussed in instruction (24).

(14) The thrust orientation must be specified by setting

BETA = angle β, deg (see sketch (a) (p. 4))

COEFN (I) = angle-of-attack schedule, $\alpha = \alpha(t)$ (see instruction (16))

ICC = fixed-point integer (see instruction (16))

For the special case of tangential thrust, none of the last three variables need be set.

(15) If aerodynamic forces are present, set in addition to AREA in instruction (13):

ATMN = name of body that has atmosphere, in "ALF" format, (Earth)

RATM = radius above which atmospheric forces are not to be considered, m

ROTATE = atmospheric-rotation rate, radians/sec ($7.29211585 \times 10^{-5}$ for Earth)

BETA = angle β, deg (see sketch (a))

COEFN (I) = angle-of-attack schedule, $\alpha = \alpha(t)$, $C_L/\sin\alpha$, $C_{D,O}$, and $C_{D,i}/C_L^2$ curves (see instruction (16))

ICC = fixed-point integers (see instruction (16))

(16) If neither thrust nor aerodynamic forces are present, skip to instruction (18). The relations $\alpha(t)$, $C_L/\sin\alpha$, $C_{D,O}$, and $C_{D,i}/C_L^2$ are assumed to be quadratic functions that involve coefficients, which are located in the COEFN(J) array. The arrangement of these coefficients is best explained by an example. Suppose the function $\alpha(t)$ is as follows:

$$\alpha = \begin{cases} a_{11} + a_{12}t + a_{13}t^2 & (t_1 \leq t \leq t_2) \\ a_{21} + a_{22}t + a_{23}t^2 & (t_2 \leq t \leq t_3) \\ a_{31} + a_{32}t + a_{33}t^2 & (t_3 \leq t \leq t_4) \\ \cdot \quad \cdot \quad \cdot & \cdot \quad \cdot \quad \cdot \\ \text{etc.} & \text{etc.} \end{cases}$$

The coefficients $a_{i,j}$ should then be loaded into the COEFN(J) array as:

$$\text{COEFN(J)} = t_1,a_{11},a_{12},a_{13},t_2,a_{21},a_{22},a_{23},t_3,a_{31},a_{32},a_{33},t_4,\ .\ .\ .,t_n$$

Furthermore, additional sets of coefficients for the other functions may simply be added to the COEFN(J) array, which results in a string of sets of coefficients, and can be represented, for example, as:

$$\begin{aligned} \text{COEFN(J)} &= \alpha \text{ coefficients, } C_L/\sin\alpha \text{ coefficients, } C_{D,O} \text{ coefficients, etc.} \\ &= t_1,a_{11},a_{12},\ .\ .\ .,t_n,N_{M,1},b_{11},b_{12},\ .\ .\ .,N_{M,k}, \text{ etc.} \end{aligned}$$

The starting point in the COEFN(J) array of each function must also be loaded to identify the correct region of coefficients. To this end, the following array must also be loaded:

ICC(1) = fixed-point value of J where α coefficients begin

ICC(2) = fixed-point value of J where $C_L/\sin\alpha$ coefficients begin

ICC(3) = fixed-point value of J where $C_{D,i}/C_L^2$ coefficients begin

ICC(4) = fixed-point value of J where $C_{D,O}$ coefficients begin

For this purpose, all values in the COEFN(J) array are called coefficients (i.e., the t's and the N_M's are coefficients). The sequence of the sets is arbitrary, since changing the sequence requires only a change in the ICC(I) array. (See appendix I for Example II, the lunar orbiting probe.)

(17) The size of the integration steps is determined primarily by the error control variables. These are loaded as:

EREF = error reference value; $\bar{\delta}$ in appendix D

ERLIMT = maximum value of δ that is acceptable on any particular step

EREF is always treated as a positive number; however, if it is loaded with a minus sign, this will cause error information to be printed at the completion of the problem. If no error control data is loaded, SUBROUTINE STDATA will set EREF = 1×10^{-6}, ERLIMT = 3×10^{-6}.

(18) The output control offers a choice on the frequency of output data as follows:

If MODOUT = 1, output will occur every nth step (n = STEPS) until t = TMIN, and then MODOUT is set equal to 2 by the program

If MODOUT = 2, output occurs at equal time intervals of DELMAX until t = TMAX

If MODOUT = 3, output occurs at equal time intervals of DELMAX until t = TMIN, then MODOUT is set equal to 4 by the program

If MODOUT = 4, output occurs every nth step (n = STEPS) until t = TMAX

STEPMX = maximum step limit before problem is completed

DELMAX = time interval between outputs

STEPS = number of steps between outputs

TMIN = time when MODOUT changes

Note that output control may, at times, strongly influence the integration step size especially if MODOUT is 2 or 3 and DELMAX is small. STDATA will put MODOUT = 4 and STEPS = 1.

Note that TMAX = time at start of a stage, plus the stage time, TB(NSTAGE), and is computed internally.

(19) Provision has been made to interrupt the integration procedure when an arbitrary value of an arbitrary parameter is attained. By interrupt it is meant that an output will occur at this point, input is permissible, and a decision is made whether to continue the stage, terminate the stage, or terminate the flight. Skip to instruction (20) if this facility is not desired. To cause an interrupt, set

LOOKX = COMMON C location of arbitrary parameter

XLOOK = value of C(LOOKX) where an interrupt is desired

INLOOK = input identification number for interrupt

END = a negative number if flight should be terminated, zero if stage should continue, or a positive number if stage should be terminated

If the interrupt is not desired the first time C(LOOKX) = XLOOK, set

LOOKSW = COMMON C location of a second arbitrary parameter

SWLOOK = value of C(LOOKSW), which must be equaled or exceeded before an interrupt may occur (interrupt occurs if C(LOOKX) = XLOOK and C(LOOKSW) $\geq$ SWLOOK)

Typically, time may be the second arbitrary parameter; thus, STDATA sets LOOKSW = 711, the COMMON location of time. INLOOK of a nonzero value will cause any data cards of that identification number to be read-in prior to the interrogation of END. The order of the cards is discussed in instruction (24).

(20) Provision has been made to save a block of initial conditions and program control parameters prior to the integration of the n^{th} stage. This allows the flight to be flown again from the n^{th} stage onward with prescribed alterations. Skip to instruction (21) if this facility is not desired. To save the program control variable array, A, and the integration variable array, XPRIM + XPRIMB, just prior to integration of the n^{th} stage, set

NSAVE = the number of the n^{th} stage

The saved data, stored in the D array, will be returned to the A and XPRIM + XPRIMB arrays after the flight is completed if

RECALL = any nonzero number

It is intended that changes in the succeeding flight will be made at the main input station ($DATA=1). NSAVE and RECALL are not contained in the array A and are therefore unaffected by the save-recall sequence. The correct sequence of these controls is not always simple and an understanding of the main program and input stationing is quite desirable.

(21) If the standard set of data contained in the SUBROUTINE STDATA is not desired, set

CLEAR = any nonzero number

It is intended that this control shall be set nonzero by the $DATA = 99 input station at the beginning of the main program. It is not affected by the save-recall sequencing explained in instruction (20).

(22) If the number of stages to be flown is not equal to the number of consecutive nonzero flight times, TB, set

LSTAGE = number of last stage to be flown

(23) When a transfer of origin occurs, provision has been made to read input into the program. This is done with the aid of $DATA = 101, followed by the data statements desired.

(24) The sequencing of the input cards is not always simple and no rigid rules may be written down. Inspection of the program may be necessary to answer some questions. However, in general, the first input cards belong to the $DATA = 300 group if an ephemerides tape is required. This group is followed by the $DATA = 1 group, which consists of the main input for a single flight. Following this are the in-flight input cards, if any, which may be any combination of $DATA = 101, $DATA = INLOOK, or $DATA = IDENT (NSTAGE) groups. The order of these groups of cards matches the order of the time sequence of events in the flight itself. For multiple flights, sets of the above groups may be added in tandem. It is usually desirable in this case, however, to read all the $DATA = 300 sets at the same time (as in instruction (3)) to avoid excessive tape handling.

(25) Following is an input check list that may be helpful at execution time:

INPUT CHECK LIST[a]

Takeoff time	Position and velocity (completely fill in one and only one block)			Reference and perturbing bodies	
				BODYCD =	
	Rectangular	Orbit elements	Spherical	Tape	Elliptic
DTOFFJ = TOFFT = TIME =	X = Y = Z = VX = VY = VZ = IMODE = 2	E = OMEGA = NODES = INCL = MA = P = IMODE = 1	LAT = LONG = AZI = ELEV = ALT = VEL = TKICK IMODE = 4	[b]TAPE 3 = 0 [b]TBEGIN = [b]TEND = [b]ELIST = TFILE =	ELIPS =

Output control	Error control	Restart feature	Parameter search	Atmosphere and coefficients	Oblateness - rotation	Stage data
TMIN = MODOUT = STEPS = DELMAX = STEPMX =	EREF = ERLIMT =	NSAVE = RECALL = CLEAR =	LOOKX = XLOOK = LOOKSW = SWLOOK = INLOOK = END =	ATMN = RATM = COEFN = ICC = BETA =	OBLATN = ROTATE =	TB = FLOW = SIMP = AREA = DELT = RMASS = AEXIT = IDENT = LSTAGE =

[a] The following standard data are loaded by SUBROUTINE STDATA:

DTOFFJ = 2440 000.0
IMODE = 1
BODYCD(1) = (ALF5)EARTH
RMASS(1) = 1.0

MODOUT = 4
STEPS = 1.0
STEPMX = 100.0
LOOKSW = 711

EREF = 1×10^{-6}
ERLIMT = 3×10^{-6}
TFILE = 1.0

[b] At input 300, setting TAPE 3 = 0 is necessary to make an ephemeris tape.

APPENDIX H

PROGRAM LISTING

```
C
C     THIS MAIN PROGRAM IS THE SUPERSTRUCTURE ABOVE ALL SUBPROGRAMS.
C     SUBROUTINE TAPE CLEARS COMMON 1 THRU 4000 AND MAY CONSTRUCT AN
C     EPHEMERIS TAPE, ALSO, IT ALWAYS SETS TAPE3 =0. SUBROUTINE STDATA
C     LOADS A STANDARD SET OF DATA. IF RECALL DOES NOT EQUAL ZERO, A
C     PREVIOUSLY SAVED SET OF DATA(FROM STAGE) IS MOVED TO THE INITIAL
C     DATA LOCATION. THE MAIN INPUT STATION IS STATEMENT 8(INPUT1)
C     WHERE THE VEHICLE DATA FOR ALL STAGES MAY BE LOADED. SUBROUTINE ORDER IS
C     CALLED TO ORDER THE LIST OF BODIES, DETERMINE THE GRAVITATIONAL CONSTANT,
C     ORIGIN ROTATION RATE, ATMOSPHERIC RADIUS, RELOCATE ELLIPTIC EPHEMERIS DATA
C     AND POSITION THE EPHEMERIS TAPE.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1   TB(10), D(1100)
C
      EQUIVALENCE
     1(A     ,C     (  11)),(B     ,C     (1111)),(CLEAR ,C     (   3)),
     2(D     ,C     (2111)),(LSTAGE,A     (  38)),(NCASE ,C     (   1)),
     3(NCASES,A     ( 600)),(NSTAGE,A     (   3)),(RECALL,C     (   5)),
     4(TB    ,A     (  63)),(TAPE3 ,C     (   2)),(TABLE ,C     (1911))
C
    1 CALL INPUT (99,C,TABLE)
      IF (TAPE3) 3,2,3
    2 CALL TAPE
    3 NCASE = NCASE + 1
      WRITE OUTPUT TAPE 6,12,NCASE
   12 FORMAT(12H1CASE NUMBERI3,1H.)
      IF (CLEAR) 5,4,5
    4 CALL STDATA
    5 IF (RECALL) 6,8,6
    6 DO 7 J=1,1100
    7 A(J) = D(J)
      WRITE OUTPUT TAPE 6,16,NSTAGE,NCASES
   16 FORMAT(33H RECALLED INITIAL DATA FROM STAGEI2,8H OF CASEI4,1H.)
    8 CALL INPUT (1,C,TABLE)
      IF (SENSE SWITCH 6) 13,14
   13 WRITE OUTPUT TAPE 6,15
   15 FORMAT(19H0EXIT VIA SENSE SW6)
      CALL EXIT
   14 IF (LSTAGE) 11,9,11
    9 DO 10 LSTAGE=1,10
      IF (TB(LSTAGE+1)) 10,11,10
   10 CONTINUE
      LSTAGE = 10
   11 CALL ORDER
   17 CALL STAGE
      GO TO 1
      END
```

```
                                                SUBROUTINE AERO
C     SUBROUTINE AERO COMPUTES THE LIFT AND DRAG ACCELERATIONS.  AS IN SUBROUT-
C     INE THRUST, THESE VECTORS ARE REFERENCED TO THE RELATIVE WIND VELOCITY.
C     COEFFICIENTS OF LIFT, INDUCED DRAG, AND DRAG AT ZERO ANGLE OF ATTACK ARE
C     ASSUMED TO BE FUNCTIONS OF MACH NUMBER AND ANGLE OF ATTACK.  TABLES OF
C     CDI/CL**2, CL/SIN(ALPHA), AND CDO ARE ASSUMED AS FITTED QUADRATIC EQUAT-
C     IONS IN THE COEFN ARRAY.  GASFAC IS THE SQRTF(SPECIFIC HEAT RATIO * STAND-
C     ARD ACCELERATION OF GRAVITY * UNIVERSAL GAS CONSTANT).  FOR EARTH, GASFAC=
C     20.064881 (METERS / SEC**2 / KELVIN DEGREE)**1/2.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1VATM(3), P(3), XIFT(3), DRAG(3), PAR(3), X(100)
C
      EQUIVALENCE
     1(A     ,C     (  11)),(ALPHA ,A     (  49)),(AREA  ,B     (   6)),
     2(B     ,C     (1111)),(BETA  ,A     (  50)),(CD    ,A     ( 165)),
     3(CDI   ,A     ( 163)),(CL    ,A     ( 164)),(COSALF,B     (  48)),
     4(COSBET,B     (  49)),(DNSITY,B     (  29)),(DRAG  ,B     (  69)),
     5(GASFAC,A     (  46)),(P     ,B     (  84)),(PAR   ,B     (  60)),
     6(PMAGN ,B     (  50)),(Q     ,B     (  59)),(R     ,B     ( 102)),
     7(SINALF,B     (  46)),(SINBET,B     (  47)),(TM    ,B     (  34)),
     8(VATM  ,B     (  97)),(VMACH ,B     (  38)),(VQ    ,B     ( 100)),
     9(VQSQRD,B     ( 101)),(X     ,B     ( 401)),(XIFT  ,B     (  72))
C
      Q = 0.5*DNSITY*VQSQRD
      QVAL = Q*AREA/X(2)
      VMACH=SQRTF(VQSQRD/TM)/GASFAC
C
C     COMPUTE THE X,Y,Z COMPONENTS OF LIFT.
      IF (ALPHA) 2,1,2
    1 CL = 0.0
      CDI=0.0
      GO TO 4
    2 CL = QUAD(VMACH,2)*SINALF
      AA = QVAL*CL/PMAGN
      AB = SINBET/VQ
      DO 3 K=1,3
    3 XIFT(K) = AA*(AB*PAR(K)+COSBET*P(K))
    7 CDI=QUAD(VMACH,3)*CL*CL
C
C     COMPUTE THE X,Y,Z COMPONENTS OF DRAG.
    4 CD = CDI+QUAD(VMACH,4)
      AC = -CD*QVAL/VQ
      DO 5 K=1,3
    5 DRAG(K) = AC*VATM(K)
    6 RETURN
      END
```

```
                                               FUNCTION ARCTAN (Y,X)
C     THE FORTRAN II LIBRARY ATANF(+ OR - Z=TAN(THETA)) USES A SINGLE
C     ARGUMENT WITH ITS SIGN TO GIVE THETA IN THE FIRST (+Z) OR FOURTH
C     (-Z) QUADRANT.
C
C     THE ARCTAN FUNCTION MAY BE USED IF + OR - Z IS DERIVED FROM A
C     FRACTION SO THAT ARCTAN (Y,X) = TAN-1 ((+OR-Y=SIN(THETA))/(+OR-X=
C     COS(THETA))). THUS THE ARCTAN (Y,X) GIVES THETA IN ITS PROPER
C     QUADRANT FROM -180 DEGREES TO +180 DEGREES.
C
      IF (X) 2,1,2
    1 ARCTAN=SIGNF(1.57079632,Y)
      GO TO 4
    2 ARCTAN=ATANF(Y/X)
      IF(X) 3,1,4
    3 ARCTAN=ARCTAN+SIGNF(3.14159265,Y)
    4 RETURN
      END
```

```
                                               SUBROUTINE CONVT1 (V,AMC)
C     THIS ROUTINE COMPUTES -- (1) ANGULAR MOMENTUM, AMC(4)
C                              (2) ANGULAR MOMENTUM SQUARED, AMC(5)
C                              (3) X,Y,Z COMPONENTS OF ANG. MOM., AMC(J)
C                              (4) VELOCITY, V(4)
C                              (5) VELOCITY SQUARED, V(5)
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1   AMC(3), V(5), RB(3), IND(3)
C
      EQUIVALENCE
     1(A     ,C     (  11)),(B     ,C     (1111)),(IND   ,A     (  60)),
     2(RB    ,B     ( 193))
C
      DO 1 J1=1,3
      J2=IND(J1)
      J3=IND(J2)
    1 AMC(J3) = RB(J1)*V(J2)-RB(J2)*V(J1)
      AMC(5) = AMC(1)**2+AMC(2)**2+AMC(3)**2
      AMC(4) = SQRTF(AMC(5))
      V(5) = V(1)**2+V(2)**2+V(3)**2
      V(4) = SQRTF(V(5))
      RETURN
      END
```

```
                                                      SUBROUTINE CONVT2
C     THIS ROUTINE CONVERTS RECTANGULAR COORDINATES INTO ORBIT ELEMENTS.
C     RECTANGULAR COORDINATES- POSITION COMPONENTS,X,AND VELOCITY COMPONENTS,VX.
C     THE ORBIT ELEMENTS ARE IN THE ORBELS ARRAY-
C     (1) ECCENTRICITY                (4) INCLINATION
C     (2) ARGUMENT OF PERICENTER               (5) MEAN ANOMALY
C     (3) LONGITUDE OF ASCENDING NODE                 (6) SEMILATUS RECTUM
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1   AMC(3), ORBELS(6), RB(3)
C
      EQUIVALENCE
     1(A     ,C     (  11)),(AM    ,B     (  90)),(AMSQRD,B     (  91)),
     2(AMC   ,B     (  87)),(B     ,C     (1111)),(COSTRU,B     (  53)),
     3(EPAR  ,B     (  26)),(GK2M  ,B     (  36)),(ORBELS,B     ( 116)),
     4(R     ,B     ( 102)),(RB    ,B     ( 193)),(SINTRU,B     (  52)),
     5(TRU   ,B     (  40)),(V     ,B     (  95)),(VSQRD ,B     (  96)),
     6(VX    ,B     (  92)),(VY    ,B     (  93)),(VZ    ,B     (  94))
C
      ORBELS(6)=AMSQRD/GK2M
      R=SQRTF(RB(1)**2+RB(2)**2+RB(3)**2)
      TRU=ARCTAN(AM/GK2M*(RB(1)*VX+RB(2)*VY+RB(3)*VZ),ORBELS(6)-R)
      IF(AMC(1)) 2,1,2
    1 ORBELS(3)=0.
      GO TO 3
    2 ORBELS(3)=ARCTAN(AMC(1),-AMC(2))
    3 ORBELS(4)=ARCTAN(SQRTF(AMC(1)**2+AMC(2)**2),AMC(3))
      SNODE=SINF(ORBELS(3))
      CNODE=COSF(ORBELS(3))
      AA=RB(1)*CNUDE+RB(2)*SNODE
      AB=RB(3)*SINF(ORBELS(4))+COSF(ORBELS(4))*(RB(2)*CNODE-RB(1)*SNODE)
      ORBELS(2)=ARCTAN(AB,AA)-TRU
      ORBELS(1)=SQRTF(ABSF(1.+ORBELS(6)*(VSQRD/GK2M-2./R)))
      EPONE=SQRTF(1.+ORBELS(1))
      E2M1=1.-ORBELS(1)**2
      EPAR=SQRTF(ABSF(E2M1))
      SINTRU=SINF(TRU)
      COSTRU=COSF(TRU)
      EPAS=SQRTF(ABSF(1.-ORBELS(1)))*SINTRU/(1.+COSTRU)
      ETHETA=ORBELS(1)*SINTRU/(1.+ORBELS(1)*COSTRU)*EPAR
    4 IF(E2M1) 5,6,6
    5 ORBELS(5)=LOGF((EPONE+EPAS)/(EPONE-EPAS))-ETHETA
      GO TO 7
    6 ORBELS(5)=2.*ARCTAN(EPAS,EPONE)-ETHETA
    7 RETURN
      END
```

```
                                                SUBROUTINE ERRORZ
C   THIS SUBROUTINE COMPUTES THE RELATIVE ERRORS BETWEEN THE R-K AND LOW-ORDER
C   INTEGRATION SCHEMES.  IT ALSO COMPUTES THE ERROR COEFFICIENT, A, AND SAVES
C   THE ERROR DATA WHEN EREF HAS A - SIGN.  THE BRANCH ON IMODE DETERMINES
C   WHICH SET OF NORMALIZING FACTORS ARE TO BE USED.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1   RELERR (8),    XPRIM (200),   XINC (100)
C
      EQUIVALENCE
     1(A     ,C      (  11)),(A1    ,B      (  10)),(A2    ,B      (  11)),
     2(B     ,C      (1111)),(DELT  ,B      (   1)),(E2    ,B      (  18)),
     3(EREF  ,A      (  13)),(IMODE ,A      (   1)),(INDERR,B      (  51)),
     4(R     ,B      ( 102)),(STEPGO,A      (  41)),(STEPNO,A      (  42)),
     5(V     ,B      (  95)),(XINC  ,B      ( 601)),(XPRIM ,C      ( 711))
      EQUIVALENCE (RELERR,XINC)
C
      E2 = 0.
      RELERR(2) = XINC(2)/XPRIM(2)
      IF (IMODE-1) 2,1,2
C
C     COMPUTE THE NORMALIZED INTEGRATION ERRORS FOR THE ORBIT ELEMENTS.
    1 RELERR(3)=XINC(3)/(XPRIM(3)+1.)/10.
      RELERR(8)=XINC(8)/XPRIM(8)/10.
      DO 10 J=1,4
   10 RELERR(J+3)=XINC(J+3)/62.831853
      GO TO 3
C
C     COMPUTE THE NORMALIZED INTEGRATION ERRORS IN RECTANGULAR VARIABLES.
    2 V1 = V+100.
      DO 20 J=1,3
      RELERR(J+2)=XINC(J+2)/V1
   20 RELERR(J+5)=XINC(J+5)/R
C
C     SELECT MAXIMUM ERROR, COMPUTE ERROR COEFFICIENT, POSSIBLY SAVE ERROR DATA.
    3 DO 5 J=2,8
      IF (ABSF(RELERR(J))-E2) 5,5,4
    4 K=J
      E2 = ABSF(RELERR(J))
    5 CONTINUE
      E2 = E2 + 2E-8
      A1 = A2
      A2 = LOGF(E2)-5.*LOGF(ABSF(DELT))
      IF (EREF) 6,7,7
    6 WRITE TAPE 4,STEPGO,STEPNO,XPRIM(1),DELT,A2,E2,(RELERR(J),J=2,8),K
      INDERR = INDERR + 1
    7 RETURN
      END
```

```
                                                SUBROUTINE EQUATE
C     THIS SUBROUTINE IS CALLED FROM NBODY  TO EVALUATE THE DERIVATIVES OF THE
C     VARIABLES OF INTEGRATION.  EITHER RECTANGULAR COORDINATES OR ORBIT ELE-
C     MENTS MAY BE USED AS THE VARIABLES OF INTEGRATION, BUT IN THE CASE OF THE
C     LATTER, THE CORRESPONDING RECTANGULAR COORDINATES MUST FIRST BE FOUND.
C     THIS IS DONE AT THE BEGINNING THRU THE USE OF KEPLERS EQUATION.  THE
C     PERTURBATING ACCELERATIONS ARE FOUND BY CALLING VARIOUS OTHER SUBROUTINES
C     AND THEIR SUM RESOLVED ALONG THE X,Y,Z AXIS.  FINALLY, THE DERIVATIVES
C     ARE CALCULATED.  IN THE CASE OF ORBIT ELEMENTS, THE X,Y,Z PERTURBATING
C     ACCELERATION COMPONENTS MUST FIRST BE RESOLVED INTO CIRCUMFERENTIAL,RADIAL
C     AND NORMAL COMPONENTS.  THIS ROUTINE ALSO CHANGES THE INTEGRATION VARI-
C     ABLES FROM ORBIT ELEMENTS TO RECTANGULAR VARIABLES IF THE ECCENTRICITY
C     APPROACHES UNITY.  THE X,XPRIM, AND XDOT ARRAYS ARE AS FOLLOWS.
C
C
C     X            ORBIT ELEMENTS         RECTANGULAR COORDINATES
C
C     1            TIME                    TIME
C     2            MASS                    MASS
C     3            ECCENTRICITY            X-VELOCITY
C     4            ARGUMENT OF PERICENTER  Y-VELOCITY
C     5            ARGUMENT OF ASC. NODE   Z-VELOCITY
C     6            INCLINATION             X
C     7            MEAN ANOMALY            Y
C     8            SEMILATUS RECTUM        Z
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1    XPRIM (100,2),         VX (3),            QX (3),
     2      RB (3),         NEFMRS (8),              X (100),
     3   XPRIMB (100,2),       FORCE (3),         XIFT (3),
     4     DRAG (3),           OBLAT (3),        COMPA (3),
     5     XDOT (100)
C
```

```
      EQUIVALENCE
     1(A     ,C     (  11)),(AMSQRD,B     (  91)),(ASYMPT,A     (   7)),
     2(B     ,C     (1111)),(BNAME ,B     ( 122)),(CINCL ,B     (  55)),
     3(CIRCUM,B     (  82)),(COMPA ,B     (  63)),(CONSTU,A     (  32)),
     4(COSTRU,B     (  53)),(COSV  ,B     (  57)),(DRAG  ,B     (  69)),
     5(EMONE ,B     (  28)),(EPAR  ,B     (  26)),(ETOL  ,A     (  30)),
     6(EXMODE,B     (  27)),(FLOW  ,B     (   5)),(FORCE ,B     (  66)),
     7(GK2M  ,B     (  36)),(GKM   ,B     (  37)),(IMODE ,A     (   1)),
     8(KSUB  ,B     (  19)),(MBODYS,B     (  42)),(NEFMRS,B     ( 185)),
     9(NSTART,B     (  24)),(OBLATN,A     (  40)),(OBLAT ,B     (  75))
      EQUIVALENCE
     1(PRESS ,B     (  33)),(PUSHO ,B     ( 391)),(QX    ,B     (  78)),
     2(RADIAL,B     (  81)),(RATMOS,B     (  23)),(RB    ,B     ( 193)),
     3(R     ,B     ( 102)),(RSQRD ,B     (  45)),(SINCL ,B     (  54)),
     4(SINTRU,B     (  52)),(SINV  ,B     (  56)),(SPD   ,A     (  44)),
     5(TABLT ,B     (  20)),(TOFFT ,A     (  24)),(TRSFER,B     (   8)),
     6(TTEST ,A     (  54)),(U     ,A     (  59)),(V     ,B     (  95)),
     7(VSQRD ,B     (  96)),(VX    ,B     (  92)),(XDOT  ,B     ( 501)),
     8(XIFT  ,B     (  72)),(XPRIM ,C     ( 711)),(XPRIMB,C     ( 911)),
     9(X     ,B     ( 401)),(ZORMAL,B     (  83)),(ZN    ,B     (  43))
C
      TABLT=X(1)/SPD+TOFFT
      IMODE=IMODE
    1 GO TO (2,16,16),IMODE
C
C     STATEMENTS 2 TO 16 FIND THE RECTANGULAR POSITION AND VELOCITY FROM ORBIT
C     ELEMENTS AND TRUE ANOMALY.  THE TRUE ANOMALY IS FOUND FROM ITERATIVE
C     SOLUTION OF KEPLERS EQUATION.
    2 E2 = X(3)**2
      E2M1 = 1.-E2
      EMONE = X(3)-1.
      EPAR=SQRTF(ABSF(E2M1))
      VCIRCL=GKM/SQRTF(X(8))
C
C     COMPUTE SINE AND COSINE OF TRUE ANOMALY.
C     PART A. E=1
    3 IF (EMONE) 10,4,5
    4 SINTRU = 0.
      COSTRU = 1.
      GO TO 14
C
C     PART B. E IS GREATER THAN 1
    5 DO 7 J=1,100
      DELM = X(7)-U+X(3)*SINHF(U)
      ECOSU = X(3)*COSHF(U)
      DELU = DELM/(1.0-ECOSU)
      U = U+DELU
    6 IF (ABSF(DELM)-CONSTU) 9,9,7
    7 CONTINUE
      ASYMPT = 1.0
      IF (MBODYS) 8,23,8
    8 CALL EPHMRS
      GO TO 23
    9 COSU = COSHF(U)
      DEM1 = 1.-X(3)*COSU
      COSTRU = (COSU-X(3))/DEM1
      SINTRU =-EPAR*SINHF(U)/DEM1
      GO TO 14
C
C     PART C. E IS LESS THAN 1
   10 DO 12 J=1,15
      DELM = X(7)-U+X(3)*SINF(U)
      ECOSU = X(3)*COSF(U)
      DELU = DELM/(1.0-ECOSU+0.01*ECOSU**3)
      U = U+DELU
   11 IF (ABSF(DELM)-CONSTU) 13,13,12
   12 CONTINUE
      WRITE OUTPUT TAPE 6,55,U,DELU
      CALL EXIT
   13 COSU = COSF(U)
      DEM1 = 1.-X(3)*COSU
      COSTRU = (COSU-X(3))/DEM1
      SINTRU = EPAR*SINF(U)/DEM1
   14 PDVR = 1.+X(3)*COSTRU
C
C     COMPUTE POSITION AND VELOCITY FROM ORBIT ELEMENTS AND TRUE ANOMALY.
C     ALSO, CLEAR THE PERTURBATING ACCELERATIONS.
   15 SOMEGA = SINF(X(4))
      COMEGA = COSF(X(4))
      SNODE = SINF(X(5))
      CNODE = COSF(X(5))
      SINCL = SINF(X(6))
      CINCL = COSF(X(6))
      SINV=SINTRU*COMEGA+COSTRU*SOMEGA
      COSV=COSTRU*COMEGA-SINTRU*SOMEGA
      AR=COSV*CNODE-SINV*SNODE*CINCL
      B1=SINV*CNODE+COSV*SNODE*CINCL
      C1=COSV*SNODE+SINV*CNODE*CINCL
      D1=SINV*SNODE-COSV*CNODE*CINCL
      E1 = X(3)*SOMEGA+SINV
      F1 = X(3)*COMEGA+COSV
      AS=E1*CNODE+F1*SNODE*CINCL
      B2=F1*CNODE*CINCL-E1*SNODE
      R = X(8)/PDVR
      RSQRD = R*R
      SINVY=SINV*SINCL
      RB(1)    = R*AR
      RB(2)    = R*C1
      RB(3)    = R*SINVY
      VX(1)=-VCIRCL*AS
      VX(2)=VCIRCL*B2
      VX(3)=VCIRCL*F1*SINCL
      GO TO 18
```

```
C
   16 DO 17 K=1,3
      VX(K) = X(K+2)
   17 RB(K) = X(K+5)
      RSQRD = RB(1)*RB(1) + RB(2)*RB(2) + RB(3)*RB(3)
      R=SQRTF(RSQRD)
   18 VSQRD=VX(1)*VX(1)+VX(2)*VX(2)+VX(3)*VX(3)
      V = SQRTF(VSQRD)
      DO 19 I=1,15
   19 FORCE(I) = 0.
C
C     TEST FOR PRESENCE OF PERTURBING BODIES.
      IF (MBODYS) 20,21,20
   20 CALL EPHMRS
   21 IF (XABSF(IMODE)-1) 26,22,26
C
C     TEST FOR CHANGE FROM ORBIT ELEMENTS TO TEMPORARY RECTANGULAR
C     COORDINATES IF E IS TOO NEAR TO UNITY.
   22 IF (ETOL-ABSF(EMONE)) 26,23,23
   23 IF (IMODE) 54,24,24
   24 IMODE=-3
      IF (NSTART) 25,54,25
   25 TTEST = X(1)
   27 CALL TESTTR
C
C     TEST FOR OBLATENESS PERTURBATION COMPUTATION.
   26 IF(OBLATN-BNAME)30,29,30
   29 CALL OBLATE
C
C     TEST FOR PRESENCE OF THRUST.
   30 XDOT(2) = -FLOW
      IF (R-RATMOS) 31,31,32
   31 CALL ICAO
      GO TO 33
   32 PRESS=0.
   33 IF (PUSHO) 37,36,37
   36 ASSIGN 40 TO NDONE
      GO TO 38
   37 CALL THRUST
      ASSIGN 41 TO NDONE
C
C     TEST FOR EXISTENCE OF ATMOSPHERE.  FIND AERODYNAMIC FORCES.
   38 IF (PRESS ) 39,42,39
   39 GO TO NDONE, (40,41)
   40 CALL THRUST
   41 CALL AERO
C
C     SUM COMPONENTS OF THE PERTURBING ACCELERATION.
   42 DO 43 J=1,3
   43 COMPA(J) = -QX(J)+OBLAT(J)+FORCE(J)+XIFT(J)+DRAG(J)
   44 GO TO (47,45,45),IMODE
C
C     COMPUTE DERIVATIVES FOR THE RECTANGULAR VARIABLES OF INTEGRATION.
   45 AA = GK2M/R/RSQRD
      DO 46 K=1,3
      XDOT(K+5) = X(K+2)
   46 XDOT(K+2) = COMPA(K)-AA*X(K+5)
      GO TO 54
C
C     COMPUTE THE DERIVATIVES OF THE ORBIT ELEMENTS.  (AFTER RESOLVING
C     PERTURBATING ACCELERATION INTO CIRCUMFERENTIAL, RADIAL, NORMAL COMPONENTS)
   47 CIRCUM=COMPA(3)*COSV*SINCL-COMPA(1)*B1-COMPA(2)*D1
      RADIAL=COMPA(1)*AR+COMPA(2)*C1+COMPA(3)*SINVY
      ZORMAL=COMPA(1)*SNODE*SINCL-COMPA(2)*CNODE*SINCL+COMPA(3)*CINCL
      ZN=VCIRCL*E2M1*EPAR/X(8)
      RDVPP1 = 1./PDVR + 1.
      RDVA = E2M1/PDVR
      XDOT(8) = 2.*R/VCIRCL*CIRCUM
      IF (X(3)) 48,48,49
   48 CSQRD  = CIRCUM*CIRCUM
      RASQRD = RADIAL*RADIAL
      DEM1 = (4.*CSQRD+RASQRD)*VCIRCL
C
C     TEST FOR IN-PLANE PERTURBATION.
      IF (DEM1) 57,56,57
   56 XDOT(3) = 0.
      XDOT(4) = 0.
      XDOT(7) = 0.
      GO TO 50
   57 VDV2R=VCIRCL/R/2.
      XDOT(3) = SQRTF(4.*CSQRD+RASQRD)/VCIRCL
      XDOT(4) = VDV2R+(2.*CSQRD+RASQRD)/DEM1*RADIAL
      XDOT(7) = ZN-VDV2R+(6.*CSQRD+RASQRD)/DEM1*RADIAL
      GO TO 50
   49 XDOT(3) = (SINTRU*RADIAL+(PDVR-RDVA)/X(3)*CIRCUM)/VCIRCL
      XDOT(4)=(SINTRU/X(3)*RDVPP1*CIRCUM-COSTRU*RADIAL/X(3))/VCIRCL
      XDOT(7)=ZN+EPAR/VCIRCL*((COSTRU/X(3)-2./PDVR)*RADIAL-(SINTRU/X(3)*
     1RDVPP1*CIRCUM))
   50 IF(SINCL) 51,52,51
   51 XDOT(5) = SINV/SINCL*ZORMAL/VCIRCL/PDVR
      GO TO 53
   52 XDOT(5) = 0.
   53 XDOT(6) = COSV*ZORMAL/PDVR/VCIRCL
   54 RETURN
   55 FORMAT(41HOKEPLERS EQUATION CONVERGENCE FAILURE, U=G15.8,7H  DELU=
     1G15.8)
      END
```

```
                                                SUBROUTINE EPHMRS
C   SUBROUTINE EPHMRS IS CALLED TO COMPUTE THE POSITIONS OF THE PERTURBING
C   BODIES RELATIVE TO THE VEHICLE AND, FROM THESE, THEIR PERTURBING ACCELERA-
C   TIONS UPON THE VEHICLE.  OCCASIONALLY THIS ROUTINE IS CALLED FOR THE PURPOSE
C   OF TRANSLATING THE ORIGIN IN WHICH CASE (TRSFER=1) THE RELATIVE VELOCITIES
C   ARE ALSO CALCULATED.  IF A BODYS POSITION IS TO BE COMPUTED FROM AN ELLIPTIC
C   APPROXIMATION SUBROUTINE ELIPSE IS CALLED. OTHERWISE, THE POSITION WILL BE
C   CALCULATED IN EPHMRS FROM THE PRECISION TAPE EPHEMERIS.  THE DO 19 LOOP
C   ENCOMPASSES ALMOST THE ENTIRE EPHMRS SUBROUTINE AND ,IN EFFECT, ELIPSE TOO.
C
      COMMON  C
C
      DIMENSION A(600), B(700), C(4000),
     1   QX(3), IBODY(8), EFMRS(7), XP(3,8), RB(3,8), R   (8), TIM(7),
     2   NEFMRS(8), TDATA(6,3,7), TDEL(7), BMASS(8), VEFM(3,8), DATA(21)
     3   , TDAT(18,7)
C
      EQUIVALENCE
     1(A     ,C      (  11)),(AU    ,A      (  29)),(B     ,C      (1111)),
     2(BMASS ,B      ( 137)),(DTOFFJ,A      (  23)),(EFMRS ,B      ( 130)),
     3(IBODY ,B      ( 177)),(MBODYS,B      (  42)),(NEFMRS,B      ( 185)),
     4(QX    ,B      (  78)),(R     ,B      ( 102)),(RB    ,B      ( 193)),
     5(SQRDK ,B      (  35)),(SPD   ,A      (  44)),(TABLT ,B      (  20)),
     6(TDATA ,B      ( 265)),(TDEL  ,B      ( 170)),(TIM   ,B      ( 163)),
     7(TRSFER,B      (   8)),(VEFM  ,B      ( 241)),(XP    ,B      ( 217))
      EQUIVALENCE (IBF,FIB), (TDAT,TDATA)
C
C     PART 2.  SET INDEXS, FIND POSITION IF ELLIPSE IS USED (NEFMRS = 20 OR UP).
      DO 19 JB=1,MBODYS
      JB1 = JB+1
      IBF = IBODY(JB1)
      IB = XABSF(IBF)
      IF (NEFMRS(JB)-20) 2,2,1
    1 CALL ELIPSE (JB1)
      IF (TRSFER) 12,12,17
C
C     PART 3.  TAPE EPHEMERIS IS TO BE USED.  FIND DIFFERENCE (DT) BETWEEN
C     CURRENT PROBLEM TIME (DTOFFJ+TABLT) AND MIDPOINT TIME (TIM) OF CURRENTLY
C     STORED TAPE DATA.  THEN SEE IF CURRENT DATA IS OKAY.  TDEL = TIME INTERVAL
C     ON EITHER SIDE OF TIM FOR WHICH CURRENT DATA IS GOOD.
    2 DT = TABL T - (TIM(JB) -DTOFFJ)
      IF (ABSF(DT)-TDEL(JB)) 10,10,3
C
C     PART 4A.  CURRENT DATA NOT OKAY.  READ IN NEXT DATA SET.  IF DT IS -,
C     BACK UP THE TAPE 2 RECORDS BEFORE READING.
    3 IF (DT) 4,5,5
    4 BACKSPACE 3
      BACKSPACE 3
    5 READ TAPE 3, (DATA(I), I=1,21)
C
C     PART 4B. IF THIS DATA IS FOR A BODY IN THE BNAME LIST, STORE IT.
C     (IF NOT STORED, WE MIGHT HAVE TO RETURN FOR IT.)  IF ELLIPSE DATA IS
C     PROVIDED FOR THE BODY FOUND, BY-PASS THE TAPE DATA AND READ IN NEXT SET.
      DO 7  J = 1,MBODYS
B     IF ((DATA(1)+EFMRS(J))*(-(DATA(1)*EFMRS(J)))) 7,6,7
    6 IF (NEFMRS(J)-20) 8,8,3
    7 CONTINUE
      GO TO 3
C
C     PART 4C.  MOVE THE DATA INTO PLACE AND THEN GO BACK AND SEE IF IT IS OKAY.
    8 TIM(J) = DATA(2)
      TDEL(J) = DATA(3)
      DO 9 JJ=1,18
      TDAT(JJ,J) = DATA(JJ+3)
    9 CONTINUE
      GO TO 2
C
C
C     PART 5.  CURRENT DATA IS OKAY.  GET POSITION FROM THE POLONOMIAL
C     P = A + BX + CX**2 + DX**3 + EX**4 + FX**5.
   10 DO 11 K=1,3
      XP(K,JB1) = TDATA(1,K,JB)
      DO 11 KT=2,6
      XP(K,JB1) = XP(K,JB1)* DT +TDATA(KT,K,JB)
   11 CONTINUE
      IF (TRSFER) 12,12,15
C
C     PART 6. COMPUTE DISTANCE FROM REFERENCE AND FROM ROCKET .
   12 DO 13 K=1,3
      XP(K,JB1) = XP(K,IB) +XP(K,JB1)*SIGNF(AU,FIB)
   13 RB(K,JB1)= RB(K,1) - XP(K,JB1)
C
C     PART 7. COMPUTE PERTURBING ACCELERATIONS (QX).  4194304=2**22 IS REMOVED
C     TO PREVENT OVERFLOW.  2048=2**11 AND 8589934592=2**33 RESTORE THE SCALE.
      PRSQRD = (RB(1,JB1)**2 + RB(2,JB1)**2 + RB(3,JB1)**2)/4194304.
      RRELL = SQRTF(PRSQRD)
      RSQRD = ( XP(1,JB1)**2 + XP(2,JB1)**2 + XP(3,JB1)**2)/4194304.
      RCUBE = RSQRD * SQRTF(R SQRD)
      PRCUBE = PRSQRD * RRELL
      R(JB1) = RRELL*2048.
      DO 14 K=1,3
   14 QX(K)=SQRDK * BMASS(JB1) * ((XP(K,JB1)/RCUBE) + RB(K,JB1)/PRCUBE)/
     1  8589934592. + QX(K)
      GO TO 19
C
C     PART 8.  COMPUTE VELOCITY FROM V = B + 2CX + 3DX**2 + 4EX**3 + 5FX**4
C     AND FROM REFERENCE BODY VELOCITY (VEFM(IB)).
   15 DO 16 K=1,3
      VEFM(K,JB1) = 0.
      DO 16 KT=1,5
   16 VEFM(K,JB1) = (VEFM(K,JB1)*DT+TDATA(KT,K,JB)*FLOATF(-KT+6))
   17 DO 18 K=1,3
   18 VEFM(K,JB1) = VEFM(K,IB) + VEFM(K,JB1)*SIGNF(AU/SPD,FIB)
      GO TO 12
   19 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EXTRA
C
C     THIS ROUTINE IS EXECUTED BETWEEN FLIGHTS AND MAY THEREFORE BE EXPANDED TO
C     DO ADDITIONAL COMPUTATION BETWEEN SUCCESSIVE FLIGHTS.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000)
C
      EQUIVALENCE
     1(A     ,C      (  11)),(B     ,C      (1111)),(QMAX  ,B      (  44)),
     2(SIGNAL,B      (  31))
C
      SIGNAL = 0.
      QMAX = 0.
      RETURN
      END



                                                  SUBROUTINE EXTRAS
C     THIS ROUTINE IS EXECUTED BETWEEN STAGES AND MAY THEREFORE BE EXPANDED TO
C     DO CALCULATIONS BETWEEN SUCCESSIVE STAGES OF A FLIGHT.
C
      RETURN
      END



                                               SUBROUTINE ELIPSE (JB1)
C   THIS SUBROUTINE IS CALLED FROM EPHMRS TO COMPUTE THE POSITION OF A BODY
C   USING APPROXIMATE ELLIPTIC DATA.  THE VELOCITY IS ALSO COMPUTED IF THE
C   ORIGIN IS BEING TRANSLATED (TRSFER=1.0).  THE ELLIPSE DATA IS READ FROM
C   INPUT CARDS AND ORGANIZED IN SUBROUTINE ORDER. TPD IS TIME SINCE PERIHELION
C   PASSAGE, ZM IS MEAN ANOMALY, U IS ECCENTRIC ANOMALY.
C     TDATA ARRAY -  (K)    SEMILATUS RECTUM            (K+7) PERIOD
C                    (K+1)  ECCENTRICITY                (K+8) SIN OMEGA
C                    (K+2)  OMEGA                       (K+9) SIN NODE
C                    (K+3)  NODE                        (K+10) SIN INCLINATION
C                    (K+4)  INCLINATION                 (K+11) COS OMEGA
C                    (K+5)  JD OF PERIHELION            (K+12) COS NODE
C                    (K+6)  FRACTIONAL PART OF (K+5)    (K+13) COS INCLINATION
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1   XP(3,8), VEFM(3,8), TDATA(121)
C
      EQUIVALENCE
     1(A     ,C      (  11)),(B     ,C      (1111)),(CONSU ,A      (  31)),
     2(DTOFFJ,A      (  23)),(TABLT ,B      (  20)),(TDATA ,B      ( 265)),
     3(TRSFER,B      (   8)),(VEFM  ,B      ( 241)),(XP    ,B      ( 217))
C
      K = 18*(JB1-2)+1
      TPD = (DTOFFJ-TDATA(K+5))+(TABLT-TDATA(K+6))
      ZN = 6.28318533/TDATA(K+7)
      ZM = ZN*MODF(TPD,TDATA(K+7))
C
C     GET THE SINE(SINTRU) AND THE COSINE (COSTRU) OF THE TRUE ANOMALY
C     BY ITERATING KEPLERS EQUATION. THEN COMPUTE X,Y,Z (XP).
      U = ZM+TDATA(K+1)*SINF(ZM)+.5*TDATA(K+1)**2*SINF(2.*ZM)
      DO 1 J=1,10
      DELM = ZM-U+TDATA(K+1)*SINF(U)
      DELU = DELM/(1.-TDATA(K+1)*COSF(U))
      U = U+DELU
      IF (ABSF(DELM)-CONSU) 2,2,1
    1 CONTINUE
    2 COSU = COSF(U)
      DENOM = 1.-TDATA(K+1)*COSU
      COSTRU = (COSU-TDATA(K+1))/DENOM
      R = TDATA(K)/(1.+TDATA(K+1)*COSTRU)
      SINTRU = SQRTF(1.-TDATA(K+1)**2)*SINF(U)/DENOM
      SINV = SINTRU*TDATA(K+11)+COSTRU*TDATA(K+8)
      COSV = COSTRU*TDATA(K+11)-SINTRU*TDATA(K+8)
      XP(1,JB1) = R*(COSV*TDATA(K+12)-SINV*TDATA(K+9)*TDATA(K+13))
      XP(2,JB1) = R*(COSV*TDATA(K+9)+SINV*TDATA(K+12)*TDATA(K+13))
      XP(3,JB1) = R*SINV*TDATA(K+10)
      IF (TRSFER) 3,4,3
C
C     COMPUTE THE VELOCITIES FOR THE TRSFER OF ORIGIN.
    3 EX = TDATA(K+1)*TDATA(K+8)+SINV
      FX = TDATA(K+1)*TDATA(K+11)+COSV
      CFACT = ZN*TDATA(K)/(SQRTF((1.-TDATA(K+1)**2)**3))
      AX = EX*TDATA(K+12)+FX*TDATA(K+9)*TDATA(K+13)
      BX = FX*TDATA(K+12)*TDATA(K+13)-EX*TDATA(K+9)
      VEFM(1,JB1) = -AX*CFACT
      VEFM(2,JB1) = BX*CFACT
      VEFM(3,JB1) = FX*CFACT*TDATA(K+10)
    4 RETURN
      END
```

```
       REM     SUBROUTINE EXADD (A,B,C)
       REM THIS ROUTINE WILL ADD IN DOUBLE PRECISION A QUANTITY C TO THE DOUBLE
       REM PRECISION VARIABLE A+B WHERE A IS THE MOST SIGNIFICANT PART AND B IS
       REM THE LEAST SIGNIFICIANT PART.
       ENTRY   EXADD
       COMMON  -206
 Q1    COMMON  1
 Q2    COMMON  1
 TEMP1 COMMON  1
 TEMP2 COMMON  1
       HTR
       BCI     1,EXADD
       SXD     *-4,1
       SXD     *-4,2
EXADD  SXD     *-4,4
       CLA*    1,4
       FAD*    3,4
       STQ     Q1
       FAD*    2,4
       STQ     Q2
       FAD     Q1
       STQ     Q1
       STO     TEMP1
       CLA     Q1
       FAD     Q2
       STO     TEMP2
       FAD     TEMP2
       FAD     TEMP1
       STQ     Q1
       FSB     TEMP2
       STO*    1,4
       STQ     Q2
       CLA     Q1
       FAD     Q2
       STO*    2,4
       TRA     4,4
       END
                                              SUBROUTINE ICAO
C   SUBROUTINE ICAO DETERMINES THE ATMOSPHERIC TEMPERATURE, PRESSURE, AND
C   DENSITY AS A FUNCTION OF ALTITUDE ABOVE THE EARTH IN ACCORDANCE WITH
C   THE 1962 U.S. STANDARD ATMOSPHERE (ICAO TO 20 KM.). A SHORT FAP
C   PROGRAM FOLLOWS ICAO WHICH PROVIDES A MEANS OF LOADING DATA INTO MACHINE.
C   IT MUST BE LOADED DIRECTLY AFTER ICAO.  IF THE LENGTH OF ICAO IS CHANGED,
C   THE DATA MUST BE RELOCATED.
C
C             R IS DISTANCE TO CENTER OF EARTH IN METERS.
C           ALT IS VEHICLE ALTITUDE ABOVE EARTH IN METERS.
C       TABLE H IS METERS OF ALTITUDE FROM THE EARTHS SURFACE AND IS
C                  THE ARGUMENT OF ATMOSPHERE PROPERTY TABLE.
C           ALM IS THE MEAN SLOPE OF THE TABLE H VS. TM CURVE AT TABLE H.
C           TMR IS TM AT TABLE H.
C         REF P IS THE PRESSURE IN MILLIBARS AT TABLE H.
C            TM IS THE TEMPERATURE TIMES STD. MOLECULAR WEIGHT / ACTUAL
C                  MOLECULAR WEIGHT.  DEGREES KELVIN.
C         PRESS IS PRESSURE IN  MILLIBARS.
C        DNSITY IS DENSITY IN  KILOGRAMS PER CUBIC METER.
C        HEIGHT IS EITHER GEOPOTENTIAL ALTITUDE OR GEOMETRIC ALTITUDE IN METERS.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1   TABLEH(23), TMR(23), REFP(23), ALM(23) , RB(3)
C
      EQUIVALENCE
     1(A      ,C        (  11)),(ALT    ,A      (    4)),(B      ,C      (1111)),
     2(DNSITY,B         (  29)),                         (OBLATN,A       (  40)),
     3(PRESS ,B         (  33)),(R      ,B      ( 102)),(RB     ,B      ( 193)),
     4(RE    ,A         (  25)),(TABLT  ,B      (  20)),(TM     ,B      (  34)),
     5(RESQRD,B         (   7))
      EQUIVALENCE (TABLEH(24),TMR),(TABLEH(47),ALM),(TABLEH(70),REFP)
C
      IF (OBLATN) 102,101,102
  101 ALT = R - RE
      GO TO 103
  102 ALT = R-6356783.28/SQRTF(.9933065783+.006693421685(RB(3)/R)**2)
  103 IF (ALT-90000.) 105,104,104
  104 HEIGHT = ALT
      GO TO 106
  105 HEIGHT = ALT/(1.0+ALT/6356766.)
  106 K=K
C
C     FIND THE                 HEIGHT IN A TABLE OF BASE DATA. DATA ARE
C     ARRANGED IN DECENDING  ALT  WITH 21 REGIONS.  ABOVE THAT, PRESSURE AND
C     DENSITY ARE SET = 0.  TEMPERATURE IS SET TO 3000.
    1 IF (K-22) 2,6,6
    2 IF (HEIGHT-TABLEH(K+1)) 5,3,3
    3 K = K+1
      GO TO 1
    4 K = K-1
    5 IF (K) 7,7,6
    6 HINC = HEIGHT - TABLEH(K)
      IF (H INC) 4,8,8
    7 K = 1
    8 IF (ALM(K)) 9,100,9
C
```

```
C     CONTROL COMES HERE FOR NONISOTHERMAL LAYERS
    9 TM = TMR(K) + ALM(K)*H INC
      IF (ALT-90000.) 107,107,108
  107 PRESS = REFP(K)*(TMR(K)/TM)**(.0341631947/ALM(K))
      GO TO 10
  108 IF (K-KC) 109,110,109
  109 KC = K
      C1 = RE+TABLEH(K)
      C2 = TMR(K)/ALM(K)
      C3 = 1./(C1-C2)
      C4 = -.0341631947*RESQRD*C3/ALM(K)
  110 PRESS = REFP(K)*EXPF(C4*(C3*LOGF(C1*(HINC/C2+1.)/(RE+HEIGHT))-
     1        HINC/C1/(RE+HEIGHT)))
   10 DNSITY = PRESS/TM/2.87053072
      GO TO 13
C
C     CONTROL COMES HERE FOR ISOTHERMAL LAYERS
  100 IF (K-22) 11,12,12
   11 TM = TMR(K)
      PRESS = REFP(K)*EXPF(-.0341631947*HINC/TMR(K))
      GO TO 10
C
C     CONTROL COMES HERE FOR EXTREME ALTITUDES
   12 PRESS = 0.0
      DNSITY = 0.0
      TM = 3000.
   13 RETURN
      END

       REM   THIS IS THE FAP PROGRAM WHICH LOADS ICAO DATA INTO MACHINE.
       REM THE 256 IN ORG 256 WAS FOUND BY SUBTRACTING 22 FROM THE DEC LOCATION
       REM OF REF P (FROM FAP LISTING OF ICAO, THIS WAS FOUND TO BE 278).
       REM THUS, 278-22=256. DISCARD THE FIRST TWO BINARY CARDS AFTER ASSEMBLY
       REM AND PLACE REMAINING CARDS IMMEDIATELY BEHIND ICAO BINARY DECK.
       REM
       REM   A1 IS REF P(23)
       REM   A2 IS ALM(23)
       REM   A3 IS TMR(23)
       REM   A4 IS TABLE H(23)
       REM
       ORG 256
 A1    DEC 0.,1.1918E-9,3.4502E-9,1.0957E-8,4.0304E-8,1.8838E-7
       DEC 6.9604E-7,1.6852E-6,2.7926E-6,3.6943E-6,5.0617E-6,2.5217E-5
       DEC 7.3544E-5,3.0075E-4,1.6438E-3,.010377,.182099,.590005
       DEC 1.10905,8.68014,54.7487,226.320,1013.25
 A2    DEC 0.,0.,.0011,.0017,.0026,.0033,.004,.005,.007,.01,.015,.02,.01
       DEC .005,.003,0.,-.004,-.002,0.,.0028,.001,0.,-.0065
 A3    DEC 0.,2700.65,2590.65,2420.65,2160.65,1830.65,1550.65,1350.65
       DEC 1210.65,1110.65,960.65,360.65,260.65,210.65,180.65,180.65
       DEC 252.65,270.65,270.65,228.65,216.65,216.65,288.15
 A4    DEC 1E30,7E5,6E5,5E5,4E5,3E5,2.3E5,1.9E5,1.7E5,1.6E5,1.5E5,1.2E5
       DEC 1.1E5,1E5,.9E5,79000.,61000.,52000.,47000.,32000.,20000.
       DEC 11000.,0.
       END                                                                     1

                                                 SUBROUTINE NBODY
C
C     NBODY COMPUTES THE TRAJECTORY IN EITHER ORBIT ELEMENTS OR RECTANGULAR
C     COORDINATES USING THE RUNGE-KUTTA TECHNIQUE. A LOWER ORDER INTEGRATION
C     TECHNIQUE IS ALSO PERFORMED TO FACILITATE AUTOMATIC STEP SIZE CONTROL.
C     THE X,XPRIM,XDOT,XINC,ETC.  ARRAYS ARE AS FOLLOWS.
C
C     X            ORBIT ELEMENTS         RECTANGULAR COORDINATES
C
C     1            TIME                    TIME
C     2            MASS                    MASS
C     3            ECCENTRICITY            X-VELOCITY
C     4            ARGUMENT OF PERICENTER  Y-VELOCITY
C     5            ARGUMENT OF ASC. NODE   Z-VELOCITY
C     6            INCLINATION             X
C     7            MEAN ANOMALY            Y
C     8            SEMILATUS RECTUM        Z
C
C     IMODE     VARIABLES
C       1   ORBIT ELEMENTS
C       2   RECTANGULAR
C       3   RECTANGULAR TEMPORARY
C       4   EARTH SPHERICAL--CHANGE TO RECTANGULAR
C      -1   ORBIT ELEMENTS--CHANGE TO RECTANGULAR
C      -2   RECTANGULAR--CHANGE TO ORBIT ELEMENTS
C      -3   ORBIT ELEMENTS--CHANGE TO TEMPORARY RECTANGULAR
C      -4   EARTH SPHERICAL -- CHANGE TO ORBIT ELEMENTS
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1    XPRIM (100,2),      XPRIMB (100,2),      XDOTPM (100,2),
     2        X (100),           XINC (100),       OLDINC (100),
     3     XDOT (100),             RB (3),             XK (100),
     4      AMC (3),               AK (3),             AW (4),
     5   XWHOLE (6),               VX (3),            BEX (14)
C
```

```
      EQUIVALENCE
     1(A     ,C     (  11)),(A1    ,B     (  10)),(A2    ,B     (  11)),
     2(ACOEF1,B     (  12)),(ACOEF2,B     (  13)),(ACOEF3,B     (  14)),
     3(AK    ,A     (  51)),(AMC   ,B     (  87)),(AMSQRD,B     (  91)),
     4(AM    ,B     (  90)),(ASYMPT,A     (   7)),(AW    ,A     (  55)),
     5(B     ,C     (1111)),(CONSTU,A     (  32)),(DELT  ,B     (   1)),
     6(DONE  ,B     (  39)),(E2    ,B     (  18)),(EMONE ,B     (  28)),
     7(ERLIMT,A     (  14)),(ETOL  ,A     (  30)),(EXMODE,B     (  27)),
     8(GK2M  ,B     (  36)),(H2    ,B     (  15)),(IMODE ,A     (   1)),
     9(INDERR,B     (  51)),(KSUB  ,B     (  19)),(MBODYS,B     (  42))
      EQUIVALENCE
     1(NEQ   ,A     (   2)),(NSTART,B     (  24)),(OLDDEL,B     (   9)),
     2(QMAX  ,B     (  44)),(RATIO ,B     (  58)),(RB    ,B     ( 193)),
     3(REVS  ,A     (  48)),(R     ,B     ( 102)),(STEPMX,A     (  16)),
     4(STEPGO,A     (  41)),(STEPNO,A     (  42)),(TRSFER,B     (   8)),
     5(TRU   ,B     (  40)),(TTEST ,A     (  54)),(VSQRD ,B     (  96)),
     6(VX    ,B     (  92)),(XDOT  ,B     ( 501)),(XINC  ,B     ( 601)),
     7(XPRIM ,C     ( 711)),(XPRIMB,C     ( 911)),(XWHOLE,B     ( 110)),
     8(X     ,B     ( 401)),(ERLOG ,B     (  17)),(EREF  ,A     (  13)),
     9(Q     ,B     (  59)),(OUTPOT,B     ( 399))
C
C      PART 1. SET UP THE STARTING SEQUENCE FOR ERROR CONTROL AND DELAY CHECKING
C      THE ERROR UNTIL TWO STEPS ARE COMPLETED.  THE ASSIGNED GO TOS NSTART AND
C      IBEGIN CONTROL STARTING.
      NEQ = NEQ
    1 DO 2 J=1,NEQ
      XPRIM(J,2) = XPRIM(J,1)
      XPRIMB(J,2) = XPRIMB(J,1)
    2 X(J) = XPRIM(J,1)
      NSTART = 0
      TRSFER = 0.
      H2 = DELT
      DELT = DELT/2.
  220 CALL EQUATE
      IF (OUTPOT) 222,221,222
  221 CALL OUTPUT
  222 DO 3 J=1,3
      XWHOLE(J)=VX(J)
    3 XWHOLE(J+3) = RB(J)
C     CHANGE INTEGRATION VARIABLES IF IMODE IS -.
      IF (IMODE) 4,5,5
    4 CALL TESTTR
      GO TO 1
    5 CALL TESTTR
      IF (TRSFER) 1,205,1
  205 ASSIGN 21 TO NSTART
C     STATEMENTS 7 TO 9 INITIALIZE NREV1 AND NREV2 FOR USE IN PART 7A.
      IF (RB(2)) 7,6,8
    6 IF(VX(2)) 7,8,8
    7 ASSIGN 37 TO NREV1
      ASSIGN 35 TO NREV2
      GO TO 9
    8 ASSIGN 33 TO NREV1
      ASSIGN 37 TO NREV2
    9 DO 10 J=1,NEQ
      XDOTPM(J,1) = XDOT(J)
      XINC(J) = 0.
   10 CONTINUE
   11 KSUB = 1
      ASSIGN 16 TO N
C
C     PART 2.  RUNGE-KUTTA SUBINTERVAL SCHEME.  EQUATE PRODUCES THE NECCESSARY
C     DERIVATIVES XDOT(J).
   12 DO 13 J=1,NEQ
      XK(J) = XDOT(J) * DELT
      XINC(J) = XINC(J) + AW(KSUB)*XK(J)
   13 X(J) = XPRIM(J,2) + AK(KSUB)*XK(J)
   14 CALL EQUATE
   15 GO TO N,(16,17,18,20)
C
C     PART 3. SUBINTERVALS 2, 3, AND 4, TO STATEMENT 19 FINISH A
C     RUNGE-KUTTA STEP AND INCREMENT XPRIM(J,2) IN DOUBLE PRECISION.
   16 KSUB = 2
      ASSIGN 17 TO N
      GO TO 12
   17 KSUB = 3
      ASSIGN 18 TO N
      GO TO 12
   18 DO 19 J=1,NEQ
      XINC(J) = XINC(J) + AW(4) *XDOT(J) * DELT
  180 CALL EXADD(XPRIM(J,2), XPRIMB(J,2), XINC(J))
      X(J) = XPRIM(J,2)
   19 CONTINUE
C
C     PART 4. BEGIN A NEW RUNGA-KUTTA STEP.  THIS ALSO GIVES DERIVATIVES
C     FOR THE LOWER ORDER INTEGRATION CHECK.
      ASSIGN 20 TO N
      GO TO 14
   20 GO TO NSTART,(27,23,21)
C
C     PART 5.  STARTING PHASE PROGRAM.
C     PART 5A. THIS SECTION COMPLETES THE FIRST STEP OF STARTING PHASE.
   21 ASSIGN 23 TO NSTART
      DO 22 J=1,NEQ
      OLDINC(J)=XINC(J)
      XINC(J)=0.
      XDOTPM(J,2) = XDOT(J)
   22 CONTINUE
      GO TO 11
C
```

```
C     PART 5B. MAX ERROR TEST--STARTING ONLY--CHECK THE MAX ERROR AND
C     EITHER ENTER RUNNING MODE OR REPEAT START WITH SMALLER STEP.
   23 DO 24 J=2,NEQ
   24 XINC(J) =(XINC(J)+OLDINC(J))*3.-(XDOTPM(J,1)+XDOTPM(J,2)*4.
     1+XDOT(J))*DELT
  240 CALL ERRORZ
   25 IF(E2-ERLIMT) 26,26,56
   26 ASSIGN 27 TO NSTART
      ASSIGN 11 TO IBEGIN
      A1 = A2
      GO TO 31
C
C     PART 6.  RUNNING PHASE PROGRAM.
C     PART 6A. CHECK THE INTEGRATION BY INTEGRATING OVER THE LAST
C     RUNGE KUTTA STEP BUT USE DOTS FOR LAST TWO INTERVALS, OLDDEL
C     AND DELT RESPECTIVELY.  STATEMENT 28 IS THE LOWER INTEGRATION
C     MINUS RUNGE-KUTTA INCREMENTS.  ERRORZ COMPUTES THE MAXIMUM RELATIVE
C     ERROR AND STATEMENT 29 TESTS THIS ERROR AGAINST THE LIMIT VALUE.
   27 RATIO = DELT/OLDDEL
      HFACT=DELT/(1.+RATIO)
      ACOEF1=-RATIO*RATIO*HFACT
      ACOEF2=RATIO*(DELT+3.*OLDDEL)
      ACOEF3=DELT+DELT+HFACT
      DO 28 J=2,NEQ
   28 XINC(J) = ACOEF1*XDOTPM(J,1)+ACOEF2*XDOTPM(J,2)-6.*XINC(J)
     1+ACOEF3*XDOT(J)
  280 CALL ERRORZ
   29 IF (E2-ERLIMT) 30,30,57
C
C     PART 7A. LAST POINT OKAY. COUNT THE REVOLUTIONS PAST THE X-AXIS.
C     A STEP GREATER THAN 1/2 REV. MAY FAIL TO ADD IN.
   30 H2 = DELT
   31 QMAX = MAX1F(Q,QMAX)
      IF(RB(2)) 32,34,34
   32 GO TO NREV1, (37,33)
   33 ASSIGN 37 TO NREV1
      ASSIGN 35 TO NREV2
      GO TO 37
   34 GO TO NREV2, (37,35)
   35 ASSIGN 33 TO NREV1
      ASSIGN 37 TO NREV2
   36 REVS = REVS + 1.
   37 IF (XABSF(IMODE)-1) 42,38,42
C
C     PART 7B. IN ORBIT ELEMENTS. ADJUST ARGUMENT OF PERICENTER AND MEAN ANOMALY
C     TO + OR - PI TO MAINTAIN ACCURACY IN SIN-COS ROUTINES.
   38 IF (EMONE) 39,42,42
   39 DO 41 J=4,7,3
      ADJ2=INTF(XPRIM(J,2)/6.28318532+SIGNF(.5,XPRIM(J,2)))
      IF (ADJ2) 40,41,40
   40 ADJ3 = -ADJ2*6.28125
  400 CALL EXADD(XPRIM(J,2),XPRIMB(J,2),ADJ3)
      ADJ3=-ADJ2*.0019353072
  401 CALL EXADD(XPRIM(J,2),XPRIMB(J,2),ADJ3)
   41 CONTINUE
C
C     PART 7C. ADVANCE THE REMAINING PARAMETERS, FIND NEW STEP SIZE,
C     AND TEST FOR AN ORIGIN TRANSLATION.
   42 DO 43 K=1,3
      XWHOLE(K)=VX(K)
   43 XWHOLE(K+3) = RB(K)
      DO 44 J=1,NEQ
      XDOTPM(J,1) = XDOTPM(J,2)
      XDOTPM(J,2) = XDOT(J)
      XPRIM(J,1) = XPRIM(J,2)
      XPRIMB(J,1) = XPRIMB(J,2)
      XINC(J) = 0.
   44 CONTINUE
      OLDDEL = DELT
   45 CALL STEP
      IF (DONE) 67,450,67
  450 IF (NSTART) 451,1,451
  451 IF (MBODYS) 46,47,46
   46 CALL TESTTR
      IF (TRSFER) 1,47,1
   47 IF (XABSF(IMODE)-3) 11,48,11
C
C     PART 7D. IF IN TEMPORARY RECTANGULAR COORDINATES, TEST FOR RETURN
C     TO ORBIT ELEMENTS.  FIRST, E IS FOUND.  IF TIME HAS NOT ADVANCED
C     SUFFICIENTLY, INTEGRATION CONTINUES IN RECTANGULAR VARIABLES (STATE. 48).
C     STATEMENT 49 DETERMINES IF KEPLERS EQUATION CAUSED IMODE = 3.  IF NOT,
C     AN E CLOSE TO 1 CHECK IS MADE IN STATEMENT 50.  IF IT DID, RECTANGULAR
C     VARIABLES WILL BE USED IF THE LIMIT IS TOO SMALL (STATEMENT 52), OR
C     IF E IS 5 OR GREATER (STATEMENT 53) OR IF THE PATH LIES CLOSE TO AN
C     ASYMPTOTE (STATEMENT 55).
   48 CALL CONVT1 (VX,AMC)
      EXMODE=SQRTF(1.+AMSQRD/GK2M*(VSQRD/GK2M-2./R))
      EMONE=EXMODE-1.
      IF ((XPRIM(1)-TTEST)*DELT) 11,11,49
   49 IF (ASYMPT) 51,50,51
   50 IF (ETOL-ABSF(EMONE)) 55,11,11
   51 IF(EMONE) 55,55,52
   52 IF(CONSTU-1.E-7) 11,53,53
   53 IF (EXMODE-5.) 54,11,11
   54 CALL CONVT2
      IF (ABSF(TRU)-2.2/SQRTF(EXMODE)) 55,55,11
   55 ASYMPT = 0.0
      IMODE=-2
  555 CALL TESTTR
      GO TO 1
C
```

```
C     PART 8. COMES HERE WHEN ERROR TEST FAILED--BOTH STARTING AND RUN.
C     RETRIEVE OLD POINT AND RECOMPUTE WITH SMALLER INTERVAL.
C     IF TWO CONSECUTIVE TRYS FAIL (STATEMENT 59) THE STARTING SEQUENCE OCCURS.
   56 ASSIGN 1 TO IBEGIN
   57 DO 58 J=1,NEQ
      XPRIM(J,2) = XPRIM(J,1)
      XPRIMB(J,2) = XPRIMB(J,1)
      XDOT(J)=XDOTPM(J,2)
      XINC(J)= 0.
   58 CONTINUE
      STEPNO=STEPNO+1.
      H2 = DELT
      DELT=SIGNF(EXPF((ERLOG-A2)/5.),DELT)
      A2 =A1
   59 IF (FAIL-STEPGO) 60,61,60
   60 FAIL = STEPGO
      GO TO IBEGIN, (11,1)
   61 ASSIGN 1 TO IBEGIN
      IF (STEPNO + STEPGO - STEPMX) 62,62,45
   62 GO TO IBEGIN, (11,1)
C
C     PART 10. PRINT OUT THE ERROR INFO. IF EREF HAS A - SIGN.  THEN RETURN.
   67 IF (EREF) 68,72,72
   68 WRITE OUTPUT TAPE 6,70
      REWIND 4
      DO 69 I=1,INDERR
      READ TAPE 4, BEX
   69 WRITE OUTPUT TAPE 6,71,BEX
      REWIND 4
      INDERR = 0
   70 FORMAT(7H1  STEP,6X,4HTIME,6X,4HDELT,7X,2HA2,8X,2HE2,7X,4HMASS,6X,
     14HE,VX,4X,8HOMEGA,VY,2X,8HNODES,VZ,3X,6HINCL,X,5X,4HMA,Y,6X,3HP,Z,
     24X,1HK//)
   71 FORMAT(F5.,1H+F3.,1P11G10.2,I2)
   72 RETURN
      END
                                                  SUBROUTINE ORDER
C     THIS ROUTINE TAKES THE BODY LIST READ FROM CARDS AND SORTS THEM IN
C     ORDER SO THAT THE DISTANCE FROM THE REFERENCE TO EACH BODY IS
C     DEPENDENT UPON ALREADY COMPUTED DISTANCES ONLY.
C
C     ELLIPSE DATA ARE READ INTO A BLOCK OF 120 STORES RESERVED FOR
C     TEN ELLIPSES.  ONE ELLIPSE IS READ INTO A 12 STORE BLOCK.
C     THE SINES AND COSINES OF THE 3 ANGLES ARE COMPUTED AND STORED
C     IN THE TDATA ARRAY ALONG WITH THE REST OF THE ELLIPSE DATA.
C     A BLOCK IS ARRANGED AS FOLLOWS'
C
C     (1) = NAME OF BODY IN BCD,ONLY 6 CHARACTERS.
C     (2) = NAME OF REFERENCE BODY IN BCD,SAME RESTRICTION.
C     (3) = MASS OF THE BODY IN SUN MASS UNITS.
C     (4) = RADUIS INSIDE OF WHICH COORDINATES WILL BE TRANSLATED TO THIS BODY.
C     (5) = SEMILATUS RECTUM IN ASTRONOMICAL UNITS.
C     (6) = ECCENTRICITY OF THE ORBIT.
C     (8) = LONGITUDE OF ASCENDING NODE.
C     (7) = ARGUMENT OF PERIHELION.
C     (9) = INCLINATION OF THE ORBIT.
C     (10)= PERIGEE PASSAGE JULIAN DAY.
C     (11)= PERIGEE PASSAGE FRACTION OF DAY.
C     (12)= PERIOD OF THE ELLIPSE IN MEAN SOLAR DAYS.
C
C     AMASS  = MASS OF EACH BODY, SUN MASSES.  ORDER OF PNAME.
C     BMASS  = SELECTED FROM AMASS. CORRESPONDS TO BNAME LIST.
C     BNAME  = THE ORDERED LIST OF BCD BODY NAMES. CAN BE USED IN OUTPUT.COMMON.
C     BODYCD = THE ORIGINAL BCD NAMES READ FROM CARDS.
C     BODY L = THE LIST OF BCD BODY NAMES WITH THE REFERENCE BODY AT TOP.
C              INITIALLY EQUAL TO BODY CARD LIST (BODYCD).
C     IBODY  = ARRAY OF SUBSCRIPTS. WHEN A DISTANCE IS FOUND FROM EPHEMERIS, IT
C              MAY BE ADDED (OR SUBTRACTED) FROM THE BODY POSITION GIVEN BY
C              XP(IBODY) TO OBTAIN THE POSITION OF THE PRESENT BODY.  COMMON.
C     KZERO  = COUNT OF ZERO REFERENCES. THERE MUST BE ONE AND ONLY ONE ZERO.
C              FROM LOCATION IN BNAME LIST. NOT IN COMMON.
C     MANE   = ARRAY OF SUBSCRIPTS.  INVERSE OF NAME.  GIVES NEW LOCATION OF
C              BNAME LIST IN TERMS OF BODYL.  NOT IN COMMON.
C     NBODYS = COUNTED INTERNALY. TOTAL NUMBER OF  BODYS.
C     MBODYS = COMPUTED INTERNALY. TOTAL NUMBER OF EPHEMERIDES (NBODYS-1).
C     NAME   = ARRAY OF SUBSCRIPTS.  GIVES OLD LOCATION OF NAMES IN BODYL
C     NEFMRS = ARRAY OF SUBSCRIPTS. GIVES LOCATION OF BODY IN PNAME LIST
C              IN TERMS OF THE EFMRS LIST.  STORED IN COMMON.
C     NREFER = ARRAY OF SUBSCRIPTS. LOCATES THE REFERENCE BODY IN BODYL.
C              ORDER OF THE ARRAY CORRESPONDS TO BODYL.  NOT IN COMMON.
C     NNREFR = ARRAY OF SUBSCRIPTS. LIKE NREFER BUT REFERS AND CORRESPONDS TO
C              BNAME LIST.  NOT IN COMMON.
C     PNAME  = A PERMANENT LIST OF BCD BODY NAMES.  1 WORD EACH (6 CHARACTERS
C              MAX).  USED TO IDENTIFY MASS, REFERENCE NAMES, ETC.  THE LIST IS
C              A MAXIMUM OF 30 NAMES.  PRECISION TAPE NAMES ARE FROM 1 TO 20,
C              ELLIPTIC NAMES ARE FROM 21 TO 30.
C     REFER  = A PERMANENT LIST OF BCD BODYS THAT ARE THE REFERENCES OF
C              DISTANCES GIVEN IN EPHERMERIDES (TAPES OR ELLIPSE). CORRESPONDS
C              TO PNAME LIST.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1    AMASS (30),          BMASS (8),            BNAME (8),
     2    BODYL (8),           EFMRS (7),            IBODY (8),
     3     MANE (8),            NAME (8),           NEFMRS (8),
     3   NEFMRT (8),          NNREFR (8),           BODYCD (8),
     4   NREFER (8),           PNAME (30),          RBCRIT (7),
     5    RCRIT (30),          REFER (30),           TDATA (18,7),
     6     TDEL (7),             TIM (7),            ELIPS (120),
     7     NDUD (9),           XPRIM (200)
C
```

```
       EQUIVALENCE
      1(A      ,C      (   11)),(AMASS ,A      ( 347)),(ATMN  ,A      (   21)),
      2(AU     ,A      (   29)),(B     ,C      (1111)),(BMASS ,B      ( 137)),
      3(BNAME  ,B      ( 122)),(BODYCD,A      ( 143)),(BODYL ,B      ( 153)),
      4(EFMRS  ,B      ( 130)),(ELIPS ,A      ( 167)),(FILE  ,B      (   22)),
      5(GK2M   ,B      (   36)),(GKM   ,B      (   37)),(IBODY ,B      ( 177)),
      6(MBODYS,B      (   42)),(NBODYS,B      (   41)),(NEFMRS,B      ( 185)),
      7(PNAME  ,A      ( 287)),(RATMOS,B      (   23)),(RATM  ,A      (   22)),
      8(RBCRIT,B      ( 145)),(RCRIT ,A      ( 377)),(REFER ,A      ( 317)),
      9(RE     ,A      (   25)),(RESQRD,B      (    7)),(REVOLV,B      (   21))
       EQUIVALENCE
      1(ROTATE,A      (   39)),(SPD   ,A      (   44)),(SQRDK1,A      (   47)),
      2(SQRDK  ,B      (   35)),(TDATA ,B      ( 265)),(TDEL  ,B      ( 170)),
      3(TFILE  ,A      (    6)),(TIM   ,B      ( 163)),(TRSFER,B      (    8)),
      4(XPRIM  ,C      ( 711)),(OUTPOT,B      ( 399))
       EQUIVALENCE (MANE(1),NOUD(2))
C
C      THIS SECTION SEES WHAT ELLIPSE DATA WAS READ FROM CARDS AND PUTS THE
C      NAMES IN PLACE SO THAT DATA  WILL BE USED IF NEEDED. ELLIPSE DATA HAS
C      PRIORITY OVER TAPE DATA BECAUSE LAST DATA IN LIST IS THAT ACTUALLY USED.
C      FUNCTION COMPARF(A,B) IS EQUIVALENT TO (A-B) BUT WILL NOT OVERFLOW.
C
B      COMPARF(A,B) = (A+B)*(-(A*B))
       DO 2 K=1,120,12
       IF(ELIPS(K)) 1,2,1
     1 KOUNT = (K-1)/12+21
       PNAME(KOUNT)  = ELIPS(K)
       REFER(KOUNT)  = ELIPS(K+1)
       AMASS(KOUNT)  = ELIPS(K+2)
       RCRIT(KOUNT)  = ELIPS(K+3)
     2 CONTINUE
C
C      PART 0. THROW AWAY BLANKS AND DUPLICATES IN BNAME LIST.
C              ALSO COUNT THE BODIES.
       IF (TRSFER) 4,3,4
     3 BNAME(1) = BODYCD(1)
     4 DO 5 K=1,8
     5 BNAME(K+1)= BODYCD(K)
       L = 1
       BODYL(0) = 0.
       DO 8 I=1,9
       BODYL(I) = 0.
       DO 6 K=1,L
       IF (COMPARF (BNAME(I), BODYL(K-1))) 6,7,6
     6 CONTINUE
       BODYL(L) = BNAME(I)
       L = L+1
     7 BNAME(I) = 0.
     8 CONTINUE
       NBODYS = L-1
       MBODYS = NBODYS-1
C
C      PART 1. FIND THE REFERENCE BODY FOR EACH BODY IN THE LIST OF BODYS
C              READ FROM CARDS.  CLEAR NREFER AND BNAME.
       DO 13 KL=1,NBODYS
       NREFER(KL) = 0
       NEFMRT(KL) =0
       BNAME (KL) = 0.
       DO 12   KP= 1,30
       IF (COMPARF(BODYL(KL),PNAME(KP))) 12,9,12
     9 NEFMRT(KL) = KP
       DO    11   KR = 1,8
       IF (COMPARF(REFER(KP),BODYL(KR))) 11,10,11
    10 NREFER(KL) = KR
    11 CONTINUE
    12 CONTINUE
    13 CONTINUE
C      PART 2 . COUNTS 0  REFERENCES AND SAVES TEMPORARY SET OF INDEXS.
    14 IF (NBODYS) 24,24,15
    15 KZEROS = 0
       MISPEL = 0
       DO   20  K = 1,NBODYS
       NNREFR(K) = NREFER(K)
    16 IF (NEFMRT(K)) 18,17,18
    17 MISPEL = MISPEL + 1
    18 IF(NREFER(K)) 20,19,20
    19 KZEROS = KZEROS + 1
    20 CONTINUE
    21 IF   (KZEROS- 1)  24,22,24
    22 IF (MISPEL) 24,23,24
    23 IF (NBODYS-8) 28,28,24
C
C      PART 3 . REPORTS ERRORS IN BODY LIST.
    24 WRITE OUTPUT TAPE 6,25 ,NBODYS,MISPEL,KZEROS,(BODYL(K),K=1,NBODYS)
       WRITE OUTPUT TAPE 6,26 ,(NREFER(K),K=1,NBODYS)
       WRITE OUTPUT TAPE 6,27 ,(K,PNAME(K),REFER(K),K=1,30)
    25 FORMAT (26HOGOOFY BODY LIST (NBODYS =I2,13H,  MISSPELL =I2,
     1 11H,  KZEROS =I2,1H)/11HOBODYLIST =8(3X,A6))
    26 FORMAT (11H   NREFER =I6,7I9)
    27 FORMAT (/5(3H  K3X,4HBODY4X,5HREFER5X,)/5(I3,2X,A6,2X,A6,5X))
       CALL EXIT
C
C      PART 4.  TRACES OUT ..REFERENCE TO BODY.. RELATIONSHIPS
    28 KK = 2
       KN = 1
       NAME(1) = 1
    29 IF (NREFER(KN))  24,31,30
    30 NAME(KK) = NNREFR(KN)
       NNREFR(KN) = 0
       KN = NAME(KK)
       KK = KK + 1
       GO TO 29
C
```

```
C     PART 5.  TRACES OUT  ..BODY TO REFERENCE..  RELATIONSHIP
   31 DO  34  KN = 1,NBODYS
      DO  34 K = 1,NBODYS
   32 IF (NNREFR(K) - NAME(KN)) 34,33,34
   33 NAME(KK) = K
      KK = KK + 1
   34 CONTINUE
C
C     PART 6. INVERTS NAME TO MANE,STORES BNAME, BMASS, RBCRIT,  AND A
C             TEMPORARY NEFMRS.
      DO 35 K = 1,NBODYS
      N = NAME(K)
      MANE(N) = K
      NEF = NEFMRT(N)
      BNAME(K) = PNAME(NEF)
      BMASS(K) = AMASS(NEF)
      RBCRIT(K) = RCRIT(NEF)
      NEFMRS(K) = NEF
   35 CONTINUE
C
C     PART 7. FINDS NNREFR REFERENCE FOR BNAME LIST , ALSO TEMP. IBODY
      DO 36  K = 1, NBODYS
      N = NAME(K)
      NRF = NREFER(N)
      NNREFR(K) = MANE(NRF)
   36 IBODY(K) = MANE(NRF)
C
C     PART 8 . FINDS IBODY FOR BACKWARD REFERENCE.
      DO 39 K=1,8
   37 IF(NNREFR(K)) 24,40,38
   38 N = NNREFR(K)
      IBODY(N) = -K
   39 CONTINUE
C     IBODY LIST IS COMPLETE.
C
C     PART 9 . WRITES OUT EPHEMERIS LIST TO BE USED IN STORING DATA AND
C              MAKES FINAL NEFMRS LIST.
   40 KK = 1
      DO 43 K=1,NBODYS
   41 IF(NNREFR(K)) 42,43,42
   42 EFMRS(KK) = BNAME(K)
      NEFMRS(KK) = NEFMRS(K)
      KK = KK + 1
   43 CONTINUE
      NEFMRS(NBODYS) = 0
C
C     PART 10. SAVES ELLIPSE DATA
      FILE = 0.
      IF (MBODYS) 430,480,430
  430 DO 48 K=1,MBODYS
   44 IF(NEFMRS(K)-20) 47,47,45
   45 DO 46 J=5,12
      L= (NEFMRS(K) - 21) • 12 +J
   46 TDATA(J-4,K) = ELIPS(L)
      DO 50 J=7,9
      L = (NEFMRS(K)-21)*12+J
      TDATA(J+2,K) = SINF(ELIPS(L))
   50 TDATA(J+5,K) = COSF(ELIPS(L))
      GO TO 48
C
C     PART 10A.  LOADS A FALSE (VERY EARLY) TAPE TIME TO FORCE TAPE
C                READING BY THE EPHMRS ROUTINE. FILE = 0 UNLESS TAPE IS USED.
   47 TDEL(K) = 0
      TIM(K) = 2400000.5
      FILE = 10.
   48 CONTINUE
C
C     PART 11. COMPUTE GRAVITATIONAL CONSTANTS. 1.9866 E+30 = KILOGRAMS/SUN MASS
C     IF ORIGIN BODY HAS AN ATMOSPHERE, SET ROTATION RATE AND ATMOSPHERE RADIUS.
C     POSITION THE EPHEMERIDES TAPE AT THE BEGINNING OF THE CORRECT EPHEMERIS
C     BY MATCHING THE EPHEMERIS NUMBER READ FROM TAPE (FILE) WITH THE DESIRED
C     EPHEMERIS NUMBER (TFILE).
C
  480 RESQRD = RE**2
      SQRDK = SQRDK1*AU**3/SPD**2
      GK2M = SQRDK*(BMASS(1) + XPRIM(2)/1.9866 E30)
      GKM = SQRTF(GK2M)
      REVOLV = 0.
      RATMOS = 0.
      IF (ATMN-BNAME(1)) 51,49,51
   49 REVOLV = ROTATE
      RATMOS  = RATM
   51 IF (FILE) 56,56,52
   52 CALL BSFILE(3)
   53 READ TAPE 3, FILE
      IF (FILE-TFILE) 54,56,55
   54 CALL SKFILE(3)
      GO TO 53
   55 BACKSPACE 3
      BACKSPACE 3
      GO TO 52
C
C     PART 12.    WRITES THE BNAME LIST ON TAPE 6 .
   56 IF (OUTPOT) 58,59,58
   59 WRITE OUTPUT TAPE 6,57,BNAME(1),(BNAME(K),K=2,NBODYS)
   57 FORMAT (19HOREFERENCE BODY IS A6,5X,23H  PERTURBING BODIES ARE
     1  7(2X,A6))
   58 RETURN
      END
```

```
                                               SUBROUTINE OBLATE
C    THIS SUBROUTINE COMPUTES THE OBLATENESS ACCELERATIONS (OBLAT) DUE TO AN
C    AXIALLY SYMMETRIC EARTH.  THE 2ND, 3RD, AND 4TH SPHERICAL HARMONIC COEFF.
C    ARE OBLATJ, OBLATH, AND OBLATD RESPECTIVELY.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1   RB(3), OBLAT(3)
C
      EQUIVALENCE
     1(A     ,C     (  11)),(B     ,C     (1111)),(GK2M  ,B     (  36)),
     2(OBLATJ,A     (  26)),(OBLATD,A     (  27)),(OBLATH,A     (  28)),
     3(OBLAT ,B     (  75)),(R     ,B     ( 102)),(RB    ,B     ( 193)),
     4(RE    ,A     (  25)),(RSQRD ,B     (  45)),(RESQRD,B     (   7))
C
      AA = RB(3)/R
      AB = AA*AA
      IF (ABSF(AA)-1.E-6) 1,1,2
    1 AA=0.
      AB=0.
    2 AC = RESQRD/RSQRD
      AD = GK2M/RSQRD/R*AC
      AE = OBLATJ*AD
      AF = OBLATH*AD*RE/R
      AG = OBLATD*AD*AC
      AH = AE*(5.AB-1.)+AF*(7.AB-3.)*AA+AG*(6.AB-9.AB**2-0.4285714286)
      OBLAT(1) = AH*RB(1)
      OBLAT(2) = AH*RB(2)
      OBLAT(3) = (AH-2.AE+AG*(4.AB-1.714285714))*RB(3)-AF*(3.AB-0.6)*R
    3 RETURN
      END



                                               SUBROUTINE OUTPUT
C     ENTS AND RECTANGULAR COORDINATES ARE OUTPUTTED.  IF THE OBJECT IS NOT WITH
C     THIS IS THE ROUTINE WHICH FORMS THE BASIC DATA OUTPUT.  BOTH ORBIT ELEM-
C     IN AN ATMOSPHERE (PRESS=0.), ONE LINE OF DATA IS DELETED.  LIKEWISE,
C     ONLY THOSE PERTURBING BODIES PRESENT HAVE THEIR DISTANCES OUTPUTTED.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1     R     (8),          ORBELS (6),            VATM (3),
     2    BNAME (8),             RB(3,8),             DIRCOS(3,8),
     3    XPRIM (200),          RAMC (5)
C
      EQUIVALENCE
     1(A     ,C     (  11)),(ALPHA ,A     (  49)),(ALT   ,A     (   4)),
     2(AMC   ,B     (  87)),(AM    ,B     (  90)),(AREA  ,B     (   6)),
     3(BNAME ,B     ( 122)),(B     ,C     (1111)),(CD    ,A     ( 165)),
     4(CL    ,A     ( 164)),(COSALF,B     (  48)),(COSTRU,B     (  53)),
     5(DTOFFJ,A     (  23)),(H2    ,B     (  15)),(IMODE ,A     (   1)),
     6(MBODYS,B     (  42)),(NBODYS,B     (  41)),(ORBELS,B     ( 116)),
     7(PRESS ,B     (  33)),(P     ,B     (  84)),(PSI   ,B     (  30)),
     8(PSIR  ,B     ( 398)),(PUSH  ,A     ( 166)),(Q     ,B     (  59)),
     9(RAMC  ,B     ( 393)),(RB    ,B     ( 193)),(REVS  ,A     (  48))
      EQUIVALENCE
     1(R     ,B     ( 102)),(SINALF,B     (  46)),(SINTRU,B     (  52)),
     2(STEPGO,A     (  41)),(STEPNO,A     (  42)),(TABLT ,B     (  20)),
     3(TRU   ,B     (  40)),(VATM  ,B     (  97)),(VQ    ,B     ( 100)),
     4(V     ,B     (  95)),(VX    ,B     (  92)),(VY    ,B     (  93)),
     5(VZ    ,B     (  94)),(XPRIM ,C     ( 711)),(OUTPOT,B     ( 399))
C
      DAYJ=(DTOFFJ-2.4E6)+TABLT
      ALPHA1 = ALPHA*57.29577951
      REV = REVS+ARCTAN(-RB(2),-RB(1))/6.28318532 + .5
   16 CALL CONVT1(VX,AMC)
      IMODE=IMODE
      GO TO (2,1,1),IMODE
    1 CODE=6HRECTAN
   18 CALL CONVT 2
      GO TO 4
    2 DO 3 K=1,6
    3 ORBELS(K) = XPRIM(K+2)
      CODE=5HORBIT
      TRU=ARCTAN(SINTRU,COSTRU)
    4 PSI = ATANF((RB(1)*VX+RB(2)*VY+RB(3)*VZ)/AM)57.2957795
      IF (OUTPOT) 19,6,19
    6 WRITE OUTPUT TAPE 6, 11,STEPGO,STEPNO,ORBELS(1),ORBELS(2),V,R(1),B
     1NAME(1),CODE,IMODE,XPRIM(1),ORBELS(6),TRU,VX,RB(1),XPRIM(2),DAYJ,D
     2RBELS(5),ORBELS(3),VY,RB(2),REV,ALPHA1,PSI,ORBELS(4),VZ,RB(3),H2
C
C     IF WITHIN AN ATMOSPHERE COMPUTE DRAG, LIFT, G, ETC., AND PRINT EXTRA LINE.
   19 IF (PRESS) 5,7,5
    5 XIFT = Q*AREA*CL
      DRAG = Q*AREA*CD
      G = (PUSH-DRAG*COSALF+XIFT*SINALF)/XPRIM(2)/9.80665
   17 CALL CONVT1(VATM,RAMC)
      PSIR = ATANF((RB(1)*VATM(1)+RB(2)*VATM(2)+RB(3)*VATM(3))/RAMC(4))*
     1 57.2957795
      IF (OUTPOT) 7,14,7
   14 WRITE OUTPUT TAPE 6,12,ALT,PSIR,DRAG,VQ,G,PUSH
C
```

```
C      IF PERTURBATING BODIES ARE PRESENT, FIND THEIR DISTANCES AND PRINT THEM.
     7 IF(MBODYS) 8,10,8
     8 DO 9 J=2,NBODYS
       DO 9 K=1,3
     9 DIRCOS(K,J) = -RB(K,J)/R(J)
       IF (OUTPOT) 10,15,10
    15 WRITE OUTPUT TAPE 6,13,
      1(BNAME(J),R(J),DIRCOS(1,J),DIRCOS(2,J),DIRCOS(3,J),J=2,NBODYS)
    10 RETURN
    11 FORMAT(6HOSTEP=F6.,2H +F4.,3X,13HECCENTRICITY=1PG15.8,7H OMEGA=G15
      1.8,4H  V=G15.8,3H R=G15.8,7H REFER=A6,1X,A6,I2/6H TIME=1PG14.7,14
      2H SEMILATUS R.=G15.8,7H TRU A=G15.8,4H VX=G15.8,3H X=G15.8,7H RMAS
      3S=G15.8/9H JDAY= 240PF10.4,15H  MEAN ANOMALY=1PG15.8,7H  NODE=G15.
      48,4H VY=G15.8,3H Y=G15.8,7H REVS.=G15.8/6H ALFA=G14.7,14H   PATH A
      5NGLE=G15.8,7H  INCL=G15.8,4H VZ=G15.8,3H Z=G15.8,7H  DELT=G15.8)
    12 FORMAT(6H ALT.=1PG14.7,14H R PATH ANGLE=G15.8,7H  DRAG=G15.8,4H VR
      1=G15.8,3H G=G15.8,7H  PUSH=G15.8)
    13 FORMAT(2(1X,A6,3H R=1PG14.7,0P3F10.6,11X))
       END

                                                FUNCTION QUAD (X,IC)
C      THIS ROUTINE COMPUTES ANY VARIABLE, QUAD, AS A QUADRATIC FUNCTION OF X.
C      QUAD = A + BX + CXX.  THERE MAY BE SEVERAL SETS OF COEFFIENTS, EACH SET
C      BELONGING TO A PARTICULAR REGION OF X.  THE COEFN ARRAY IS ARRANGED AS --
C         X1,A1,B1,C1,X2,A2,B2,C2,X3,A3,B3,C3,X4, ..............
C      WHERE  A1,B1,C1 ARE THE COEFFIENTS TO BE USED FOR X BETWEEN X1 AND X2,ETC.
C      AND X1 IS LESS THAN X2, X2 IS LESS THAN X3, X3 IS LESS THAN X4, ETC.
C      IC IDENTIFIES WHICH DEPENDENT VARIABLE, QUAD, IS BEING SOUGHT.
C      ICC(IC) DEFINE THE STARTING LOCATIONS IN THE COEFN ARRAY FOR VARIABLES X.

       COMMON C
C
       DIMENSION A(600), B(700), C(4000),
      1   COEFN(190), ICC(5)
C
       EQUIVALENCE
      1(A      ,C      (  11)),(B      ,C      (1111)),(COEFN ,A      ( 407)),
      2(ICC    ,A      ( 153))
C
       I=ICC(IC)
     1 IF (X-COEFN(I)) 2,3,3
     2 I = I-4
       GO TO 1
     3 IF(X-COEFN(I+4)) 5,5,4
     4 I = I+4
       GO TO 3
     5 QUAD = COEFN(I+1)+X*(COEFN(I+2)+X*COEFN(I+3))
       ICC(IC)=I
       RETURN
       END


                                                      SUBROUTINE STAGE
C      THIS ROUTINE IS CALLED TO PREPARE DATA FOR USE IN NBODY.  STAGE DATA IS
C      TAKEN FROM PERMINENT STORES AND LOADED INTO WORKING STORES.  STAGE DATA
C      MAY BE SET ASIDE FOR LATER USE (IF ON NSAVE-NSTAGE).  WHEN IMODE IS 4,
C      CONVERSION FROM EARTH-SPHERICAL TO RECTANGULAR OR ORBIT ELEMENTS TAKES
C      PLACE IN TUDES.
C
       COMMON C
C
       DIMENSION A(600), B(700), C(4000),
      1XPRIM(200),XPRIMB(200),TB(10),FLOW1(10),AEXIT1(10),SIMP1(10),
      2AREA1(10),DELT1(10),IDENT(10),TABLE(200),RMASS1(10),D(600)
C
       EQUIVALENCE
      1(A      ,C      (  11)),(AEXIT ,B      (   3)),(AEXIT1,A      ( 103)),
      2(AREA1  ,A      ( 113)),(AREA  ,B      (   6)),(B      ,C      (1111)),
      3(DELT1  ,A      ( 133)),(DELT  ,B      (   1)),(D      ,C      (2111)),
      4(DEL    ,A      (  43)),(DELMAX,A      (  19)),(DONE   ,B      (  39)),
      5(EREF   ,A      (  13)),(ERLOG ,B      (  17)),(EXITA  ,B      ( 392)),
      6(FLOW   ,B      (   5)),(FLOW1 ,A      (  83)),(IDENT  ,A      ( 123)),
      7(IMODE  ,A      (   1)),(LSTAGE,A      (  38)),(MODOUT,A      (  20)),
      8(NCASE  ,C      (   1)),(NCASES,A      ( 600)),(NSAVE  ,C      (   4)),
      9(NSTAGE,A       (   3)),(PUSHO ,B      ( 391)),(RMASS1,A      (  73))
       EQUIVALENCE
      1(SIMP1  ,A      (  93)),(SIMP  ,B      (   2)),(TB     ,A      (  63)),
      2(TABLE  ,C      (1911)),(TKICK ,A      (  15)),(TMAX   ,B      (   4)),
      3(TTOL   ,A      (  45)),(XPRIMB,C      ( 911)),(XPRIM  ,C      ( 711)),
      4(RETURN,B       ( 400)),(OUTPOT,B      ( 399))
C
```

```
C     PART 0. SAVE INITIAL DATA IF DESIRED.  LOAD STAGE DATA INTO WORKING
C     STORAGE.  ALLOW ADDITIONAL STAGE INPUT.
      IF (DEL) 100,99,100
   99 DEL = DELMAX-TKICK
  100 IF (NSAVE-NSTAGE) 103,101,103
  101 NCASES = NCASE
      DO 102 J=1,1100
  102 D(J) = A(J)
      IF (OUTPOT) 103,97,103
   97 WRITE OUTPUT TAPE 6,98,NSTAGE,NCASE
   98 FORMAT(29H SAVED INITIAL DATA FOR STAGEI2,8H OF CASEI4,1H.)
  103 NSTAGE = NSIAGE
      TMAX = XPRIM(1)+TB(NSTAGE)
      XPRIMB(2) = 0.
      IF (RMASS1(NSTAGE)) 117,117,118
  117 XPRIM(2) = XPRIM(2)+RMASS1(NSTAGE)
      GO TO 119
  118 XPRIM(2) = RMASS1(NSTAGE)
  119 FLOW = FLOW1(NSTAGE)
      SIMP = SIMP1(NSTAGE)
      AEXIT = AEXIT1(NSTAGE)
      AREA = AREA1(NSTAGE)
      DELT = DELT1(NSTAGE)
      ID = IDENT(NSTAGE)
    3 CALL INPUT (ID,C,TABLE)
      ERLOG = LOGF(ABSF(EREF))
      TTOL = 5E-8*ABSF(TMAX)+1E-8
      PUSHO = SIMP*FLOW*9.80665
      EXITA = AEXIT*100.
      MODOUT = MODOUT
      IF (DELT) 105,104,105
  104 DELT = TB(NSTAGE)/100.
      DELT1(NSTAGE) = DELT
  105 GO TO (109,106,106,109), MODOUT
  106 IF (DEL-DELMAX) 108,108,107
  107 DEL = MODF(DEL,DELMAX)
  108 IF (DEL) 114,109,114
  114 DELT = MINIF(DELT,DEL)
  109 IF (XABSF(IMODE)-4) 1,110,1
  110 CALL TUDES
      IMODE = XSIGNF(2,IMODE)
    1 CALL NBODY
    2 CALL EXTRAS
C
C     PART 9. COMES HERE FOR END OF SUB TRAJECTORY.
      IF (DONE) 113,111,111
  111 DONE = 0.
      IF (NSTAGE-LSTAGE) 112,115,115
  112 NSTAGE = NSTAGE+1
      GO TO 100
  113 DONE = 0.
  115 CALL EXTRA
      IF (RETURN) 103,116,100
  116 RETURN
      END
                                                      SUBROUTINE STEP
C   SUBROUTINE STEP TESTS FOR THE END OF THE PROBLEM, COMPUTES STEP SIZE, AND
C   CONTROLS QUANTITY OF OUTPUT DATA.  END OF PROBLEM OCCURS IF TIME = TMAX,
C     STEPGO+STEPNO = STEPMX, OR C(LOOKX) = XLOOK.  THE LAST OPTION ALLOWS STOP-
C     PING ON A DEPENDENT VARIABLE.  THE TEST FOR STOPPING AT XLOOK IS NOT MADE
C     UNTIL C(LOOKSW) IS GREATER THAN SWLOOK. CONTROL ON QUANTITY OF OUTPUT IS
C
C     MODOUT=1  OUTPUT EVERY NTH STEP(N=STEPS) UNTIL TIME = TMIN, THEN
C                   GO TO MODE 2 .
C            2  OUTPUT AT INTERVALS OF DELMAX UNTIL TIME = TMAX.
C            3  OUTPUT AT INTERVALS OF DELMAX UNTIL TIME = TMIN, THEN
C                   GO TO MODE 4 .
C            4  OUTPUT EVERY NTH STEP UNTIL TIME = TMAX.
C

      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1   XPRIM(200),   DELT1 (10)
C
      EQUIVALENCE
     1(A      ,C      (   11)),(A1     ,B      (   10)),(A2     ,B      (   11)),
     2(B      ,C      (1111)),(DELMAX,A      (   19)),(DEL    ,A      (   43)),
     3(DELT   ,B      (    1)),(DONE   ,B      (   39)),(E2     ,B      (   18)),
     4(END    ,A      (    5)),(ERLOG ,B      (   17)),(H2     ,B      (   15)),
     5(INLOOK,A      (  599)),(LOOKSW,A      (    9)),(LOOKX ,A      (    8)),
     6(MODOUT,A      (   20)),(NSTAGE,A      (    3)),(DELT1 ,A      (  133)),
     7(RATIO ,B      (   58)),(SIGNAL,B      (   31)),(SPACES,B      (   16)),
     8(STEPGO,A      (   41)),(STEPMX,A      (   16)),(STEPNO,A      (   42)),
     9(STEPS ,A      (   17)),(SWLOOK,A      (   10)),(TABLE ,C      (1911))
      EQUIVALENCE
     1(TMAX   ,B      (    4)),(TMIN   ,A      (   18)),(TTOL   ,A      (   45)),
     2(XLOOK ,A      (   12)),(XPRIM ,C      ( 711)),(XTOL   ,A      (   11)),
     3(NSTART,B      (   24)),(SWITCH,A      (601)),(OUTPOT,B      ( 399))
      CHECKF(A,B,C) = ABSF(A-B) - ABSF(A-C)
C
C     PART 1.  TEST FOR END OF THE PROBLEM (MAXIMUM PROBLEM TIME OR MAXIMUM
C              NUMBER OF STEPS).
      STEPGO = STEPGO + 1.
      OUT = OUTPOT
      IF (ABSF(TMAX-XPRIM(1))-TTOL) 1,1,3
    1 DONE = 1.0
  112 CALL OUTPUT
      IF (OUTPOT) 26,111,26
  111 WRITE OUTPUT TAPE 6,2,NSTAGE
    2 FORMAT(6HOSTAGEI2,11H COMPLETED.//)
      GO TO 26
    3 IF (STEPGO+STEPNO-STEPMX) 7,4,4
    4 CALL OUTPUT
      WRITE OUTPUT TAPE 6,5,STEPMX
    5 FORMAT (22HOSTEPGO+STEPNO=STEPMX=F6.)
      CALL EXIT
C
```

```
C       PART 2.  COMPUTE STEP SIZE (DELT) AND CONTROL OUTPUT.
      7 N=1
        A3 = (A2-A1)*RATIO+A2
        AA = (ERLOG-A3)/5.
        IF ((ABSF(AA)-88.028)*ABSF(SWITCH)) 8,8,60
      8 DELT = SIGNF(EXPF(AA),DELT)
        IF (DELT/H2-3.) 10,10,9
      9 DELT = 3.*H2
     10 MODOUT = MODOUT
        GO TO (11,15,13,21),MODOUT
     11 IF(DELT*(XPRIM(1) + 3.*DELT-TMIN)) 21,12,12
     12 MODOUT = 2
        DEL = TMIN - XPRIM(1)
        GO TO 16
     13 IF(DELT * (XPRIM(1) - TMIN)) 15,15,14
     14 MODOUT = 4
        GO TO 21
     15 DEL = DEL-H2
     16 SPACES = INTF((DEL/DELT)+SIGNF(.9,(DEL/DELT)))
     17 IF(SPACES) 20, 18,20
     18 CALL OUTPUT
        N=2
        DEL = DELMAX
        IF (ABSF(DEL) - ABSF(DELT)) 19,16,16
     19 DELT = SIGNF(DEL,DELT)
        GO TO 16
     20 DELT = DEL/SPACES
        GO TO 23
     21 IF (MODF(STEPGO,STEPS)) 23,22,23
     22 CALL OUTPUT
        N=2
C
C       PART. 3.  SEARCH FOR C(LOOKX) = XLOOK UNLESS LOOKX=0.
     23 IF(LOOK X) 27,42,27
     27 LOOK X = LOOK X
        LOOK SW = LOOK SW
        OUTPOT = 1.
        GO TO (44,45),N
     44 CALL OUTPUT
     45 IF(SWITCH) 32,28,33
     28 IF(SW LOOK - C(LOOK SW)) 29,29,42
     29 XTOL1 = XTOL*ABSF(XLOOK)
        IF (XTOL1) 31,30,31
     30 XTOL1 = XTOL
     31 SWITCH = -1.
        GO TO 41
     32 SWITCH = 1.
        ASSIGN 43 TO MODE
        OVER = 0.
        F = 0.
        T=0.
     33 SLOPE = (C(LOOKX)-OLDX)/H2
        GO TO MODE, (43,35)
     43 IF(SLOPE *(C(LOOK X) - X LOOK)) 350,41,41
    350 ASSIGN 35 TO MODE
     35 IF(ABSF(C(LOOK X)- X LOOK) - XTOL1) 36,36,37
     60 T=1.
     36 IF (OUT) 63,46,63
     46 OUTPOT = 0.
        CALL OUTPUT
     63 IF (T) 61,47,61
     61 IF (OUT) 62,51,62
     51 WRITE OUTPUT TAPE 6,64, LOOKX,C(LOOKX),H2,LOOKX,SLOPE
     64 FORMAT(3H0C(I4,4H) = 1PG15.8,31H   CONVERGENCE TROUBLE.   DELT=
       1G15.8,14H   SLOPE OF C(I4,13H) VS. TIME = G15.8//)
        GO TO 62
     47 IF (OUT) 62,50,62
     50 WRITE OUTPUT TAPE 6,48,LOOK X, C(LOOK X)
     48 FORMAT(3H0C(I4,2H)=1PG15.8//)
     62 LOOKX = 0
        XTOL1 = 0.
        SIGNAL = 1.
        SWITCH = 0.
        DONE = END
        NSTART = 0
        NSTAGE=NSTAGE
        DELT = DELT1(NSTAGE)
     49 CALL INPUT(INLOOK,C,TABLE)
        IF (DONE) 110,42,110
    110 IF (OUT) 26,111,26
     37 SIGN = CHECKF(OLDX,XLOOK,C(LOOK X))
        IF(SIGN) 40,40,38
     40 OVER = 1.
        GO TO 400
     38 IF (OVER) 400,401,400
    401 XGUESS = C(LOOKX)+SLOPE*DELT
        IF (CHECKF(C(LOOKX),XLOOK,XGUESS)) 402,41,41
    402 F = F+1.
        IF (F-7.) 400,400,403
    403 SLOPE = SLOPE/F
    400 IF (SLOPE) 404,60,404
    404 DELT = SIGNF(ABSF(XLOOK-C(LOOKX))/SLOPE,SIGN*H2)
     41 OLDX = C(LOOK X)
     42 IF (ABSF(TMAX-XPRIM(1))-ABSF(DELT)) 25,26,26
     25 DELT = TMAX-XPRIM(1)
        GO TO (26,24,24,26),MODOUT
     24 DEL = DEL-DELT
     26 OUTPOT = OUT
        RETURN
        END
```

```
                                                 SUBROUTINE STDATA
C     THIS ROUTINE CLEARS THE A, XPRIM, XPRIMB ARRARYS AND LOADS A SET OF
C     STANDARD DATA INTO THE MACHINE.  ANY VALUES SET HERE MAY BE OVERWRITTEN BY
C     INPUT 1 IN THE MAIN PROGRAM.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1    PNAME (12),          AMASS (30),          XPRIM (200),
     2                         COEFN (190),           ICC (4),
     3       AK (3),            XDOT (100),           IND (3),
     4     REFER (12),         RCRIT (30),             AW (4),
     5   RMASS1 (10)
C
      EQUIVALENCE
     1(A     ,C     (  11)),(AK    ,A     (  51)),(AMASS ,A     ( 347)),
     2(AU    ,A     (  29)),(AW    ,A     (  55)),(B     ,C     (1111)),
     3(BODYCD,A     ( 143)),(COEFN ,A     ( 407)),(CONSTU,A     (  32)),
     4(CONSU ,A     (  31)),(DTOFFJ,A     (  23)),(EREF  ,A     (  13)),
     5(ERLIMT,A     (  14)),(ETOL  ,A     (  30)),(GASFAC,A     (  46)),
     6(ICC   ,A     ( 153)),(IMODE ,A     (   1)),(IND   ,A     (  60)),
     7(LOOKSW,A     (   9)),(MODOUT,A     (  20)),(NEQ   ,A     (   2)),
     8(NSTAGE,A     (   3)),(OBLATD,A     (  27)),(OBLATH,A     (  28)),
     9(OBLATJ,A     (  26)),(PNAME ,A     ( 287)),(RCRIT ,A     ( 377))
      EQUIVALENCE
     1(REFER ,A     ( 317)),(RE    ,A     (  25)),(SPD   ,A     (  44)),
     2(SQRDK1,A     (  47)),(STEPMX,A     (  16)),(STEPS ,A     (  17)),
     3(TFILE ,A     (   6)),(XDOT  ,B     ( 501)),(XPRIM ,C     ( 711)),
     4(XTOL  ,A     (  11)),(RMASS1,A     (  73))
C
C     CLEAR INITIAL CONDITIONS AND CONTROL PARAMETERS.
      DO 1 J=1,1100
    1 A(J) = 0.
C
C     THE FOLLOWING NH STATEMENTS LOAD THE BODY NAMES INTO THE MACHINE.
      PNAME(1) = 3HSUN
      PNAME(2) = 6HMERCUR
      PNAME(3) = 5HVENUS
      PNAME(4) = 5HEARTH
      PNAME(5) = 4HMARS
      PNAME(6) = 6HJUPITE
      PNAME(7) = 6HSATURN
      PNAME(8) = 6HURANUS
      PNAME(9) = 6HNEPTUN
      PNAME(10)= 5HPLUTO
      PNAME(11)= 4HMOON
      PNAME(12)= 6HEARTHM
C
C     FILL OUT SUN REFERENCE LIST.  INITIALIZE MASS ARRAY.
      DO 2 K=1,10
      RMASS1(K) = 1.
    2 REFER(K+1) = PNAME(1)
      REFER(12) = PNAME(1)
C
C     FILL OUT EARTH REFERENCE LIST.
      REFER(1) = PNAME(4)
      REFER(4) = 5HZERO+
      REFER(11) = PNAME(4)
C
```

```
C     LOAD THE REMAINING STANDARD DATA.
      AK(1) = 0.5
      AK(2) = 0.5
      AK(3) = 1.0
      AMASS(1) = 1.0
      AMASS(2) = 1.0/6120000.0
      AMASS(3) = 1.0/408645.0
      AMASS(4) = 1.0/332951.3
      AMASS(5) = 1.0/3088000.0
      AMASS(6) = 1.0/1047.39
      AMASS(7) = 1.0/3500.0
      AMASS(8) = 1.0/22869.0
      AMASS(9) = 1.0/18889.0
      AMASS(10) = 1.0/400000.0
      AMASS(11) =AMASS(4)/81.335
      AMASS(12) =AMASS(4)+ AMASS(11)
      AU = 1.49599 E11
      AW(1)=1./6.
      AW(2)=AW(1)+AW(1)
      AW(4)=AW(1)
      AW(3)=1.-(AW(2)+(AW(1)+AW(4)))
      BODYCD = PNAME(4)
      COEFN(1) = -1E20
      COEFN(189) = 1E20
      CONSTU = 1.0 E-6
      CONSU = 1E-6
      ETOL = 0.01
      DTOFFJ = 244.E4
      EREF = 1E-6
      ERLIMT = 3E-6
      GASFAC = 20.064881
      ICC(1) =185
      ICC(2) =185
      ICC(3) =185
      ICC(4) =185
      IMODE = 1
      IND(1)=2
      IND(2)=3
      IND(3)=1
      LOOKSW = 711
      MODOUT = 4
      NEQ=8
      NSTAGE = 1
      OBLATJ = 1.62345 E-3
      OBLATH = -5.75 E-6
      OBLATD = 7.875 E-6
      RCRIT(1) = 1.0 E+20
      RCRIT(2) = 1.0 E+8
      RCRIT(3) = 6.14 E+8
      RCRIT(4) = 9.25 E+8
      RCRIT(5) = 5.78 E+8
      RCRIT(6) = 4.81 E+10
      RCRIT(7) = 5.46 E+10
      RCRIT(8) = 5.17 E+10
      RCRIT(9) = 8.61 E+10
      RCRIT(10) =3.81 E+10
      RCRIT(11) =1.60 E+8
      RE = 6378165.
      SPD = 86400.0
      SQRDK1 = 2.959122083 E-4
      STEPMX= 100.0
      STEPS = 1.
      TFILE = 1.
      XDOT(1) = 1.0
      XPRIM(2) = RMASS1(1)
      XTOL = 5E-8
      WRITE OUTPUT TAPE 6,3
    3 FORMAT (15HOSTANDARD DATA.)
      RETURN
      END
```

```
                                              SUBROUTINE TESTTR
C     SUBROUTINE TESTTR MAY BE CALLED FOR ONE OF TWO REASONS, (1) TO TEST FOR AND
C     POSSIBLY TRANSLATE THE ORIGIN (WHEN IMODE IS +) OR (2) TO CHANGE THE
C     VARIABLES OF INTEGRATION (WHEN IMODE IS -).  A TRANSLATION OF THE ORIGIN
C     OCCURS WHEN THE OBJECT MOVES INTO A SPHERE OF INFLUENCE WHICH IS SMALLER
C     THAN ANY OTHERS IT MAY ALSO BE IN.  WHEN THIS HAPPENS, THE NAME OF THE NEW
C     ORIGIN IS MOVED TO THE BEGINNING OF THE BNAME LIST AND ORDER IS
C     CALLED TO REORDER THE BNAME LIST.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1     XPRIM(100,2),XPRIMB(100,2),XWHOLE(6),VEFM(3,8),VX(3),
     2ORBELS(6),BMASS(8),BNAME(8),RB(3,8),RBCRIT(8),R(8)
C
      EQUIVALENCE
     1(A     ,C     (  11)),(AMC   ,B     (  87)),(ASYMPT,A     (   7)),
     2(B     ,C     (1111)),(BMASS ,B     ( 137)),(BNAME ,B     ( 122)),
     3(CHAMP ,B     (  25)),(DELT  ,B     (   1)),(GK2M  ,B     (  36)),
     4(IMODE ,A     (   1)),(NBODYS,B     (  41)),(ORBELS,B     ( 116)),
     5(RBCRIT,B     ( 145)),(RB    ,B     ( 193)),(REVS  ,A     (  48)),
     6(R     ,B     ( 102)),(SQRDK ,B     (  35)),(TABLE ,C     (1911)),
     7(TMAX  ,B     (   4)),(TRSFER,B     (   8)),(TRU   ,B     (  40)),
     8(TTEST ,A     (  54)),(VEFM  ,B     ( 241)),(VX    ,B     (  92)),
     9(XPRIM ,C     ( 711)),(XPRIMB,C     ( 911)),(XWHOLE,B     ( 110))
      EQUIVALENCE
     1(OUTPOT,B     ( 399))
C
      IMODE = IMODE
      IF (IMODE) 12,12,1
C
C     IF IMODE IS +, TEST FOR TRANSLATION OF THE ORIGIN.
    1 CHAMP= 1.E+30
      DO 4 JB=1,NBODYS
      IF (R(JB)-RBCRIT(JB)) 2,4,4
    2 IF (CHAMP-RBCRIT(JB)) 4,4,3
    3 CHAMP = RBCRIT(JB)
      NCHAMP = JB
    4 CONTINUE
      IF (NCHAMP-1) 26,26,5
    5 TRSFER = 1.0
    8 BTEMP = BNAME(1)
      BNAME(1) = BNAME(NCHAMP)
      BNAME(NCHAMP) = BTEMP
      TTEST = 0.
      REVS = 0.
      IF (OUTPOT) 6,9,6
    9 WRITE OUTPUT TAPE 6,10,BNAME(NCHAMP),BNAME(1)
   10 FORMAT (28HOORIGIN IS TRANSLATING FROM A6,4H TO A6)
    6 CALL EPHMRS
      DO 11 K=1,3
      VX(K) = VX(K)-VEFM(K,NCHAMP)
      RB(K) = RB(K,NCHAMP)
      XPRIM(K+2,1)=VX(K)
      XPRIM(K+5,1)=RB(K)
      XPRIMB(K+2,1) = 0.
      XPRIMB(K+5,1) = 0.
      XWHOLE(K)= VX(K)
   11 XWHOLE(K+3) = RB(K)
      GO TO 20
C
C     IF IMODE IS -, CHANGE THE VARIABLES OF INTEGRATION.
   12 DO 13 K=1,3
      XPRIM(K+2,1)=XWHOLE(K)
      XPRIM(K+5,1)=XWHOLE(K+3)
      XPRIMB(K+2,1) = 0.
      XPRIMB(K+5,1) = 0.
      VX(K) = XWHOLE(K)
   13 RB(K) = XWHOLE(K+3)
      GO TO (16,14,15),IMODE
   14 CODE = 5HORBIT
      IMODE = 1
      GO TO 18
   15 IMODE = 3
      GO TO 17
   16 IMODE = 2
   17 CODE = 6HRECTAN
   18 NCHAMP = 1
      IF (OUTPOT) 20,7,20
    7 WRITE OUTPUT TAPE 6,19,CODE
   19 FORMAT (33HOINTEGRATION MODE IS CHANGING TO A6)
   20 GO TO (21,26,26),IMODE
   21 CALL CONVT1(VX,AMC)
      GK2M= SQRDK*(BMASS(NCHAMP)+XPRIM(2,1)/1.9866 E+30)
   30 CALL CONVT2
C     IF ORIGIN TRANSLATION CAUSES PATH TO LIE NEAR AN ASYMPTOTE, CHANGE
C     INTEGRATION VARIABLES TO RECTANGULAR IF THEY ARE ORBIT ELEMENTS.
      IF (ORBELS(1)-1.) 24,24,22
   22 IF (ABSF(TRU)-2.3/SQRTF(ORBELS(1))) 24,24,23
   23 ASYMPT = 1.0
      GO TO 15
   24 DO 25 J=1,6
   25 XPRIM(J+2,1) = ORBELS(J)
   26 IF (TRSFER) 27,28,27
   27 CALL INPUT (101,C,TABLE)
   29 CALL ORDER
   28 RETURN
      END
```

```
                                                  SUBROUTINE THRUST
C     THIS ROUTINE COMPUTES X,Y,Z THRUST ACCELERATIONS.  THE THRUST VECTOR IS
C     ASSUMED COINCIDENT WITH THE LONGITUNDINAL AXIS OF THE VEHICLE, WHICH IS
C     ORIENTED TO THE RELATIVE WIND VELOCITY BY THE ANGLE OF ATTACK (ALPHA) AND
C     THE ROLL ANGLE (BETA). ALPHA IS ASSUMED TO BE A QUADRATIC FUNCTION OF TIME
C     WHEREAS BETA IS ASSUMED TO BE CONSTANT.
C     REVOLV IS THE EARTHS ROTATION RATE IN RADIANS/SEC (7.29211585E-5) AND THE
C     FACTOR 8589934592.= 2**33 IS REMOVED TO PREVENT OVERFLOW.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1 FORCE(3), PAR(3), VATM(3), P(3), IND(3),RAMC(5),RB(3),X(100)
C
      EQUIVALENCE
     1(A     ,C      (  11)),(AEXIT ,B      (   3)),(ALPHA ,A      (  49)),
     2(B     ,C      (1111)),(BETA  ,A      (  50)),(COSALF,B      (  48)),
     3(COSBET,B      (  49)),(EXITA ,B      ( 392)),(FLOW  ,B      (   5)),
     4(FORCE ,B      (  66)),(IND   ,A      (  60)),(PAR   ,B      (  60)),
     5(PMAGN ,B      (  50)),(PRESS ,B      (  33)),(P     ,B      (  84)),
     6(PUSHO ,B      ( 391)),(PUSH  ,A      ( 166)),(RAMC  ,B      ( 393)),
     7(RATMOS,B      (  23)),(RB    ,B      ( 193)),(REVOLV,B      (  21)),
     8(R     ,B      ( 102)),(RSQRD ,B      (  45)),(SIMP  ,B      (   2)),
     9(SINALF,B      (  46)),(SINBET,B      (  47)),(VATM  ,B      (  97))
      EQUIVALENCE
     1(VQ    ,B      ( 100)),(VQSQRD,B      ( 101)),(VX    ,B      (  92)),
     2(VY    ,B      (  93)),(VZ    ,B      (  94)),(X     ,B      ( 401))
C


      SINBET = SINF(BETA/57.2957795)
      COSBET = COSF(BETA/57.2957795)
      VATM(1)=VX+REVOLV*RB(2)
      VATM(2)=VY-REVOLV*RB(1)
      VATM(3)=VZ
    3 CALL CONVT1(VATM,RAMC)
    4 ALPHA = QUAD(X(1),1)/57.2957795
      SINALF=SINF(ALPHA)
      COSALF=COSF(ALPHA)
      DO 1 J1=1,3
      J2=IND(J1)
      J3=IND(J2)
    1 P(J1) = (VATM(J2)*RAMC(J3)-VATM(J3)*RAMC(J2))/8589934592.
      PMAGN= SQRTF(P(1)*P(1)+P(2)*P(2)+P(3)*P(3))
      PUSH = PUSHO-EXITA*PRESS
      TDPMAG = PUSH/PMAGN/X(2)
      R4    =  SINBET/VQ
      R5    =  COSALF/RAMC(4)
      DO 2 J1=1,3
      J2=IND(J1)
      J3=IND(J2)
      PAR(J1)=P(J2)*VATM(J3)-P(J3)*VATM(J2)
    2 FORCE(J1) = TDPMAG*(SINALF*(COSBET*P(J1)+R4*PAR(J1))-R5*(P(J2)*
     1               RAMC(J3)-P(J3)*RAMC(J2)))
      RETURN
      END


                                                  SUBROUTINE TUDES
C     THIS ROUTINE COMPUTES THE RECTANGULAR POSITION AND VELOCITY COMPONENTS
C     WITH RESPECT TO THE EARTH MEAN EQUINOX AND EQUATOR OF 1950.0 FROM THE
C     LATITUDE, LONGITUDE, AZIMUTH, ELEVATION, ALTITUDE, TOTAL VELOCITY, AND
C     TIME.  ALSO, WHEN TKICK DOES NOT EQUAL ZERO, A NON-DRAG VERTICAL STEP OF
C     SIZE TKICK IS MADE IN CLOSED FORM (STATEMENTS 2 TO 4).  THE INTEGRATION
C     WILL THEN BEGIN AT TIME EQUAL TO TIME+TKICK WITH THE ORIENTATION SPECIFIED
C     BY THE ABOVE FOUR ANGLES AND THE COMPUTED VALUES OF ALTITUDE AND VELOCITY.
C     FOR THE CLOSED FORM APPROXIMATION, A CONSTANT FLOW RATE (FLOW), VACUUM
C     SPECIFIC IMPULSE (SIMP) AND ENGINE EXIT AREA (AEXIT) ARE ASSUMED KNOWN.
C     THE ATMOSPHERIC PRESSURE IS TAKEN TO BE THE SEA LEVEL VALUE.
C
      COMMON C
C
      DIMENSION A(600), B(700), C(4000),
     1   SINA(4), COSA(4), ANGLEB(4), XPRIM(200)
C
      EQUIVALENCE
     1(A     ,C      (  11)),(AEXIT ,B      (   3)),(ALT   ,A      (   4)),
     2(AZI   ,A      (  35)),(B     ,C      (1111)),(DTOFFJ,A      (  23)),
     3(ELEV  ,A      (  36)),(FLOW  ,B      (   5)),(GK2M  ,B      (  36)),
     4(LAT   ,A      (  33)),(LONG  ,A      (  34)),(OBLATJ,A      (  26)),
     5(OBLATN,A      (  40)),(RE    ,A      (  25)),(RESQRD,B      (   7)),
     6(ROTATE,A      (  39)),(SIMP  ,B      (   2)),(SPD   ,A      (  44)),
     7(STEPGO,A      (  41)),(STEPNO,A      (  42)),(TKICK ,A      (  15)),
     8(TOFFT ,A      (  24)),(VEL   ,A      (  37)),(XPRIM ,C      ( 711)),
     9(OUTPOT,B      ( 399))
      EQUIVALENCE (QLAT,LAT),( QLONG,LONG)
C
```

```
      ALT1 = 0.
      VEL1 = VEL
      DEL1 = 0.
      DEL = 0.
      ASSIGN 1 TO NGO
      DAYS = DTOFFJ - 2433282.5
      GREEN = MODF(100.0755426+.985647346DAYS+2.9015E-13DAYS**2
     1+7.29211585E-5*(TOFFT*SPD+XPRIM(1))*57.2957795,360.)
      SINA(1) = SINF(QLAT/57.2957795)
      IF (OBLATN) 102,101,102
  101 RADIUS = RE + ALT
      GO TO 8
  102 RADIUS=6356783.28/SQRTF(.9933065783+.006693421685*SINA(1)**2)+ALT
      GO TO 8
    1 XPRIM(6) = COSA(2)*COSA(1)*RADIUS
      XPRIM(7) = SINA(2)*COSA(1)*RADIUS
      XPRIM(8) = SINA(1)*RADIUS
      RMASSO = XPRIM(2)
      XPRIM(2) = XPRIM(2)-FLOW*TKICK
      IF (OUTPOT) 12,11,12
   11 WRITE OUTPUT TAPE 6,3,STEPGO,STEPNO,LAT,LONG,AZI,ELEV,ALT,XPRIM(
     11),VEL,RMASSO,(XPRIM(J),J=6,8)
    3 FORMAT(6H0STEP=F5.,2H +F4.,4X,6H LAT.=1PG15.8,7H LONG.=G15.8,6H AZ
     1I.=G15.8,7H ELEV.=G15.8,6H ALT.=G15.8/6H TIME=G15.8,6H VEL.=G15.8,
     67H RMASS=G15.8,4X,2HX=G15.8,5X,2HY=G15.8,4X,2HZ=G15.8)
   12 IF (TKICK) 2,50,2
    2 XPRIM(1) = XPRIM(1)+TKICK
      B1 = LOGF(RMASSO/XPRIM(2))
      SIMPSL = SIMP-AEXIT/FLOW*10332.275
      VEL1 = VEL+SIMPSL*9.80665*B1-G*TKICK
      ALT1 = TKICK*(VEL-G*TKICK/2.+9.80665*SIMPSL*(1.-B1*XPRIM(2)/
     1      (RMASSO-XPRIM(2))))
    4 RADIUS = RADIUS + ALT1
      GREEN = GREEN + 7.29211585E-5*TKICK*57.2957795
      ASSIGN 5 TO NGO
      GO TO 8
    5 XPRIM(6) = COSA(2)*COSA(1)*RADIUS
      XPRIM(7) = SINA(2)*COSA(1)*RADIUS
      XPRIM(8) = SINA(1)*RADIUS
   50 IF (OBLATN) 6,7,6
    6 DEL1 = ATANF((C2-1.)/(C3-1.)*SINA(1)/COSA(1))*57.2957795-QLAT
    7 DEL2 = RADIUS/G*SINA(1)*COSA(1)*ROTATE*ROTATE*57.29577951
      DEL = DEL1 + DEL2
      ASSIGN 10 TO NGO
    8 ANGLEB(1) = QLAT + DEL
      ANGLEB(2) = QLONG + GREEN
      ANGLEB(3) = AZI
      ANGLEB(4) = ELEV
      DO 9 I=1,4
      SINA(I) = SINF(ANGLEB(I)/57.2957795)
    9 COSA(I) = COSF(ANGLEB(I)/57.2957795)
      C1 = 5.*RESQRD/RADIUS/RADIUS*OBLATJ
      C2 = C1*(SINA(1)*SINA(1)-.6)
      C3 = C1*(SINA(1)*SINA(1)-.2)
      G = GK2M/RADIUS/RADIUS
      GO TO NGO, (1,5,10)
   10 COS1 = COSA(1)*SINA(4)-COSA(4)*COSA(3)*SINA(1)
      COS2 = COSA(4)*SINA(3)
      XPRIM(3) = VEL1*(COS1*COSA(2)-COS2*SINA(2))-XPRIM(7)*ROTATE
      XPRIM(4) = VEL1*(COS1*SINA(2)+COS2*COSA(2))+XPRIM(6)*ROTATE
      XPRIM(5) = VEL1*(SINA(1)*SINA(4)+COSA(1)*COSA(3)*COSA(4))
      RETURN
      END

                                                    SUBROUTINE TAPE
C     SUBROUTINE IAPE USES THE MASTER MERGED EPHEMERIDES TAPE (TAPE 9 AT LEWIS)
C     TO COMPILE A WORKING EPHEMERIS TAPE (TAPE 3 AT LEWIS) WHICH CONTAINS ONLY
C     THAT DATA NEEDED AT EXECUTION TIME.  THIS MINIMIZES TAPE HANDLING DURING
C     EXECUTION.  2 EPHEMERIS FILES ARE ON TAPE 9, FIRST FILE HAS DATA AND IS
C     IDENTIFIED BY THE SECOND WORD OF EACH 254 WORD RECORD (FIRST WORD IS THE
C     DUMMY FORTRAN COMPATIBLE WORD, SECOND WORD=2).  THE SECOND FILE IS ONLY 2
C     WORDS LONG, FIRST WORD IS FORTRAN COMPATIBLE, SECOND WORD=3).
C     MASTER FILE 1 -- PLANETS (EXCEPT MERCURY AND EARTH), SUN, MOON, AND
C                      EARTH-MOON BARYCENTER FROM SEPT.25, 1960 TO ABOUT 2000.
C     EACH EPHEMERIS COMPILED REQUIRES A SET OF INPUT 300 DATA.  THE FIRST PIECE
C     OF DATA WRITTEN ON A FILE IS THE FILE IDENTIFICATION NUMBER, FILE.  EACH
C     FILE IS NUMBERED CONSECUTIVELY STARTING WITH FILE=1. SINCE MOON DATA IS IN
C     TERMS OF EARTH RADII, THE CONVERSION OF MOON DATA TO A.U. IS MADE BEFORE
C     WRITING ON TAPE 3.  THE COMMON USED IN SUBROUTINE TAPE IS LOCAL AND ALL
C     BUT TAPE3 IS CLEARED BY A FINAL CLEARING LOOP.
C     FUNCTION COMPARF(A,B) IS EQUIVALENT TO (A-B) BUT WILL NOT OVERFLOW.
C     NORMAL INPUT - ELIST, TBEGIN, TEND, TAPE3
C
C     ELIST-  THE BCD LIST OF EPHEMERIS DATA NAMES TO BE PLACED ON
C             TAPE 3 .  THE NAMES ARE READ FROM CARDS,  AND IS USED TO
C             MAKE THE TMAKE LIST. ELIST IS NOT CHANGED IN STORAGE UNTIL
C             THE FINAL CLEAR FOR THIS SUBROUTINE.
C     TMAKE-  THE LIST OF EPHEMERIS NAMES WITH DUPLICATES DROPPED AND
C             ZERO SPACES CLOSED IN. AS THE EPHEMERIDES ARE FINISHED THE
C             NAMES ARE ERRASED FROM THIS LIST.
C     TMADE-  LIKE TMAKE BUT IS HELD FOR OUTPUT.
C     TBEGIN- THE BEGINNING DATE  EXPRESSED AS A JULIAN DAY.
C     TEND-   ENDING DATE EXPRESSED AS A JULIAN DAY.
C     INTVAL- THE APPROX. NUMBER OF DAYS COVERED BY ONE SET OF COEFF. IT
C             IS USED TO DECIDE WHICH DATA ARE TO BE ENTERED DOUBLE. THE
C             DOUBLE ENTRIES PERMIT FASTER OPERATION IF REVERSAL OF
C             INTEGRATION IS REQUIRED FOR ANY REASON.
C     EDATE-  JULIAN ENDING DATE FOR THE MASTER EPHEMERIS.
C     ERTOAU- EARTH RADII PER A.U.
C
      COMMON   C
C
```

```
      DIMENSION
     1        C (700),        TMAKE (12),           LIST (30),
     2    EDATE (12),        INTVAL (30),           KTAG (12),
     3    ELIST (11),         TMADE (12),          INTVA (2),
     4    PNAME (30),        TDATUM (252),        DATUMT (21,12)
C
      EQUIVALENCE
     1( TAPE3,C(  2)),(ERTOAU,C(  3)),(  KTAG,C(  4)),(  FILE,C( 16)),
     2( ELIST,C( 17)),(TBEGIN,C( 29)),(  TEND,C( 30)),( PNAME,C( 31)),
     3( KHAMP,C( 61)),( TMADE,C( 73)),( TMAKE,C( 85)),(TDATUM,C(441)),
     4( EDATE,C(127)),(INTVAL,C(157)),( INTVA,C(156)),(DATUMT,C(189))
C
B     COMPARF(A,B) = (A+B)*(-(A*B))
      REWIND 3
      DO 1  K=1,4000
    1 C(K) = 0.0
C
C     THE FOLLOWING NH STATEMENTS LOAD THE BODY NAMES INTO THE MACHINE.
C     NOTE.  THE EARTH IS NOT IN THIS LIST (NO EPHEMERIS FOR EARTH.)
      PNAME(1) = 3HSUN
      PNAME(2) = 6HMERCUR
      PNAME(3) = 5HVENUS
      PNAME(4) = 4HMARS
      PNAME(5) = 6HJUPITE
      PNAME(6) = 6HSATURN
      PNAME(7) = 6HURANUS
      PNAME(8) = 6HNEPTUN
      PNAME(9) = 5HPLUTO
      PNAME(10)= 4HMOON
      PNAME(11)= 6HEARTHM
C
C     PART 2.  SET UP JULIAN DATES ENDING EACH EPHEMERIS.
      EDATE(1) = 2451872.5                                              11/24/00
      EDATE(3) = 2451848.5                                              10/31/00
      EDATE(4) = 2451020.5                                               7/26/98
      EDATE(5) = 2473520.5                                                  2060
      EDATE(6) = 2473520.5                                                  2060
      EDATE(7) = 2473520.5                                                  2060
      EDATE(8) = 2473520.5                                                  2060
      EDATE(9) = 2473520.5                                                  2060
      EDATE(10)= 2440916.5                                              11/26/70
      EDATE(11)= 2451848.5                                              10/31/00
      INTVA  = 30000
      INTVAL(1) = 8
      INTVAL(2) = 5
      INTVAL(3) = 15
      INTVAL(4) = 44
      INTVAL(5) = 330
      INTVAL(6) = 825
      INTVAL(7) = 1211
      INTVAL(8) = 1172
      INTVAL(9) = 1101
      INTVAL(10) = 2
      INTVAL(11) = 15
      FILE = 1.
      ERTOAU = 4.26546512 E-5
    2 MOON = 0
      LI = 1
C
C     PART 2B. CALL INPUT AND SEE IF TAPE IS TO BE MADE.  INPUT  MUST ALWAYS
C              MAKE TAPE3=0.0 IF TAPE IS TO BE MADE.
      TAPE3 = 3.
    8 CALL INPUT(300,C,LIST)
      IF (TAPE3) 63,3,63
    3 IF (FILE-1.) 20,10,20
   10 CALL SKFILE(9,2)
C
C     PART 3. TAPE IS TO BE MADE SO MOVE EPHEMERIS LIST TO TMAKE AND
C         TO TMADE (FOR OUTPUT), CANCEL ANY ZERO OR DUPLICATE NAMES.
   20 KOUNT = 1
      DO 6 K=1,11
      TMAKE(K) = 0.
      TMADE(K) = 0.
    4 DO 5 J=1,KOUNT
      IF (COMPARF(ELIST(K),TMAKE(J-1))) 5,6,5
    5 CONTINUE
      TMAKE(KOUNT) = ELIST(K)
      TMADE(KOUNT) = ELIST(K)
      KOUNT = KOUNT+1
    6 CONTINUE
      KOUNT = KOUNT - 1
C
C     PART 4. FIND INPUT ERRORS.
    7 IF(TBEGIN-2437202.5) 66,9,9
    9 KM = 2
   11 ERROR = 0.
      WRITE TAPE 3,FILE
      DO 21 J=1,KOUNT
      KTAG(J) = 0
   12 DO 13 K=1,20
      IF (COMPARF(PNAME(K),TMAKE(J))) 13,16,13
   13 CONTINUE
C

C     PART 5. PRINTS OUT THE  MISSPELLED NAMES AND OTHER ERRORS.
   14 PRINT   15,  TMAKE(J), TBEGIN, TEND
      WRITE OUTPUT TAPE 6 , 15,  TMAKE(J), TBEGIN, TEND,(PNAME(K),
     1EDATE(K),K=1,20)
   15 FORMAT( 23H TROUBLE ON TAPE 3 MAKE  / 2X,A6,10H  T BEGIN= F10.1,8H
     1  T END= F10.1//2(2X,A6,F20.1))
      ERROR = 1.
      GO TO 21
C
```

```
C       PART 4B. CHECKS DATES AND STORES INDEX FOR MOON SO THAT EARTH
C       RADII CAN BE CONVERTED TO A.U.
     16 IF (10-K) 18,17,18
     17 MOON = J
     18 KTAG(J) = K
     19 IF (EDATE(K)- TEND)  14,21,21
     21 CONTINUE
        ASSIGN 36  TO NS1
        IF (ERROR) 22,22,68
C
C       PART 6. FIX UP A TAG (KTAG) TO INDICATE WHETHER TO ENTER DATA DOUBLE OR
C               NOT.  KHAMP WILL BE SHORTEST INTERVAL.  KTAG WILL BE NON-ZERO IF
C               ANY DATA ENTERS MORE THAN ONCE FOR 10 ENTRIES OF THE MOST
C               FREQUENT DATA.
     22 KHAMP = INTVAL(0)
        DO 23  J=1,KOUNT
        K = KTAG(J)
        KHAMP = XMINOF(KHAMP,INTVAL(K))
     23 CONTINUE
        KHAMP = KHAMP *10
        DO 24  J=1,KOUNT
        K = KTAG(J)
     24 KTAG(J) = INTVAL(K) / KHAMP
C
C       PART 7.  LOCATE FILE 2 ON TAPE 9.
     25 READ TAPE 9, KFILE
     26 IF (KM-KFILE) 27,31,29
     27 IF (KFILE - 3)  28,28,29
     28 BACKSPACE 9
        BACKSPACE 9
        CALL BSFILE(9)
        GO TO 25
C       BY PASS A FILE.
     29 CALL SKFILE(9)
        GO TO 25
C
C       PART 8. THIS IS CORRECT FILE ON TAPE 9, READ DATA. THERE CAN BE UP
C          TO 12 SETS OF DATA PER RECORD. A SET OF DATA IS 21 WORDS.
     31 BACKSPACE 9
     32 READ TAPE 9, KTAPE,(TDATUM(I), I=1,252)
        GO TO NS1, (36,46)
C
C       PART 9. IS THIS A SATISFACTORY STARTING POINT, QUESTION MARK.
C       THE 1ST SET OF DATA FOR EACH PLANET MUST PRE DATE TBEGIN.
C       PART 9 IS EXECUTED ONLY ONCE.
     36 DO 42 J=LI,KOUNT
        DO  37 K=1,232,21
        IF (COMPARF(TDATUM(K),TMAKE(J))) 37,39,37
     37 CONTINUE
     38 LI = J
        BACKSPACE 9
        BACKSPACE 9
        GO TO 32
     39 IF (TDATUM(K+1)-TDATUM(K+2)-TBEGIN) 40,40,38
     40 DO 41 KJ=1,21
        K1 = K + KJ - 1
     41 DATUMT(KJ,J) = TDATUM(K1)
     42 CONTINUE
        IF (MOON) 43,45,43
     43 DO 44 KJ=4,21
     44 DATUMT(KJ,MOON) = DATUMT(KJ,MOON)*ERTOAU
     45 ASSIGN 46 TO NS1
C
C       PART 10. PUT AWAY NEEDED DATA.  TEST NAME, TIME OF BEGIN AND END.  DO NOT
C                WRITE TAPE 3 UNTIL TBEGIN PREDATES THE END OF THE FITTED
C                INTERVAL.  50 REPEATS OLD DATA, 57 WRITES NEW DATA.  THE NAMES
C                ARE ERASED FROM TMAKE AS SOON AS THE DATA POST DATES TEND.  WHEN
C                ALL NAMES ARE GONE, RETURN TO INPUT 300 TO SEE IF ANOTHER
C                EPHEMERIS IS TO BE CONSTRUCTED.
     46 DO 65 K=1,232,21
        DO 47 J=1,KOUNT
        IF (COMPARF(TDATUM(K),TMAKE(J))) 47,48,47
     47 CONTINUE
        GO TO 65
     48 SWT = TBEGIN-TDATUM(K+1)-TDATUM(K+2)
        IF (SWT) 49,49,52
     49 IF(KTAG(J)) 50,52,50
     50 WRITE TAPE 3,(DATUMT(KJ,J) , KJ=1,21)
     52 DO  53 KJ=1,21
        K1 = K + KJ
     53 DATUMT(KJ,J) = TDATUM(K1-1)
        IF (J-MOON) 56,54,56
     54 DO  55 KJ = 4,21
     55 DATUMT(KJ,J) = DATUMT(KJ,J)*ERTOAU
     56 IF (SWT) 57,57,58
     57 WRITE TAPE 3,(DATUMT(KJ,J),KJ=1,21)
     58 IF(TEND-DATUMT(2,J)-DATUMT(3,J)) 59,59,65
     59 TMAKE(J) = 0.
        DO 60 KK=1,KOUNT
        IF (TMAKE(KK)) 65,60,65
     60 CONTINUE
        WRITE OUTPUT TAPE 6, 61, FILE,TBEGIN,TEND, KOUNT,(TMADE(KK),
       1KK=1,KOUNT)
     61 FORMAT(28H0EPHEMERIS COMPLETED,  FILE=F3.,6H, FROM F10.1,3H TO
       1 F10.1, 4H FOR I2, 18H BODIES AS FOLLOWS / 12(2X,A6))
        FILE = FILE + 1.
        END FILE 3
        GO TO 2
     63 WRITE TAPE 3, FILE
        REWIND 3
        REWIND 9
        TAPE3 = 3.
        DO 64 J=3,4000
     64 C(J) = 0.
        RETURN
C
```

```
    65 CONTINUE
       GO TO 32
    66 PRINT 67, TBEGIN
       WRITE OUTPUT TAPE 6,67,TBEGIN
    67 FORMAT(33H TBEGIN PREDATES 2437202.5,IT IS F10.1)
    68 CONTINUE
       REWIND 9
       END

       REM BSFILE(I,J) BACKSPACES TAPE I UNTIL IT IS POSITIONED JUST
       REM BEHIND THE J TH EOF MARK.
       REM
       ENTRY    BSFILE
       PZE
       PZE
       PZE
       BCD 1BSFILE
BSFILE SXD      *-4,1
       SXD      *-4,2
       SXD      *-4,4
       XEC*     $(TES)
       TSX      $(RER),4
       LXD      BSFILE-2,4
       CLA*     1,4
       TSX      $(IOS),4
       CLA*     $(RDS)
       STA      BSF
       ANA      A07000
       STA      BTT1
       STA      BTT2
       LXD      BSFILE-2,4
       CAL      2,4
       ANA =0777777700000
       ERA =0007400000000
       TNZ ONEARG
       CLA* 2,4
       TZE BACK
       PDX ,1
       AXC      *+1,4
       XEC*     $(TCO)
BTT1   BTTA     **
       TRA      *+1
BSF    BSFA     **
       XEC*     $(RDS)
       XEC*     $(BSR)
       AXC      *+1,4
       XEC*     $(TCO)
BTT2   BTTA     **
       TRA CHECK
       TIX BSF,1,1
       XEC* $(RDS)
BACK   AXC      *+1,4
       XEC*     $(TCO)
       AXC      *+1,4
       XEC*     $(TRC)
       NOP
       AXC      *+1,4
       XEC*     $(TEF)
       NOP
       LXD      BSFILE-4,1
       LXD      BSFILE-3,2
       LXD      BSFILE-2,4
       TRA 3,4
CHECK  TXL BACK,1,1
       LXD BSFILE-2,4
       CLA ERR+1
       STO 0
       CLA* 1,4
       LDQ* 2,4
ERR    TSX 8,4
       TXI BACK,0,14
       PZE BSFILE-2,0,ERR
ONEARG CLA BSFILE-2
       ADD =01000000
       STO BSFILE-2
       LXD CHECK,1
       TRA BTT1-2
A07000 OCT 7000
       END
```

```
       REM SKFILE(I,J) SKIPS TAPE I OVER J EOF MARKS.
       REM
       ENTRY   SKFILE
       PZE
       PZE
       PZE
SKFILE SXD     *-3,1
       SXD     *-3,2
       SXD     *-3,4
       TSX     $(RER),4       CHECK LAST READ
       TEFA    *+1
       TEFB    *+1
       LXD     SKFILE-1,4
       CLA*    1,4            PICK UP THE TPE NUMBER
       TSX     $(IOS),4       SET UP THE TAPE ADDRESSES
       LXD     SKFILE-1,4     LOAD IT AGAIN--MAN
       CAL     2,4            IS THERE A SECOND ARGUMENT
       ANA     =0777777700000
       ERA     =0007400000000
       TNZ     ONEARG         NO SECOND ARGUMENT
GOGO   CLA*    2,4            PICK UP THE SECOND ARGUMENT
       TZE     BUMP+1         DID SOME DUMMY WANT   NO FILES
LOOP   SUB     =01000000
RDS    XEC*    $(RDS)         READ THE TAPE
       TCOA    *
       TCOB    *
       TEFA    BUMP           DID WE HIT
       TEFB    BUMP           AN END OF FILE
       TRA     RDS            GO READ SOME MORE
BUMP   TNZ     LOOP
       LXD     SKFILE-3,1
       LXD     SKFILE-2,2
       LXD     SKFILE-1,4
       NOP
       TRCA    *+1            TURN OFF TAPE CHECK
       TRCB    *+1
       TRA     3,4
ONEARG CLA     SKFILE-1
       ADD     =01000000      SET UP XR4 FOR PROPER RETURN
       STO     SKFILE-1
       PXD     0,,0           SET UP FOR ONE FILE
       TRA     RDS
       END
       COUNT   1200                                                       00020
       REM INPUT ROUTINE USING ARITHMETIC STATEMENTS. CF NASA TN D-1092   00030
       LBL     INPUT,6                                                    00040
       ENTRY   INPUT                                                      00050
       REM THIS IS SUBROUTINE INPUT.  ITS CALLING SEQUENCE                00060
       REM CONTAINS THREE ARGUMENTS---AN IDENTIFICATION                   00070
       REM CODE NUMBER, THE FIRST LOCATION RELATIVE TO WHICH              00080
       REM ALL DATA IS TO BE LOADED, AND THE FIRST LOCATION               00090
       REM OF A TABLE TO BE USED BY THE ROUTINE.                          00100
       REM                                                                00110
       REM                                                                00120
       REM INCLUDED IN THIS ASSEMBLY ARE SUBROUTINES                      00130
       REM     1  INPUT                                                   00140
       REM     2  CHRCTR                                                  00150
       REM     3  CLEAR                                                   00160
       REM     4  COMPAR                                                  00170
       REM     5  ERROR                                                   00180
       REM     6  LOOK                                                    00190
       REM     7  NAME                                                    00200
       REM     8  NUMBR                                                   00210
       REM     9  STORE                                                   00220
       REM    10  TABLE                                                   00230
       REM    11  TEST                                                    00240
       REM    12  ACCUM, FIX, FLT, BINARY                                 00250
       REM    13  PRINX                                                   00260
       REM    14  READ.                                                   00270
       REM                                                                00280
INTAPE PZE     0,,7          LEWIS INPUT TAPE  NOT STD.
OUTAPE PZE     0,,6          FORTRAN STANDARD OUTPUT TAPE
 INDX  PZE                         STORAGE FOR IRA                        00290
       PZE                         IRB                                    00300
       PZE                         IRC                                    00310
       BCI     1,INPUT                                                    00320
INPUT  SXD     INDX,1        SAVE INDEX REGISTER A.                       00330
       SXD     INDX+1,2      SAVE INDEX REGISTER B.                       00340
       SXD     INDX+2,4      SAVE INDEX REGISTER C.                       00350
       NZT*    1,4           IF THE IDENTIFICATION  NUMBER IS Z           00360
       TRA     4,4           RETURN TO THE CALLING PROGRAM.               00370
       CLA     =1835                                                      00380
       ADD     2,4           2,4 IS THE BASE LOCATION.                    00390
       STA     SET                                                        00400
       STA     LOC1                                                       00410
       STA     LOC4                                                       00420
       CLA     TSXBS         OPEN BACKSPACE GATE                          00430
       STO*    $(LINK)       CALL CHAIN WILL BACKSPACE                    00440
LOCA   CLA     1,4           1,4 IS THE IDENTIFICATION NUMBER.            00450
       STA     NREG1                                                      00460
       AXT     36,1          INITIALIZE 36                                00470
       STZ     1+1,1         LOCATIONS                                    00480
       TIX     *-1,1,1         TO ZERO.                                   00490
       STO     ILOC1         MAKE NON'ZERO.                               00500
       CLA     3,4           3,4 IS THE LOCATION OF THE TABLE.            00510
       STA     LOCFC         PREPARE                                      00520
       STA     NREG1-1                                                    00530
       ADD     =1835               THE                                    00540
       STA     LOCFA           ARGUMENT STORAGES                          00550
       STA     LOCKL                                                      00560
       TSX     CLEAR,4       CLEAR THE VAR REGION.                        00570
```

```
LOCA1  CLA     =0076100000000       INHIBIT READING UNTIL              00580
       STO     READ.                 ARRAY RECORD REFRESHED            00590
       AXT     43,2            43 FORCES RECORD TO BE FILLED           00600
       SXD     I,2             IN CHRCTR                               00610
       REM LOOK AT  THE FIRST CHARACTER ON THE FIRST CARD              00620
       REM IN SEARCH OF A $ SIGN.                                      00630
LOCAA  TSX     CHRCTR,4                                                00640
       SUB     =H0000$0              CHECK FOR A $ SIGN                00650
 LOCA. STO     WORD                                                    00660
       TSX     COMPAR,4                                                00670
       OCT     242517630000          D, E, FILE FLAG, T                00680
       LXA     NREG1,4         ZERO IF $D HAS BEEN READ.               00690
       TXL     *+2,4,0                                                 00700
       TXI     *+1,2,4         BEFORE $D ADD 4 TO INDEX 2.             00710
       TXH     ERRU,2,7        JUNK                                    00720
       TXH     SGNOUT,2,6      $17 BEFORE $D. FILE FLAG. OFF           00730
       TXL     *+3,2,5         $E BEFORE $D                            00740
       TSX     READ.+1,4       CRASH READ GATE                         00750
       TRA     LOCA1           SHOULD NOW HAVE $D CARD                 00760
       TXH     LOCAD,2,4       FIRST $D.                               00770
       TXH     LOCAJ,2,3       $T AFTER $D.                            00780
       TXH     LOCCK,2,2       $17 AFTER $D. FILE FLAG                 00790
       TXH     LOCBG,2,1       $E AFTER $D.                            00800
       REM                                                             00810
LOCAC  LXA     READ.,4         $D AFTER $D. TEST IF BUFFER             00820
       TXL     ERRU,4,0              OVERWRITTEN                       00830
       REM THIS IS THE PROGRAM RETURN.                                 00840
RTN    LXD     INDX,1          RESET INDEX A.                          00850
       LXD     INDX+1,2        RESET INDEX B.                          00860
       LXD     INDX+2,4        RESET INDEX C.                          00870
       TRA     4,4             RETURN TO CALLING PROGRAM.              00880
       REM HUNT FOR THE = SIGN OF THE $ DATA CARD.                     00890
 LOCAD CLA     =0076100000000        INHIBIT READING UNTIL             00900
       STO     READ.                 $DATA FIELD SCANNED               00910
       TSX     CHRCTR,4                                                00920
       TSX     COMPAR,4                                                00930
       BCI     1,=00000                                                00940
       TRA     *+5,2,2                                                 00950
       TRA     ERRD            JUNK                                    00960
       TRA     LOCAD           ALPHABETIC                              00970
       TRA     ERRD            NUMERIC                                 00980
       SXD     ALF,4           = SIGN                                  00990
       REM USE ALF MODE TO TEST ALL CHARACTERS.                        01000
       REM                                                             01010
       REM COMES HERE WHEN = SIGN HAS BEEN FOUND.  GET THE             01020
       REM IDENTIFICATION NUMBER FROM THE CARD.                        01030
 LOCAF LXD     I,4                                                     01040
       TXH     *+2,4,43                                                01050
       TXH     LOCAG,4,42      CARD SCANNED OUT.                       01060
       TSX     CHRCTR,4                                                01070
       TSX     COMPAR,4                                                01080
       BCI     1,,$+- 0                                                01090
       TRA     *+9,2,2                                                 01100
       TRA     ERRM            JUNK                                    01110
       TRA     ERRM            ALPHABETIC                              01120
 LOCAE TSX     BINARY,4        FORM BIN WD IN VAR                      01130
       TRA     LOCAF           BLANK                                   01140
       SXD     ERSW,2          MINUS  SET TO BY PASS.                  01150
       TRA     LOCAF           PLUS   NO EFFECT.                       01160
       STO     SIGN            DOLLARS                                 01170
       REM COMES HERE TO CHECK THE REGION CODE AND THE                 01180
       REM VALUE APPEARING ON THE $DATA CARD.                          01190
LOCAG  CLA     VAR             COMMA                                   01200
       TZE     ERRU            DATA SET NO. MISSING                    01210
       ALS     18                                                      01220
       STD     **              SAVE IDENT AT TABLE(1),                 01230
NREG1  SUB     **              PLACE FIRST ARG IN THIS ADDRESS.        01240
       TNZ     RTN                   0 IF CALL CODE = $DATA CODE       01250
       STZ     ALF             ALF = 0 MEANS NO ALF INFO.              01260
       SXA     NREG1,0               INDICATE $DATA IS READ.           01270
       REM INST. BELOW ALSO EXECUTED AT READ., PLACED THERE BY CHRCTR  01280
 TSXRD TSX     READ.+1,4       HERE SNEAK PAST READ. GATE              01290
       SXD     TESTJK,0                                                01300
       TRA     LOCAN                                                   01310
       REM                                                             01320
       REM COMES HERE IF IT WAS A $ TABLE CARD.                        01330
LOCAJ  TSX     TABLE,4                                                 01340
       TRA     LOCAN3                                                  01350
       REM                                                             01360
       REM COMES HERE IF AN ALPHABETIC CHARACTER WAS FOUND.            01370
LOCAK  TSX     NAME,4                                                  01380
       TNZ     SET-1           ZERO MEANS ON LEFT OF = SIGN.           01390
       LXD     JK1,1           IF JK1 DIDNOT INCREASE THEN             01400
TESTJK TXL     ERRL,1,**       AN = SIGN WAS NOT USED.                 01410
       SXD     TESTJK,2        SAVE JK1 FOR NEXT TEST.                 01420
       CLA     ILOC            SAVE SIGN OF TABLE ENTRY.               01430
       STO     ILOC1                                                   01440
       TRA     LOCAN2                                                  01450
       REM                                                             01460
       LXD     JK,2            PREPARE TO ACCUMULATE THE NUMBERS       01470
SET    CLA     **,2            IN THE PSEUDO ACCUMULATOR.              01480
       STO     TEMP                                                    01490
       CLA     ILOC                                                    01500
       TPL     LOCAM           MINUS MEANS FLOAT THE NUMBER.           01510
       TSX     FLT,4                                                   01520
       TRA     LOCAM                                                   01530
       REM                                                             01540
       REM COMES HERE IF NUMERIC FIELD.                                01550
LOCAL  TSX     NUMBER,4                                                01560
       STO     TEMP                                                    01570
```

```
LOCAM  TSX    ACCUM,4     ACCUMULATE RESULTS IN ACC.            01580
       TSX    CLEAR,4                                           01590
       LXA    WORD,4                                            01600
       PXA    0,4             + WORD IN ACC FOR LOCAR           01610
       TXL    LOCAR,4,58  NOT COMMA                             01620
       TXH    LOCAR,4,59  NOT COMMA                             01630
       LXD    JK1,2       COMMA                                 01640
       CLA    ACC                                               01650
       STZ    ACC         INITIALIZE                            01660
       LDQ    ILOC1       IS THIS VARIABLE FIXED POINT.         01670
       TQP    LOC1        NEGATIVE IS FIXED POINT.              01680
       TSX    FIX,4                                             01690
LOC1   STO    **,2        STORE THE NUMBER RELATIVE TO BASE.    01700
LOCAN  LXD    JK1,2                                             01710
LOCAN1 TXI    *+1,2,1     RAISE STORING INDEX BY ONE.           01720
LOCAN2 SXD    JK1,2       SAVE IT.                              01730
LOCAN3 LXD    OPER,1      ANY OPERATORS LEFT OVER.              01740
       TXL    *+3,1,0                                           01750
ERRL   TSX    ERROR,4                                           01760
       BCI    1,0(L)                                            01770
       CLA    ACC         ANY DATA LEFT OVER.                   01780
       TNZ    ERRL                                              01790
       REM                                                      01800
       REM CALL THIS THE SWITCH HOUSE.                          01810
LOCAO  TSX    CLEAR,4                                           01820
LOCAP  TSX    CHRCTR,4                                          01830
LOCAQ  TSX    COMPAR,4                                          01840
       BCI    1,.(0000                                          01850
       TRA    *+6,2,2                                           01860
       TRA    LOCAR       $D, $T, OR OPERATORS.                 01870
       TRA    LOCAK       ALPHABETIC                            01880
       TRA    LOCAL       NUMERIC                               01890
       TRA    LOCAT       ( SIGN                                01900
       TRA    LOCAL       DECIMAL                               01910
LOCAR  LXD    OPER,1      ANY OPERATORS LEFT OVER.              01920
       TXH    ERRL,1,0    HIGH MEANS ALREADY HAS OPERATOR.      01930
       SUB    =H0000$0    SPLIT OFF $ FROM OTHERS               01940
       TPL    LOCA.       IF + PROCESS $ TYPE CH                01950
       REM WHAT KIND OF OPERATOR IS THIS.                       01960
       TSX    COMPAR,4                                          01970
       BCI    1,+-/*,0                                          01980
       TXH    ERRL,2,5    REMOVE THE JUNK.                      01990
       TXH    LOCAN,2,4   COMMA                                 02000
       SXD    OPER,2      SAVE REST, WILL BRANCH IN SUB ACCU    02010
       TRA    LOCAP       AFTER BOTH OPERANDS HAVE BEEN FOUN    02020
       REM                                                      02030
       REM COMES HERE IF THE OCT OR ALF MODE.                   02040
LOCAT  TSX    CHRCTR,4                                          02050
       TSX    COMPAR,4                                          02060
       BCI    1,)OA000                                          02070
       TRA    *+5,2                                             02080
       TRA    ERRL        JUNK                                  02090
       TRA    LOCAZ       A CHARACTER                           02100
       TRA    LOCAU       O CHARACTER                           02110
       REM                                                      02120
       REM COMES HERE IF EMPTY PARENTHESIS WERE FOUND.          02130
       TSX    CHRCTR,4    )SIGN,  GET NEXT CHARACTER.           02140
       TQP    *+2         MINUS FOR NEW CARD                    02150
       TSX    TEST,4      INSERT COMMA IF NEEDED.               02160
       CLA    ILOC1                                             02170
       STO    ILOC        PREPARE TO GET VALUE OF               02180
       LXD    JK1,2       CURRENT LEFT SIDE.                    02190
       TRA    SET                                               02200
       REM COMES HERE IF OCTAL MODE.                            02210
LOCAU  TSX    CHRCTR,4                                          02220
       SUB    =H00000)                                          02230
       TNZ    LOCAU                                             02240
       TRA    LOCAW       ) SIGN                                02250
 LOCAV LDQ    VAR                                               02260
       RQL    3           REPLACE TOP 3 BITS                    02270
       LGR    3           BY NEXT OCTAL CHARACTER               02280
       RQL    3           PUT IN BOTTOM OF MQ                   02290
       STQ    VAR                                               02300
       REM COMES HERE WHEN ) IS FOUND.                          02310
LOCAW  TSX    CHRCTR,4                                          02320
       TQP    *+2         MINUS FOR NEW CARD                    02330
       TSX    TEST,4                                            02340
       LXA    WORD,4      CHARACTER TO IRC                      02350
       TXL    LOCAV,4,7   OCTAL DIGITS                          02360
       TXL    ERRJ,4,58   ALPHABETIC, JUNK, 8, 9.               02370
       TXH    ERRJ,4,59   SPLITS (                              02380
LOCAX  LXD    JK1,2       COMMA                                 02390
       CLA    VAR                                               02400
       TRA    LOC1                                              02410
       REM            CONVERT THE NUMBER TO BINARY.             02420
LOCAY  TSX    BINARY,4                                          02430
       REM                                                      02440
       REM COMES HERE IF ALF MODE.                              02450
LOCAZ  TSX    CHRCTR,4                                          02460
       TSX    COMPAR,4                                          02470
       BCI    1,)00000                                          02480
       TRA    *+5,2,2                                           02490
       TRA    ERRK        JUNK                                  02500
       TRA    LOCAZ       ALPHABETIC                            02510
       TRA    LOCAY       NUMERIC                               02520
       REM COMES HERE WHEN ) IS FOUND                           02530
```

```
LOCBA   LXA     VAR,1             ) SIGN
        TNX     ERRK,1,0          ALF COUNT WAS ZERO.
        SXD     ALF,1
        TSX     CLEAR,4

        TSX     CHRCTR,4          PULL THROUGH CHARACTERS AND STORE
        SUB     =017              FILE FLAG, NEVER NEG.
        TZE     ERRB                     COUNT WENT PAST E O JOB.
        TSX     STORE,4           THEM ONE AT A TIME.
        TIX     *-4,1,1           GO BACK TILL NCHAR = 1
        LXD     J,1
        LXD     MSHIFT,4
        CAL     BLANK
        LGR     42,4
        ORS     VAR+1,1           FILL IN PARTIAL WORD WITH BLANKS.
 LOCBB  AXT     1,4               IRC TO 1
        LXD     JK1,2
        CLA     J                 PREPARE TO STORE ALF WDS
        STD     LOCBC1
 LOCBC  SXD     JK1,2
        CLA     VAR+1,4
LOC4    STO     **,2
        TXI     *+1,4,1           J = J + 1
LOCBC1  TXH     LOCBD,4,**
        TXI     LOCBC,2,1         JK=JK+1
LOCBD   STZ     ALF
        TSX     CLEAR,4
        TSX     CHRCTR,4          LOOK AT NEXT CHARACTER.
        TQP     *+2               MINUS FOR NEW CARD
        TSX     TEST,4            PUT IN COMMA IF NEEDED.
        SUB     =H00000,
        TZE     LOCAN             GO RAISE AND STORE JK1.
        REM
        REM THESE ARE ERROR CALLS
ERRB    TSX     ERROR,4
        BCI     1,0(B)
ERRD    TSX     ERROR,4
        BCI     1,0(D)
ERRJ    TSX     ERROR,4
        BCI     1,0(J)
ERRK    TSX     ERROR,4
        BCI     1,0(K)
ERRM    TSX     ERROR,4
        BCI     1,0(M)
ERRU    TSX     ERROR,4
        BCI     1,0(U)
        REM
        REM         $E COMES HERE AFTER $D
LOCBG   CLA     =0076100000000     NOP
        STO*    $(LINK)           CLOSE BACKSPACE GATE
        TRA     LOCAC             RETURN
        REM PURPOSE OF $END CARD IS TO PROTECT FORIEGN DATA FROM
        REM BACKSPACE WHEN CHAIN IS CALLED.
        REM
        REM     END OF THE MAIN SEGMENT
        REM THIS A ROUTINE TO BACKSPACE THE INPUT TAPE WHEN A
        REM CALL CHAIN IS GOING TO SPILL THE BUFFER.
        REM THIS ROUTINE IS EXECUTED FROM CHAIN VIA THE ONE
        REM WORD SUBROUTINE (LINK) WHICH CONTAINS EITHER TSX OR NOP
TSXBS   TSX     LOCBS,4           TO BE STORED AT (LINK
LOCBS   SXA     *+4,4             SAVE INDEX 4
        CLA     INTAPE            INPUT TAPE NUMBER
        CALL    $(IOS)            SELECT INPUT TAPE
        XEC*    $(BSR)            BACKSPACE IT
        AXT     **,4              RESTORE INDEX
        TRA     1,4               RETURN TO THE CHAIN ROUTINE
        EJECT
        REM THIS IS SUBROUTINE CHRCTR.  IT STORES SUCCESSIVE
        REM CHARACTERS FROM THE CARD AT LOCATION WORD, READS
        REM SUCCESSIVE CARDS INTO THE ARRAY RECORD, AND PRINTS
        REM $$ TYPE CARDS. THE FIRST CHARACTER FROM A NEW CARD
        REM IS STORED IN WORD WITH A MINUS SIGN.
        REM
        REM
CHRCTR  SXD     TEMP-10,2
        SXD     TEMP-17,4
        LXD     I,2               CARD COL COUNT, SAW COUNT
        TXH     *+2,2,83          TOO EARLY TO READ.
        XEC     READ.             GATE MAY BE CLOSED
        LDQ     Q                 HAS UNUSED CHARACTERS FROM BEFORE
        CLA     SIGN              ZERO OR $ GOES TO TAG
LOCCA   ALS     6                 SHIFT LEFT 1 CHARACTER
        SLW     TAG               CLEARS OR PRELOADS TAG
LOCCB   LXD     ALF,4             NONZERO MEANS ALF MODE.
LOCCC   TXH     LOCCD,2,43        SAW COUNT GIVES COL 81 = 43.
        TXH     LOCCG,2,42        WAS COL 80 PROCESSED.
LOCCD   PXD     0,0               CLEAR ACCUMULATOR.
        LGL     6                 SHIFT NEXT CHARACTER INTO ACC.
        TIX     LOCCE,2,14        COUNT DOWN BY 14
        LDQ     RECORD+3,2        LOAD NEXT WORD
        TXI     *+1,2,69          JUMP BACK COUNTER.
LOCCE   TXH     LOCCF,4,0         RETURN IF ALF MODE.
        PAX     0,1               MOVE CHR. INTO  INDEX  1
        TXH     LOCCF,1,48        TRA MEANS GOOD CHARACTER.
        TXH     LOCCC,1,47        TRA IF BLANK
        TXH     LOCCF,1,43        TRA IF GOOD CHARACTER.
        TXL     LOCCF,1,42        TRA IF GOOD CHARACTER.
        ZET     TAG               HERE ON $
        TRA     PRINT             HERE ON $$  GO PRINT
        TRA     LOCCA             $ GOES TO TAG.
        REM
```

```
LOCCF  SXD     1,2             SAVE SAW COUNT                              03540
       STQ     Q               SAVE UNUSED CHARACTERS.                     03550
       ADD     TAG             ATTACH $ SIGN IF PRESENT.                   03560
       STO     WORD            SAVE THE CHARACTER AT WORD.                 03570
       LDQ     SIGN            SIGN OF MQ NEGATIVE IF NEW CARD.            03580
       STZ     SIGN            CLEAR SIGN.                                 03590
       STZ     TAG             CLEAR TAG OF ANY $                          03600
       LXD     TEMP-17,4                                                   03610
       LXD     TEMP-10,2                                                   03620
       TRA     1,4             RETURN                                      03630
       REM PRINT OUT THE  $$ CARDS.                                        03640
PRINT  STQ     Q                                                           03650
       XEC*    $(TES)          CHECK FOR QUIET BUFFERS.                    03660
       XEC     READ.           FETCH NEXT CARD.                            03670
       LDQ     Q                                                           03680
       LGL     6               SPACE CONTROL SAFE IN ACC                   03690
       LDQ     BLANK                                                       03700
       AXT     4,4             FILL END OF OUTPUT                          03710
       STQ     OUTBUF+19,4      BUFFER WITH BLANKS.                        03720
       TIX     *-1,4,1                                                     03730
       LGR     6               SPACE CONTROL BACK TO MQ.                   03740
       STQ     OUTBUF          STORE SPACE CONTROL.                        03750
       AXT     14,4                                                        03760
       LDQ     RECORD+2,4                                                  03770
       STQ     OUTBUF+15,4                                                 03780
       TIX     *-2,4,1                                                     03790
       TSX     PRINX,4                                                     03800
       TRA     *+3                                                         03810
LOCCG  XEC     READ.           ALMOST ALWAYS A NOP.                        03820
       XEC*    $(TES)          WAIT FOR QUIET READ BUFFER.                 03830
       STZ     TAG             CLEAR THE $$ CHARACTERS.                    03840
       AXT     14,2            FETCH CARD.                                 03850
       LDQ     INBUF+14,2      14 WORDS                                    03860
       STQ     RECORD+2,2                                                  03870
       TIX     *-2,2,1                                                     03880
       CLA     TSXRD           OPEN READ. GATE                             03890
       STO     READ.                                                       03900
LOCCJ  AXT     84,2            CARD COL 1 IS 84                            03910
       CLS     =0              SET MINUS ZERO IN SIGN                      03920
       STO     SIGN                                                        03930
       LGL     12              SAVE COLUMN 79 AND 80
       LDQ     BLANK           BLANK OUT COLUMN 81 TO 84
       LGR     12              MAY HAVE LOOK AHEAD
       STQ     RECORD+1
       LDQ     RECORD-12                                                   03940
       TRA     LOCCA                                                       03950
       REM                                                                 03960
       REM          COMES HERE ON END OF FILE FLAG                         03970
 LOCCK LXD     TESTJK,4                                                    03980
       TXH     RTN,4,0         WAS DATA LOADED.  YES RTN                   03990
SGNOUT XEC*    $(TES)          WAIT FOR QUIET OUTPUT BUFFER                04000
       AXT     6,4                                                         04010
       LDQ     OUT+6,4                                                     04020
       STQ     OUTBUF+6,4                                                  04030
       TIX     *-2,4,1                                                     04040
       AXT     13,4                                                        04050
       LDQ     BLANK                                                       04060
       STQ     OUTBUF+19,4                                                 04070
       TIX     *-1,4,1                                                     04080
       TSX     PRINX,4                                                     04090
       XEC*    $(TES)          WAIT FOR QUIET BUFFER.                      04100
LOCOUT CALL    $EXIT           THIS WAY OUT FOR KEEPS                      04110
       REM                                                                 04120
OUT    BCI     6,1END OF FILE INPUT TAPE JOB COMPLETE                      04130
       REM                                                                 04150
       REM END OF THE SAP SUBROUTINE CHRCTR.                               04160
       EJECT                                                               04170
       REM THIS IS SUBROUTINE CLEAR.  IT INITIALIZES                       04180
       REM NECESSARY PARAMETERS FOR SUBROUTINE STORE.                      04190
       REM                                                                 04200
 CLEAR SXD     J,0                     SET J TO 0.                         04210
       STZ     VAR             CLEAR VAR(1).                               04220
       SXD     MSHIFT,0                RESET MSHIFT.                       04230
       TRA     1,4             RETURN TO CALLING PROGRAM                   04240
       REM                                                                 04250
       REM END OF THE SAP SUBROUTINE CLEAR.                                04260
       REM                                                                 04270
       REM                                                                 04280
       REM THIS IS FUNCTION COMPAR.  IT EXAMINES THE CURRENT               04290
       REM CHARACTER AND TESTS IT AGAINST THE CHARACTERS                   04300
       REM FOUND IN THE ARGUMENT. ALPHABETIC AND NUMERIC                   04310
       REM SPLITS ARE MADE IF THE CHARACTER IS NOT FOUND                   04320
       REM IN THE ARGUMENT. THESE TESTS ARE COUNTED AND                    04330
       REM THE NUMBER LEFT IN INDEX 2 CORRESPONDS TO THE                   04340
       REM SUCCESSFUL TEST. IF NO TEST IS SUCCESSFUL                       04350
       REM THEN INDEX 2 CORRESPONDS TO THE TOTAL TESTS +1.                 04360
       REM                                                                 04370
COMPAR LDQ     1,4             USE FIRST ARGUMENT IN CALLING               04380
       AXT     1,2                                                         04390
LOCDA  PXD     0,0                                                         04400
       LGL     6               PULL IN 1ST TEST CHARACTER.                 04410
       TZE     LOCDD           DONE IF ZERO.                               04420
       CAS     WORD            CHECK TEST WORD AGAINST CARD                04430
       TXI     LOCDA,2,1       CHARACTER.                                  04440
       TRA     LOCDC           EQUAL.                                      04450
LOCDB  TXI     LOCDA,2,1       NOT EQUAL.  GET NEXT TEST                   04460
LOCDC  CLA     WORD            CHARACTER.                                  04470
       TRA     2,4             PROGRAM RETURN.                             04480
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LOCDD  CLA     2,4           USE SECOND ARGUMENT IN THE CALLING               04490
       PDX     0,1           SEQUENCE (DECREMENT) AS THE TEST                 04500
       TNX     LOCDC,1,1024  FOR ALPHABETIC-NUMERIC SPLIT.                    04510
       SXD     LOCDF,1              BECOMES INCREMENT                         04520
       LXA     WORD,1               CHARACTER TO IRA                          04530
       TXL     LOCDC,1,9            NUMERIC                                   04540
       TXH     LOCDF,1,57           SPECIAL 0 ZONE, $X                        04550
       TXH     LOCDE,1,49           ALPHABETIC 0 ZONE, NO /                   04560
       TIX     *+2,1,32             KNOCK OFF 11 ZONE EXCEPT -                04570
       TIX     *+1,1,16             KNOCK OFF 12 ZONE EXCEPT +                04580
       REM     + AND - SIGNS WILL BE (16)10, / WILL BE (17)10                 04590
       TXH     LOCDF,1,9            SPECIAL                                   04600
 LOCDE TXI     LOCDF,2,-1           ADJUST IRB FOR ALPHABETIC                 04610
 LOCDF TXI     LOCDC,2,**           ADJUST IRB FOR SPLIT                      04620
       REM                                                                    04630
       REM END OF THE SAP SUBROUTINE COMPAR.                                  04640
       EJECT                                                                  04650
       REM THIS IS SUBROUTINE ERROR.  IT IS CALLED IF AN                      04660
       REM ERROR WAS DETECTED ON ANY OF THE INPUT CARDS.                      04670
       REM                                                                    04680
 ERROR SXA     *+2,4         SAVE SOURCE                                      04690
       XEC*    $(TES)        WAIT FOR QUIET BUFFERS                           04700
       AXT     **,4                                                           04710
       CLA     1,4           GET PRINT ARGUMENT                               04720
       STO     OUTBUF                                                         04730
       AXT     1,1                                                            04740
       CAS     R                                                              04750
       TRA     *+3           S THROUGH V                                      04760
       TXI     *+1,1,-1      R                                                04770
 MESSA PXD     BLANK+4,1     A THROUGH N                                      04780
       ANA     =7B17                                                          04790
       ARS     16                                                             04800
       ACL     MESSA                                                          04810
       STA     I02.                                                           04820
       AXT     4,4                                                            04830
 I02.  LDQ     **,4                                                           04840
       STQ     OUTBUF+5,4                                                     04850
       TIX     *-2,4,1                                                        04860
       AXT     14,4                                                           04870
       LDQ     RECORD+2,4                                                     04880
       STQ     OUTBUF+19,4                                                    04890
       TIX     *-2,4,1                                                        04900
       TSX     PRINX,4                                                        04910
       XEC*    $(TES)        WAIT FOR QUIET BUFFER                            04920
       AXT     19,2                                                           04930
       CLA     BLANK                                                          04940
       STO     OUTBUF+19,2                                                    04950
       TIX     *-1,2,1                                                        04960
       LDQ     =H     *      PICK UP *                                        04970
       LXD     I,2           SAW COUNT                                        04980
       TXL     *+2,2,71      BACK UP IF OVER 71                               04990
       TXI     *+3,2,-69                                                      05000
       RQL     6             ROTATE ACCORDING TO CHR PART.                    05010
       TIX     *-1,2,14      COUNT CHARACTER PART.                            05020
       STQ     OUTBUF+19,2   STORE ACCORDING TO RESIDUAL                      05030
       TSX     PRINX,4       PRINT THE *                                      05040
       XEC*    $(TES)        WAIT FOR THE *  TO BE PRINTED                    05050
       LXD     ERSW,4        PICK UP ERROR SWITCH.                            05060
       TXL     LOCOUT,4,0    NON ZERO MEANS TRY NEXT SET                      05070
       AXT     1208,4        BYPASS MARK                                      05080
       SXD     BLANK,4       MARK BYPASSED CARDS                              05090
       LXA     NREG1,4       NONZERO IF THIS $DATA CARD.                      05100
       TXL     *+2,4,0                                                        05110
       TSX     READ.+1,4     CRASH READ GATE IF $DATA CARD.                   05120
LOCEB  TSX     CHRCTR,4      SKIP TO NEXT $DATA AND TRY THAT SET.             05130
       TQP     LOCEB                                                          05140
       SUB     =H0000$D                                                       05150
       TNZ     LOCEC         TRA NOT A $DATA CARD                             05160
       STQ*    NREG1-1       PUTS - SIGN IN TABLE(1)                          05170
       LXD     BLANK+7,4                                                      05180
       SXD     BLANK,4                                                        05190
       LXD     INDX+2,4                                                       05200
       TRA     LOCA                                                           05210
LOCEC  ADD     =5            TEST FOR END FILE FLAG                           05220
       TZE     SGNOUT        END FILE.. GET OFF                               05230
       TRA     LOCEB         OTHER                                            05240
       REM                                                                    05250
       REM ERROR MESSAGES. FIRST WORD ALSO USED AS A BLANK.                   05260
 BLANK BCI     4,      REDUNDANCY CHECK                                       05270
       BCI     4,ILLEGAL CHARACTER                                            05280
       BCI     4,NO MANTISSA BEFORE E.                                        05290
       BCI     4,NO ENTRY IN TABLE                                            05300
       BCI     4,$TYPE MISSING OR WRONG                                       05310
       BCI     4,EXPON. OUT OF RANGE                                          05320
       REM                                                                    05330
       REM END OF THE SAP SUBROUTINE ERROR.                                   05340
       EJECT                                                                  05350
       REM THIS IS SUBROUTINE LOOK.  IT SEARCHES THE TABLE                    05360
       REM FOR THE NAME STORED AT LOCATION VAR.  IF FOUND,                    05370
       REM THE ACC IS NON-ZERO AT THE RETURN.                                 05380
       REM                                                                    05390
LOOK   SXD     TEMP-12,4     SAVE INDEX REGISTER C.                           05400
       CLA     J             SUBROUTINE.                                      05410
       STD     LOCFE                                                          05420
       AXT     2,2     JK = 2 IN INDEX B                                      05430
       AXT     1,1                  J1 = 1 IN INDEX A                         05440
LOCFA  CAL     **,2          CAL TABV(JK).                                    05450
       TZE     LOCFG                NO ENTRY THIS VARIABLE                    05460
       STD     LOCFD                DECREMENT HAS NEXT                        05470
       ACL     =0377777000000                                                 05480
       ANA     =0377777000000       ENTRY LOC. SAVE DECR                      05490
       SUB     J             ONLY.   CHECK ENTRY LENGTH.                      05500
       TNZ     LOCFD         IF NOT THE SAME, LOOK AT NEXT ENTR               05510
       PXD     0,2                                                            05520
       PDX     0,4           JM = JK IN INDEX C.                              05530
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LOCFB  CLA     VAR+1,1        SEE IF VAR AND THIS                       05540
LOCFC  CAS     **,4                ENTRY AGREE                          05550
       TRA     *+2                 IF SO, CHECK REST OF NAME            05560
       TXI     *+2,4,1        RAISE JM BY ONE.                          05570
LOCFD  TXI     LOCFA-1,2,**     IF NOT SO, GO TO NEXT ENTRY.            05580
       TXI     *+1,1,1        RAISE J1 BY ONE.                          05590
LOCFE  TXL     LOCFB,1,**     FINISHED IF J1 IS GREATER THAN J.         05600
       TSX     CLEAR,4        CLEAR IF THE ENTRY AGREES.                05610
 LOCFF CLA*    LOCFA                                                    05620
       STO     ILOC           SAVE COMMON INDEX AT ILOC.                05630
LOCFG  LXD     TEMP-12,4      PREPARE TO RETURN.                        05640
       TRA     1,4            RETURN TO THE CALLING PROGRAM.            05650
       REM                                                              05660
       REM                                                              05670
       REM END OF THE SAP SUBROUTINE LOOK.                              05680
       EJECT                                                            05690
       REM THIS IS SUBROUTINE NAME.  IT IS USED TO                      05700
       REM CORRELATE NAMES FROM INPUT CARDS WITH INTERNAL               05710
       REM MEMORY LOCATIONS BY REFERRING TO THE TABLE.                  05720
       REM                                                              05730
       REM                                                              05740
NAME   SXD     TEMP-20,4      SAVE INDEX C.                             05750
       REM GET THE REST OF THE VARIABLE NAME. STOP AT ANY               05760
       REM NON ALPHANUMERIC CHARACTER.                                  05770
LOCGB  TSX     STORE,4                                                  05780
LOCGC  TSX     CHRCTR,4                                                 05790
       TQP     *+2            MINUS FOR NEW CARD                        05800
       TSX     TEST,4         COMMA MAY BE NEEDED.                      05810
       TNZ     *+3            LOOK FOR ZERO. IF ZERO, MAKE IT           05820
       ACL     =H000000              A LETTER O                         05830
       STO     WORD                                                     05840
LOCGE  TSX     COMPAR,4                                                 05850
       BCI     1,=(0000                                                 05860
       TRA     *+5,2,1                                                  05870
       TRA     LOCGF          JUNK OR OPERATORS                         05880
       TRA     LOCGB          NUMERIC OR ALPHABETIC                     05890
       TRA     LOCGG          ( SIGN                                    05900
       STZ     ILOC1          = SIGN                                    05910
       REM GO TO THE TABLE LOOKUP ROUTINE IF AN = SIGN                  05920
       REM   OR AN OPERATOR WAS FOUND.                                  05930
LOCGF  TSX     LOOK,4         FIND THE NAME IN TABLE.                   05940
       TZE     ERRT           NAME WAS FOUND IN TABLE IF NON-ZER        05950
       LXA     ILOC,2                                                   05960
       TRA     LOCGL                                                    05970
       REM                                                              05980
       REM GO TO THE TABLE VARIABLE LOOKUP ROUTINE IF A                 05990
       REM ( SIGN WAS FOUND.                                            06000
LOCGG  TSX     LOOK,4                                                   06010
       TNZ     LOCGJ                                                    06020
ERRT   TSX     ERROR,4                                                  06030
       BCI     1,0(T)                                                   06040
       REM CONVERT THE INDEX TO BINARY.                                 06050
LOCGH  TSX     BINARY,4                                                 06060
       REM GET THE NUMERICS FOR THE INDEX TO THE VARIABLE.              06070
LOCGJ  TSX     CHRCTR,4                                                 06080
       TXL     LOCGH,1,9      NUMERIC                                   06090
       TXL     ERRC,1,27      JUNK                                      06100
       TXH     ERRC,1,29      JUNK                                      06110
       TSX     CHRCTR,4       ) SIGN. GET NEXT CHARACTER.               06120
       TQP     *+2            MINUS FOR NEW CARD                        06130
       TSX     TEST,4         COMMA MAYBE NEEDED.                       06140
       TSX     COMPAR,4                                                 06150
       BCI     1,=00000                                                 06160
       TRA     *+4,2,1                                                  06170
       TRA     LOCGK          OPERATORS                                 06180
       TRA     ERRL           ALPHABETIC AND NUMERIC                    06190
       STZ     ILOC1          = SIGN                                    06200
       REM                                                              06210
LOCGK  CLA     VAR            COMPUTE STORING INDEX.                    06220
       ACL     ILOC                                                     06230
       PAX     0,2            STORE ADDRESS AT DECREMENT WITHOUT        06240
       TXI     *+1,2,-1                                                 06250
LOCGL  SXD     JK,2           ACCUMULATOR OVERFLOW.                     06260
       CLA     ILOC1                                                    06270
       LXD     TEMP-20,4      RESTORE INDEX C.                          06280
       TRA     1,4            RETURN TO CALLING PROGRAM.                06290
       REM     CONSTANTS AND ERROR CALL.                                06300
ERRC   TSX     ERROR,4                                                  06310
       BCI     1,0(C)                                                   06320
       REM                                                              06330
       REM END OF THE SAP SUBROUTINE NAME.                              06340
       EJECT                                                            06350
       REM THIS IS SUBROUTINE NUMBER.  IT IS USED TO                    06360
       REM ASSEMBLE NUMERIC DATA FROM CARDS.  ALL VALUES ARE            06370
       REM TREATED AS FLOATING POINT NUMBERS IN THIS ROUTINE.           06380
       REM                                                              06390
NUMBER SXD     TEMP-23,4      SAVE INDEX C.                             06400
       SXD     KNT2,4         INITIALIZE                                06410
       STZ     KNT3             THE SUBROUTINE                          06420
       STZ     KNT1               BRANCH PARAMETERS.                    06430
       STZ     KNT4                                                     06440
       STZ     TEMP                                                     06450
       TRA     LOCHB                                                    06460
       REM                                                              06470
LOCHA  TSX     CHRCTR,4                                                 06480
       TQP     *+2,           MINUS MEANS FROM NEW CARD                 06490
       TSX     TEST,4                                                   06500
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LOCHB  TSX     COMPAR,4
       BCI     1,.E0000
       TRA     *+6,2,2
       TRA     LOCHK           JUNK OR AN OPERATOR
       TRA     ERRE            ALPHABETIC
       TRA     LOCHC           NUMERIC
       TRA     LOCHE           E
       CLA     KNT2            DECIMAL POINT.
       TNZ     *+3             ZERO MEANS THIS IS THE SECOND POIN
       TSX     ERROR,4
       BCI     1,0(N)
       STZ     KNT2
       STZ     NEXP
       TRA     LOCHA
LOCHC  CLA     NEXP            COUNT THE NUMBER OF DIGITS BEHIND
       ADD     =1B35           THE.  IF THERE IS ONE
       STO     NEXP.
 LOCHD LXA     KNT1,1
       TXH     LOCHD2,1,10             DO NOT ACCUMULATE PAST 10
LOCHD1 TSX     BINARY,4        CONVERT THE DIGIT TO BINARY.
       TZE     LOCHA           DO NOT COUNT LEADING ZEROS.
LOCHD2 TXI     *+1,1,1         COUNT TOTAL NO. OF DIGITS
       SXA     KNT1,1
       TRA     LOCHA
       REM COMES HERE WHEN THE EXPONENT FIELD IS
LOCHE  CLA     KNT1            ENCOUNTERED.
       TNZ     LOCHH           THERE MUST BE AT LEAST ONE DIGIT
       TSX     ERROR,4         BEFORE THE E OF AN E FORMAT NUMBER
       BCI     1,0(S)
LOCHF  CLA     KNT3            SEE IF EXPONENT DIGITS HAVE ARRIVE
       TRA     *+2
LOCHG  CLS     KNT3            SEE IF EXPONENT DIGITS HAVE ARRIVE
       TNZ     LOCHK-2         NON ZERO MEANS SIGN IS OPERATOR.
       STO     TEMP            STORE SIGN OF EXPONENT.
       CLA     KNT4
       TNZ     ERRF            NONZERO MEANS MORE THAN 1 EXP SIGN
       SXD     KNT4,2          MAKE NOZERO.
LOCHH  TSX     CHRCTR,4
       TQP     *+2,            MINUS MEANS FROM NEW CARD
       TSX     TEST,4
       TSX     COMPAR,4
       BCI     1,+-.000
       TRA     *+7,2,2
       TRA     LOCHK-2         OTHERS
       TRA     ERRF            ALPHABETIC
       TRA     LOCHJ           NUMERIC
       TRA     ERRF            DECIMAL
       TRA     LOCHG           MINUS
       TRA     LOCHF           PLUS
       REM CONVERT THE EXPONENT TO BINARY.
LOCHJ  CLA     TEMP
       ALS     2
       ADD     TEMP
       ALS     1
       ACL     WORD
       STO     TEMP
       SXD     KNT3,2          RECORD FACT FOR SECOND SIGN.
       TRA     LOCHH
       REM COMES HERE WHEN AN OPERATOR WAS FOUND.
       CLA     KNT3            TEST FOR THE PRESENCE OF EXPONENT.
       TZE     ERRF            ZERO MEANS NO EXPONENT CAME.
LOCHK  CLA     KNT2
       TZE     *+2
       STZ     NEXP
       CLA     KNT1            SEE IF MORE THAN TEN NUMBERS HAVE
       SUB     =10B35                  BEEN CONVERTED
       TPL     *+2             IF SO, USE THE DIFFERENCE IN THE
       PXD     0,0             COMPUTATION OF THE EXPONENT.
       SUB     NEXP
       ADD     TEMP
       STO     NEXP
       REM MANTISSA IN VAR AND THE EXPONENT IS IN NEXP.
       CLA     VAR
       TZE     LOCHQ           SHORT CUT IF ZERO.
       LDQ     =0233000000000          CHARACTERISTIC FOR LOW BITS
       LGR     8                       LOW 8 BITS TO MQ
       RQL     8
       LRS     0                       BRING SIGN
       STQ     VAR
       ORA     =0243000000000          CHARACTERISTIC FOR HIGH BITS
       FAD     VAR
       FRN
       STO     VAR
       CLA     NEXP            THE EXPONENT
       AXT     1,2
       LDQ     =1.             PUT 1 IN  MQ
 LOCHL LBT                     EXPONENT IN ACCU
       TRA     LOCHM        FOUND NO BIT.
       TXH     ERRV,2,6        EXPONENT EXCEEDS 63
       STO     VAR-2
       FMP     TAB+1,2      THIS FORMS 10 **NEXP
       XCA                  SAVE IN MQ
       CLA     VAR-2
 LOCHM ARS     1
       TZE     LOCHN         10**NEXP FINISHED.
       TXI     LOCHL,2,1
 LOCHN TMI     LOCHO        MULTIPLY IF PLUS.
       FMP     VAR
       FRN
       TRA     LOCHQ
 LOCHO STQ     VAR-2
       CLA     VAR             DIVIDE IF NEXP IS MINUS.
       FDP     VAR-2
       XCA                     ANSWER BACK TO THE ACCUM
LOCHQ  LXD     TEMP-23,4       RESTORE INDEX C.
       TRA     1,4             RETURN TO CALLING PROGRAM.
       REM THESE ARE THE ERROR CALLS FOR SUB NUMBR.
```

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ERRE   TSX     ERROR,4                                                  07580
       BCI     1,0(E)                                                   07590
ERRF   TSX     ERROR,4                                                  07600
       BCI     1,0(F)                                                   07610
ERRV   TSX     ERROR,4                                                  07620
       BCI     1,0(V)                                                   07630
       REM                                                              07640
       REM THIS IS THE FLOATING PT. TABLE USED IN DBC                   07650
       DEC     1E+32,1E+16,1E+8,1E+4,1E+2      CONVERSION TABLE         07660
 TAB   DEC     1E+1                                                     07670
       REM                                                              07680
       REM END OF THE SAP SUBROUTINE NUMBER.                            07690
       EJECT                                                            07700


       REM THIS IS SUBROUTINE STORE.  IT STORES CHARACTERS              07710
       REM AT THE ARRAY VAR.                                            07720
       REM                                                              07730
STORE  SXD     TEMP-13,1       SAVE INDEX A.                            07740
       SXD     TEMP-14,2       SAVE INDEX B.                            07750
       LXD     J,1             PUT J INTO INDEX REGISTER A.             07760
LOCJA  LXD     MSHIFT,2        LOAD INDEX B WITH MSHIFT.                07770
       TIX     LOCJB,2,6       ADVANCE MSHIFT.                          07780
       AXT     36,2            REFRESH MSHIFT.                          07790
       TXI     *+1,1,1         RAISE J BY ONE IF MSHIFT IS OVER         07800
       STZ     VAR,1           CLEAR NEXT CELL                          07810
 LOCJB CLA     WORD            LEAVE SIGN BEHIND                        07820
       LDQ     =0                                                       07830
       LGR     42,2            MOVE CHARACTER                           07840
       STQ     TEMP-7          PLACES TO THE LEFT.                      07850
       CAL     TEMP-7                                                   07860
       ORS     VAR+1,1         STORE THE CHARACTER AT VAR.              07870
       SXD     MSHIFT,2        SAVE MSHIFT.                             07880
       SXD     J,1             SAVE J.                                  07890
       LXD     TEMP-13,1       RESTORE INDEX A.                         07900
       LXD     TEMP-14,2       RESTORE INDEX B.                         07910
       TRA     1,4             RETURN TO CALLING PROGRAM.               07920
       REM                                                              07930
       REM END OF THE SAP SUBROUTINE STORE.                             07940
       EJECT                                                            07950
       REM THIS IS SUBROUTINE TABLE.  IT IS USED TO                     07960
       REM CONSTRUCT A TABLE OF NAMES TO BE USED ON CARDS               07970
       REM AND THEIR MEMORY LOCATIONS RELATIVE TO ARG 2 OF              07980
       REM THE CALLING SEQUENCE.                                        07990
       REM                                                              08000
       REM                                                              08010
TABLE  SXD     TEMP-15,4       SAVE INDEX C.                            08020
       STZ     TEMP                                                     08030
LOCKA  TSX     CHRCTR,4                                                 08040
       TSX     COMPAR,4                                                 08050
       BCI     1,,00000                                                 08060
       TRA     *+5,2,2                                                  08070
       TRA     LOCKD+1         JUNK                                     08080
       TRA     LOCKA           ALPHABETIC                               08090
       TRA     LOCKD+1         NUMERIC                                  08100
LOCKB  STZ     TEMP            COMMA                                    08110
       TRA     LOCKD                                                    08120
       REM COMES HERE TO CONVERT THE ADDRESS TO OCTAL FOR               08130
LOCKC  CLA     TEMP            THE TABLE.                               08140
       ALS     2                                                        08150
       ADD     TEMP                                                     08160
       ALS     1                                                        08170
       ACL     WORD                                                     08180
       STO     TEMP            ADDS TO MAGNITUDE                        08190
       REM                                                              08200
       REM COMES HERE TO GET NUMERICS.                                  08210
LOCKD  TSX     CHRCTR,4                                                 08220
       TSX     COMPAR,4                                                 08230
       BCI     1,.=/000                                                 08240
       TRA     *+7,2,2                                                  08250
       TRA     ERRA            JUNK                                     08260
       TRA     ERRA            ALPHABETIC                               08270
       TRA     LOCKC           NUMERIC                                  08280
       TRA     LOCKT                 / CHARACTER                        08290
       TRA     LOCKF           = SIGN                                   08300
       REM                                                              08310
       REM COMES HERE IF A DECIMAL PT WAS FOUND.                        08320
 LOCKE CAL     TEMP            DECIMAL POINT                            08330
       CHS                     MAKE SIGN MINUS                          08340
       STO     TEMP                                                     08350
       TRA     LOCKD                                                    08360
       REM                                                              08370
       REM COMES HERE IF AN = SIGN WAS FOUND.                           08380
LOCKF  TSX     CLEAR,4                                                  08390
LOCKG  TSX     CHRCTR,4                                                 08400
       TQP     *+2,            MINUS MEANS FROM NEW CARD                08410
       TSX     TESTT,4                                                  08420
       TZE     LOCKH                                                    08430
       TSX     COMPAR,4                                                 08440
       BCI     1,/,0000                                                 08450
       TRA     *+5,2,1                                                  08460
       TRA     ERRG            JUNK                                     08470
       TRA     LOCKJ           ALPHABETIC OR NUMERIC                    08480
       SXD     B,2             COMMA                                    08490
       SXD     B,2             SLASH                                    08500
       TRA     LOCKK                                                    08510
       REM                                                              08520
       REM COMES HERE TO STORE CHARACTER.                               08530
 LOCKH ACL     =H000000                 REPLACE ZERO WITH LETTER O      08540
       STO     WORD                                                     08550
LOCKJ  TSX     STORE,4                                                  08560
       TRA     LOCKG                                                    08570
       REM COMES HERE AT END OF NAME.                                   08580
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LOCKK  TSX     LOOK,4                                                   08590
       TNZ     LOCKR            GOES TO LOCKR IF THERE IS AN ENTRY      08600
       LXD     J,1                                                      08610
       TXI     *+1,1,1          ASSEMBLE KEY                            08620
       PXD     0,1              IRB HAS FIRST FREE LOC.                 08630
       ACL     TEMP                                                     08640
 LOCKL SLW     **,2             STORE KEY INTO TABLE                    08650
       SXD     *+1,1            ADVANCE TO END                          08660
       TXI     *+1,2,**                                                 08670
 LOCKM CAL     VAR+1,1          MOVE NAME, 0 TO TABLE                   08680
 LOCKN XEC     LOCKL             SLW IN TABLE                           08690
       TNX     *+2,1,1          TRANSFER WHEN DONE                      08700
       TXI     LOCKM,2,-1       GO BACK TO FINISH                       08710
       ARS     34               KEEP ZONE OF 1ST VAR CH.                08720
       TZE     ERRG             WAS NUMERIC, OR J=0                     08730
       REM                                                              08740
       REM     REEXAMINE THE  CUT OFF CHARACTER.                        08750
LOCKP  LXD     B,2                                                      08760
       TXH     LOCKB,2,1              COMMA                             08770
LOCKQ  LXD     TEMP-15,4        / CHARACTER                             08780
       TRA     1,4              RETURN.                                 08790
       REM                                                              08800
       REM     COMES HERE TO REPLACE KEY                                08810
 LOCKR ANA     =0377777000000         J+1 IN DECREMENT                  08820
       ACL     TEMP                   LOCATION AND SIGN                 08830
 LOCKS XEC     LOCKL            SLW IN TABLE                            08840
       TRA     LOCKP                                                    08850
 LOCKT CAL     TEMP                   IS / LEGAL                        08860
       TZE     LOCKQ                  YES                               08870
       REM TRA     ERRA                   NO, NUMERICS WAITING          08880
       REM                                                              08890
       REM THESE ARE THE ERROR CALLS.                                   08900
ERRA   TSX     ERROR,4                                                  08910
       BCI     1,0(A)                                                   08920
ERRG   TSX     ERROR,4                                                  08930
       BCI     1,0(G)                                                   08940
       REM                                                              08950
       REM END OF THE SAP SUBROUTINE TABLE                              08960
       EJECT                                                            08970
       REM THIS IS SUBROUTINE TEST. IT LOOKS AHEAD TO CLASSIFY          08980
       REM A NEW CARD. ACOMMA WILL BE PUT INTO THE CURRENT              08990
       REM CHARACTER POSITION ONLY IF EITHER (1) THE NEXT               09000
       REM CARD BEGINS WITH A $ SIGN FOLLOWED BY SOME OTHER             09010
       REM CHARACTER OR (2) THE NEXT CARD BEGINS WITH AN                09020
       REM ALPHABETIC AND AN = SIGN IS FOUND AND IT PRECEEDS            09030
       REM     ALL , $ AND . CHARACTERS ON THAT CARD.                   09040
       REM                                                              09050
       REM                                                              09060
TEST   SKD     TEMP-12,4        SAVE INDEX FOR RETURN.                  09070
       SUB     =H0000$0         TEST FOR A $  SIGN.                     09080
       TPL     LOCLA            POSITIVE MEANS  $ SIGN.                 09090
       XEC     READ.            SAFE TO REFILL BUFFER                   09100
       TXL     LOCLB,1,16       NUMBERS AND SPECIAL                     09110
       TIX     *+1,1,33         FIX SO SLASH IS SPECIAL
       TIX     *,1,16           MOD OUT ZONE                            09130
       TXH     LOCLB,1,9        SPECIALS                                09140
       REM                      ALPHABETIC COME THRU.                   09150
LOCLC  AXT     15,1             SCAN THE CARD.                          09160
       LDQ     RECORD+3,1                                               09170
       TXI     *+1,1,69         FOR CHARACTER COUNT                     09180
       TXL     LOCLB,1,70       DONE IF WHOLE CARD SCANNED              09190
LOCLD  PXD     0,0              OK TO·SEARCH 84  COLUNMS                09200
       LGL     6                                                        09210
       PAX     0,2              ZONE TO IRB                             09220
       ANA     =017             KEEP DIGIT                              09230
       SUB     =013             DIGIT PART OF ,$.= CHR.                 09240
       TZE     LOCLJ                  CHECK ZONE                        09250
       TIX     LOCLD,1,14       TRY NEXT CHARACTER                      09260
       TRA     LOCLC+1                                                  09270
 LOCLJ TXH     LOCLB,2,15             , . $ NEED NO COMMA               09280
LOCLA  AXT     84,1             84 IS CARD COL 1                        09290
       SXD     I,1              RESET CHRCTR TO BEGIN CARD              09300
       CLA     RECORD-12                                                09310
       STO     Q                                                        09320
       CLA     =H00000,         SUBSTITUTE A COMMA.                     09330
       STO     WORD                                                     09340
LOCLB  LXD     TEMP-12,4                                                09350
       CLA     WORD             IN AC FOR SR NAME, TABLE                09360
       TRA     1,4              RETURN TO THE CALLING PROGRAM.          09370
       REM                                                              09380
       REM       FOR TABLE SUB STATEMENTS
 TESTT SXD     TEMP-12,4                                                09390
       AXT     84,4             IF NEXT CARD HAS VALID                  09400
       LDQ     RECORD-12        LEFT PART OF SUBSTATEMENT               09410
 LOCNB PXD     0,0                                                      09420
       LGL     6                                                        09430
       PAX     0,2                                                      09440
       TXH     LOCLB,2,48       0 ZONES EXCEPT BLANK                    09450
       TXH     LOCNC,2,47       BLANK                                   09460
       TXH     LOCLB,2,27       11 ZONES AND )                          09470
       TXH     LOCLA,2,26       .                                       09480
       TXH     LOCLB,2,11       12 ZONES AND 8-4                        09490
       TXH     LOCLA,2,10             =                                 09500
LOCNC  TIX     LOCNB,4,14       NUMERICS AND BLANK                      09510
       LDQ     RECORD+3,4                                               09520
       TNX     LOCLB,4,1                                                09530
       TXI     LOCNB,4,70                                               09540
       REM                                                              09550
       REM END OF THE SAP SUBROUTINE TEST.                              09560
       EJECT                                                            09570
       REM THE FOLLOWING FOUR SUBROUTINES ARE USED TO                   09580
       REM CONVERT DECIMAL DIGITS TO BINARY  IN VAR,                    09590
       REM FIX FLOATING POINT NUMBERS, FLOAT FIXED POINT                09600
       REM     NUMBERS, AND  FORM ARITHMETIC RESULTS IN THE             09610
       REM     PSEUDO ACCUMU LATOR (ACC) FOR EACH OPERATION             09620
       REM     ON A CARD.                                               09630
       REM                                                              09640
```

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BINARY CLA     VAR           ACCUMULATE A SERIES OF BASE 10
       ALS     2             DIGITS IN BINARY IN VAR.
       ADD     VAR
       ALS     1
       ACL     WORD
       STO     VAR
       TRA     1,4
       REM
FLT    CLA     TEMP          CONVERT TO FLOATING POINT THE
       LRS     18            CONTENTS OF THE STORAGE CALLED
       ORA     =0233000000000      TEMP.
       FAD     =0233000000000
       STO     TEMP          LEAVE THE ANSWER IN TEMP.
       TRA     1,4
       REM
 FIX   UFA     =0233000000000      CONV TO FIXED PT THE CONT
       LRS     0             OF THE ACCUMULATOR.
       ANA     =0377777
       LLS     0
       ALS     18            LEAVE THE FIXED POINT NUMBER IN
       TRA     1,4           THE ACCUMULATOR.
       REM
ACCUN  LXD     OPER,2        BRANCH FOR OPERATOR
       STZ     OPER          PREPARE FOR NEXT OPERATOR.
       CLA     TEMP
       TRA     *+5,2
       TRA     LOCMB         *
       TRA     LOCMA         /
       CHS                   MINUS
       FAD     ACC           PLUS
 ACCUN STO     ACC                 NONE
       TRA     1,4
       REM
LOCMA  CLA     ACC           DIVIDE.
       FDP     TEMP
       STQ     ACC
       TRA     1,4
       REM
LOCMB  LDQ     ACC           MULTIPLY.
       FMP     TEMP
       TRA     ACCUN
       REM
       REM
       REM END OF THE SAP SUBROUTINES ACCUM, FIX, FLOAT.
       EJECT
       REM SUBROUTINE PRINX DRAINS PRINT BUFFER TO LOGICAL TAPE
       REM                   GIVEN IN DECREMENT OF  OUTAPE
 PRINX SXA     PRINY,4             BUFFERED WRITE ROUTINE
       CLA     OUTAPE        LOGICAL OUTPUT TAPE NUMBER
       CALL    (IOS)
       AXC     IOCD,4
       XEC*    $(WRS)              =WTDL 6
       XEC*    $(RCH)              =RCHL 0,4
       PXA     0,4                 SAVE LOC OF
       STA*    $(WTC)              IO COMMAND FOR (WER)
       CLA     TSXWR               PRESET END ACTION
       STO*    $(TES)
 PRINY AXT     **,4
       TRA     1,4
 TSXWR CALL    (WER)               EXECUTED FROM (TES)
 IOCD  IORT    OUTBUF,,19
       EJECT
       REM SUBROUTINE READ. FILLS READ BUFFER FROM LOGICAL TAPE 7.
 READ. TSX     READ.+1,4           READ. GATE INITIALLY OPEN
       CLA     =0076100000000      CLOSE READ GATE
       STO     *-2
       SXA     AXT,4
       CLA     INTAPE        LOGICAL INPUT TAPE NO.
       CALL    (IOS)
       AXC     IOCD.,4
       XEC*    $(RDS)              =RTDL5
       XEC*    $(RCH)              =RCHL 0,4
       CLA     TSXTS               SET UP BUFFER TEST
       STO*    $(TES)
 AXT   AXT     **,4
       TRA     1,4
 TSXTS TSX     *+1,4               EXECUTED FROM (TES)
       SXA     AXT,4               CLOSE OUT BUFFER
       CLA     =0076100000000      SAY BUFFER IS QUIET
       STO*    $(TES)
       AXT     5,4                 PRESET REDUNDANCY
       SXA     RTT,4               COUNT
 TSXTT AXC     *+1,4
       XEC*    $(TCO)              =TCOL 0,4
       AXC     RTT,4
       XEC*    $(TRC)              =TRCL 0,4
       AXC     XIT.,4
       XEC*    $(TEF)              =TEFL 0,4 JOB COMPETE
       TRA     AXT                 RETURN
 RTT   AXT     **,4                INTERROGATE COUNT
       TIX     SXA.,4,1            GIVE ANOTHER TRY
       AXT     14,4                CARD SURE BAD
       CLA     INBUF+14,4          SAVE IMAGE
       STO     RECORD+2,4
       TIX     *-2,4,1
       AXT     84,4          MAKE ERROR ROUTINE LOSE*
       SXD     I,4                 IN INPUT BUFFER
       TSX     ERROR,4
 R     BCI     1,0(R)
 SXA.  SXA     RTT,4               SAVE COUNT
       AXC     *+2,4
       XEC*    $(TEF)              TURN OFF EOF IND
       XEC*    $(BSR)              BACKSPACE,
       AXC     IOCD.,4
       XEC*    $(RDS)              REREAD
       XEC*    $(RCH)
       TRA     TSXTT
```

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