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A COMPUTER PROGRAM FOR QUICKLY ANALYZING ELECTRIC PROPULSION MISSIONS

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16. Abstract

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Planet orbiters or flybys
Launch to parking orbit or direct to escape
Built in stable of launch vehicles or specified by input
High- or low-thrust Earth departure
High- or low-thrust planet arrival
Optimum or constrained power
Optimum or constrained thrust time
Optimum or constrained hyperbolic velocities
Optimum ($\alpha = f(P)$) or constrained propulsion system specific mass
All-ballistic high-thrust comparisons
Three output formats, including graphical

The program is quite accurate in simulating entire missions and can define their requirements very quickly due to the short execution times, which range from 0.1 second to 0.5 second, on an IBM 360-50 (0.05 to 0.25 on IBM 7094, 0.02 to 0.1 on IBM 360-75) depending on the option selected. Convergence is guaranteed.

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SUMMARY

A computer program is described that is capable of determining the performance and system requirements of electrically propelled spacecraft in combination with specific launch vehicles and high-thrust upper stages. The formulation of the logic and optimization techniques are described as well as the functional relationships that define the characteristics of the high- and low-thrust systems. The several output formats, including a plot option, are illustrated, and complete descriptions of all input and output parameters and a program listing in Fortran IV are given. The input is simplified by use of colloquial variables. Example problems are provided which depict the usage of the various options available to the user. These options include:

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INTRODUCTION

As the national space program progresses, there is growing interest in performing missions that have greater propulsive energy requirements than those performed to date. One method of accomplishing such missions is through the use of electric propulsion. The analysis of the performance and system requirements for this type of advanced propulsion has in the past centered on detailed trajectory studies (ref. 1). The computation of optimized low-thrust trajectories is complicated by the requirement for integration of the equations of motion and the solution of the subsequent boundary-value problem with concomitant optimization of the system parameters. More than 50 attempts have been made over the years to develop low-thrust trajectory and mass-computation programs that ease this computer-time-consuming problem (ref. 2).

The slow execution speeds of most of these programs have excluded their use in investigating wide ranges of variables necessary to identify commonality in mission and system characteristics. Many programs are quite inflexible and do not allow study of interesting options such as constrained power level and contrained thrusting time, or various departure and arrival modes. The program described in this paper evolved from an effort to produce a useful low-thrust mission-analysis tool of acceptable accuracy and compute time that would be applicable to a range of problems.

The computer program defines the performance and system requirements of electrically propelled unmanned planet-orbiter and flyby missions using existing launch vehicles for the Earth launch phase, and high-thrust upper stages or low-thrust spiral maneuvers for Earth-departure and planet-arrival phases. The characteristics of the launch vehicles and high-thrust stages may be specified in lieu of the built-in values. The electric propulsion system may be completely optimized, or may be constrained in power level, thrusting time, propulsion system specific mass, or departure and arrival velocities. Rather than integrate the low-thrust trajectory, functional relationships for the energy requirements of precomputed optimum trajectories obtained from accurate computer programs are stored within the code (refs. 3, 4). Curve-fitting procedures have been used in defining the energy parameters as a function of time and hyperbolic excess velocity at Earth departure and planet arrival. A method of system optimization based on the near invariance of certain parameters with system variables was found to be quite accurate. Low-thrust and high-thrust planetocentric operations are expressed analytically, and their velocity is matched with the heliocentric phase. Correlation with exact trajectory data is excellent, and the computer times are less than a second per fully optimized case.

Most important are the fail-safe and user-convenience features of the code. Convergence is assured on any case that has a solution. On all other cases, the code repairs any damage to its logic and proceeds to the next input case. This facilitates the running of numerous cases with large ranges in parameters. Also, much effort has been expended in developing the program with the lay user in mind. The input has been simplified through the use of colloquial variables such as the proper names of launch vehicles and planets, and the straightforward spelling of parameters to indicate their function such as MODE = FLYBY, ARRIVE = HIGH, LAUNCH = ESCAPE. The Fortran IV program coding has been kept relatively simple so that the logic flow may be followed easily and changed to suit a user's particular needs. The program is being sent to the regional dissemination center, COSMIC, located at the University of Georgia, for general availability.

ANALYSIS

The definition of the performance and system requirements of an unmanned interplanetary space mission involves the apportionment of stage masses at each phase such that maximum payload may be delivered for a given launch weight and given constraints. The problem complexity increases when one of these stages is electrically propelled, for it is then necessary to properly mate both high- and low-thrust systems having markedly different characteristics. The optimization of the various stage and system parameters has generally required many iterations involving time-consuming low-thrust trajectory integration. To provide a computational tool for electric-propulsion mission analysis of sufficient speed to allow broad coverage of cases, the low-thrust trajectories have been precomputed and stored within the program described herein. The data, ready for instant recall, is stored in the form of functional relationships between the trajectory parameters $J = \int a^2 dt$, coast time, operating time, and initial and final velocities. Since J is a good indicator of energy requirements, the minimization of this parameter over the planetocentric and heliocentric phases will yield the optimum apportionment of the operating times within these phases. The energy parameter J is heavily time-dependent and is additive over the phases:

$$J_T = J_D + J_H + J_C \tag{1}$$

where

$$J_T = f(T_T)$$

$$J_D = f(T_D)$$

$$J_H = f(T_H)$$

$$J_C = f(T_C)$$

and subscripts:

T total

D departure

H heliocentric

C capture

The program thus minimizes the summation of J_T while seeking the best division of the total mission time among the various phases. The description of this problem solution will proceed in the order in which the code handles each phase.

Launch

Since most analyses of unmanned interplanetary missions begin on the launch pad, the characteristics of a stable of 11 presently conceived or operational launch vehicles have been built into the program. The characteristics of these vehicles, an example of which is shown in figure 1, are stored in 16 valued tables of PAYUP (payload mass of vehicles, kg) versus VC (characteristic velocity of vehicle, km/sec). The stored values of the selected launch vehicles may be found in subroutine DPART. If the analyst desires to use a vehicle that is not in storage, he need only input the tabular values of PAYUP and VC (a maximum of 16 values each). The convention adopted in this study is that all launch vehicles attain at least low circular orbit speed so that the initial values in the tables should correspond to low Earth orbit conditions.

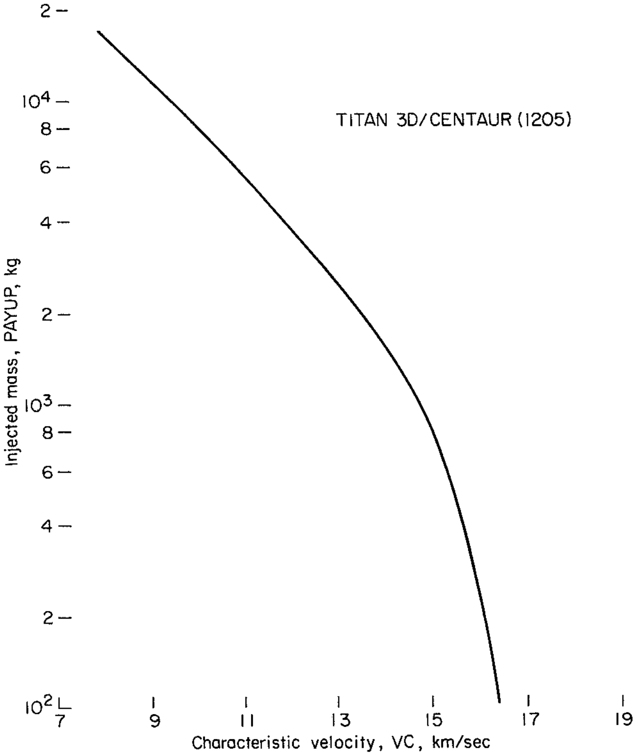


Figure 1.- Example of built-in launch vehicle characteristics.

If the launch vehicle is to place its payload into a parking orbit (LAUNCH = PARK), the input parameters of the parking orbit (RP1 and EPSD) are used to calculate the required characteristic velocity, VC. Since the performance of the vehicles are stored with minimum requirements starting in low Earth orbit, all launch velocities computed internally are additive to circular velocity, 7.75 km/sec, at 185-km (100-n.mi.) altitude. The velocity requirement to transfer from the 185-km circular orbit to the trajectory that will coast to the specified orbit perigee (RP1) is given by:

$$V1 = \sqrt{\frac{GM}{A_{12}}\left(\frac{1 + \varepsilon_{12}}{1 - \varepsilon_{12}}\right)} - 7.75 \qquad (2)$$

where

GM 39.86 (10^4 km^3/sec^2)

A_{12} semimajor axis of transfer orbit = $\frac{RG}{2}$ (RP1 + 1.029)

ε_{12} eccentricity of transfer orbit = $\frac{RP1 - 1.029}{RP1 + 1.029}$

The velocity requirement to establish the desired parking orbit at the radius RP1 is given by:

$$V2 = \sqrt{\frac{GM}{A_D}\left(\frac{1 + EPSD}{1 - EPSD}\right)} - \sqrt{\frac{GM}{A_{12}}\left(\frac{1 - \varepsilon_{12}}{1 + \varepsilon_{12}}\right)} \qquad (3)$$

where

EPSD eccentricity of desired orbit

A_D semimajor axis of desired orbit $= \frac{(RG)RP1}{1.0 - EPSD}$

RG radius of Earth

The total velocity required of the launch vehicle is:

$$VC = 7.75 + V1 + V2$$

The code then enters the tabular values of VC using a second-order interpolation to determine exact values of launch vehicle payload, BOOSTL.

If the launch vehicle is to place its payload unto an escape trajectory (LAUNCH = ESCAPE), the required velocity is simply:

$$VC = \sqrt{(VINF1)^2 + 2(7.75)^2} \qquad (4)$$

where VINF1 is the departure velocity either constrained by input of VA or left for program optimization. The code then determines the payload (BOOSTL) from the appropriate launch vehicle tabular values.

Depart

When the launch vehicle is used to place its payload into a parking orbit (LAUNCH = PARK), the user should indicate his choice of departure stage thrust level by input. Departure from orbit via a high-thrust rocket (DEPART = HIGH) requires the calculation of the energy and performance based on the stage and orbital characteristics. The velocity increment required of the system is:

$$\Delta V = \sqrt{(VINF1)^2 + \frac{2(GM)}{RP1(RG)}} - \sqrt{\frac{GM}{A_D}\left(\frac{1 + EPSD}{1 - EPSD}\right)} \qquad (5)$$

The payload ratio of the high-thrust system is given by:

$$DEPL = \frac{BOOSTL - WFUEL - WINERT}{BOOSTL} \qquad (6)$$

where

WFUEL	$\left\{1 - \exp\left[\frac{-\Delta V}{\mathrm{DISP}(0.00981)}\right]\right\}$ BOOSTL
WINERT	DINERT + DSIGMA[WFUEL]
DINERT	input fixed stage weight
DSIGMA	input tankage fraction
DISP	input specific impulse

For internal accounting purposes, the high-thrust departure payload ratio is set equal to 1 whenever LAUNCH = ESCAPE, since the departure stage is part of the launch vehicle.

With DEPART = LOW, the code will simulate a low-thrust sprial escape of Earth from the designated parking orbit. The method of describing the spiral escape maneuvers uses expressions developed by Edelbaum (ref. 5) on the basis of the work of Breakwell and Rauch (ref. 6), and considers the asymptotic matching of the planetocentric and heliocentric trajectories that are under the influence of both the Sun and the Earth. The low-thrust characteristic velocity increment under optimal steering during planet escape is given by:

$$\Delta V = V - 1.84V\left[\frac{A_o A_D A_D}{(GM)\mu_1}\right]^{1/4} \tag{7}$$

where

A_o	initial acceleration = $\frac{C(1 - \mu_1)}{T_D}$
V	parking orbit velocity
μ_1	departure phase mass ratio
C	exhaust velocity of system
T_D	departure time

The low-thrust system is assumed to operate continuously during the spiral escape, therefore, T_D is the powered time. The final mass ratio for this maneuver is:

$$\mu_1 = \exp\left(\frac{-\Delta V}{C}\right) \tag{8}$$

and the energy parameter $J = \int a^2 dt$ for constant-thrust planet departure is given by:

$$J_D = \left(\frac{A_o^2}{\mu_1}\right) T_D \tag{9}$$

from which it follows that for a given orbit J_D is simply a function of C and T_D. Further, it can be shown that the influence of exhaust velocity on J_D is very slight and is herein calculated for a fixed value of C. Hence, the departure phase is described by:

$$J_D = f(T_D)$$

$$T_D = \text{departure time} = \text{powered time}$$

which will be used in the minimization of total J_T for the electric-propulsion system optimization. Again, for internal accounting purposes, the high-thrust departure payload ratio is set equal to 1 whenever DEPART = LOW.

Mode

The low-thrust heliocentric phase is the next stage of the analysis and may be either a flyby (MODE = FLYBY) or an orbiter (MODE = ORBIT). Under the flyby mode, the spacecraft is assumed to traverse an optimum heliocentric travel angle and to pass within the vicinity of the target planet with an unconstrained approach velocity. Orbiter spacecraft are assumed to traverse an optimum travel angle and to apply some braking propulsion such that a useful payload may be placed in a specified orbit about the target planet. To avoid the time-consuming problem of trajectory integration at each step of the optimization within this program, the low-thrust trajectories for a range of mission times and initial and final velocities have been precomputed using accurate programs (see fig. 2) and the data have been stored in the form of the following relationships:

$$\ln J_H = A + B \ln T_H + (\ln T_H)^2 \left[C_o + C_1 (V_1 + V_2)^{C_3}\right] \tag{10}$$

and powered time

$$T_{HP} = D T_H^{E} \tag{11}$$

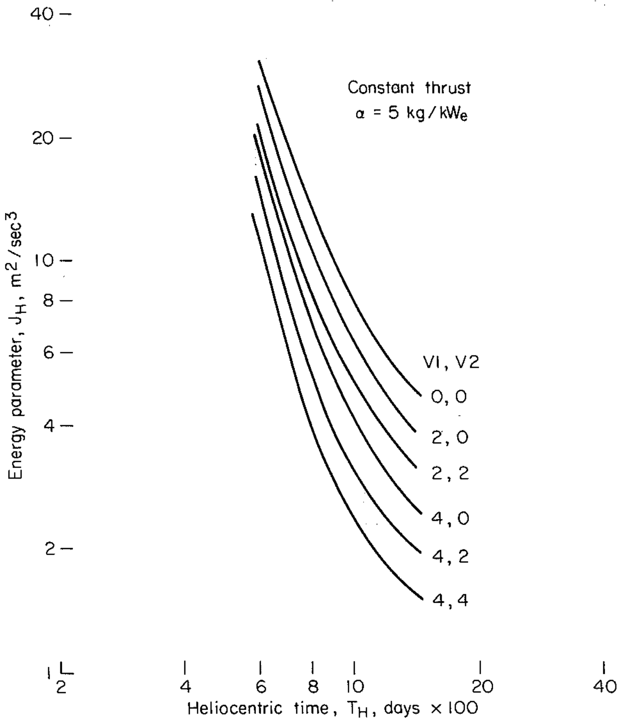


Figure 2.- Example of actual low-thrust performance stored in program for planet Jupiter.

where the constants A, B, C, D, and E are determined by the method of least squares to best represent the precomputed data. Hence, for given initial velocity V_1 and final velocity V_2 (in the case of orbiters), the heliocentric phase is described by:

$$J_H = f(T_H), \qquad T_{HP} = f(T_H)$$

For ease of convergence, the stored data have been generated using a powerplant specific mass α of 5 kg/kWe. The energy parameter J_H and the thrust time T_{HP} vary slightly with the system parameter α and are empirically described by:

$$J_H = J_H(1 + \text{vary}) \tag{12}$$

$$T_{HP} = T_{HP}(1 + \text{vary})^{1/3} \tag{13}$$

where

$$\text{vary} = 0.0001667 J_H(\alpha - 5)$$

Planetoheliocentric Matching

The heliocentric initial velocity V_1 differs from the planetocentric high-thrust departure velocity VINF1 by the amount gained in thrusting along the planetary escape trajectory immediately following high-thrust engine cutoff. This gain in velocity, due to applying even a small amount of finite thrust close to a gravitating body, is accounted for by either the method of asymptotic matching of the high-thrust hyperbolic departure trajectory with the low-thrust heliocentric trajectory (ref. 7) (MATCH = ASYMPT) or by the method of sphere of influence matching (MATCH = SPHERE built-in). Under sphere-of-influence matching, the low-thrust system initial velocity is related to the high-thrust system departure velocity by:

$$V1 = \sqrt{(VINF1)^2 + \frac{2GM}{145RG}} \tag{14}$$

$$V2 = \sqrt{(VINF2)^2 + \frac{2GM}{(RSPHERE)RGP}} \tag{15}$$

Under asymptotic matching, the low-thrust system initial velocity is related to the high-thrust system departure velocity by:

$$V_1 = G_{(X)} A_o{}^{1/4} \tag{16}$$

where

$$X = \frac{(VINF1)^2}{4\sqrt{(GM)A_o}}$$

$G_{(X)}$ contains complete elliptic integrals of the first and second kind, which have been accurately curve-fitted and stored within the program. Hence, it is noted that:

$$V_1 = f(\mathrm{VINF1}, A_o)$$

In similar fashion for orbiters with high-thrust capture,

$$V_2 = G_{(X)} \left(\frac{A_o}{\mu_1}\right)^{1/4} \tag{17}$$

where

X	$\dfrac{(\mathrm{VINF2})^2}{4\sqrt{\mathrm{GMP}(A_o/\mu_1)}}$
GMP	gravitational constant of target planet
VINF2	arrival velocity to be applied by high-thrust retrostage (constrained by input or left for optimization)
μ_1	final mass ratio of electric stage

Arrival

In the case of orbiters, a choice may be made on the thrust level for planet capture. ARRIVE = HIGH instructs the code to retrobrake into the desired orbit using a high-thrust stage of specified characteristics. The velocity increment is:

$$\Delta V = \sqrt{(\mathrm{VINF2})^2 + \frac{2(\mathrm{GMP})}{\mathrm{RP2(RGP)}}} - \sqrt{\frac{\mathrm{GMP}}{A_c}\left(\frac{1 + \mathrm{EPST}}{1 - \mathrm{EPST}}\right)} \tag{18}$$

where

RGP	radius of target planet
RP2	periapsis of capture orbit
EPST	eccentricity of capture orbit
A_c	semimajor axis of capture orbit = RP2(RGP)/(1 - EPST)

The payload ratio of the high-thrust arrival system is given by:

$$\mathrm{ARRL} = \frac{\mathrm{APROCH - WFUEL - WINERT}}{\mathrm{APROCH}} \tag{19}$$

where

WFUEL	$\left\{1 - \exp\left[\frac{-\Delta V}{\mathrm{AISP}(0.00981)}\right]\right\}$ APROCH
WINERT	AINERT + ASIGMA(WFUEL)
AINERT	input fixed stage weight
ASIGMA	input tankage fraction
AISP	input specific impulse

With ARRIVE = LOW, the code will simulate a low-thrust spiral capture into the designated arrival orbit. The method of asymptotic matching similar to that described under DEPART = LOW yields the following:

$$J_c = f(T_c)$$

$$T_c = \text{capture time} = \text{powered time}$$

Optimization

The maximization of final payload requires the optimum allotment of mass during each phase. The overall payload is given by:

$$\mathrm{PAYLOAD} = (\mathrm{MLE})(\mathrm{ARRL})(\mathrm{DEPL})(\mathrm{BOOSTL} - \mathrm{WEJECT}) \tag{20}$$

where WEJECT represents any interstage mass, low-thrust start-up equipment, etc., which the analyst wishes to discard after launch vehicle injection. Thus, DEPL(BOOSTL - WEJECT) defines the initial gross mass of the low-thrust system. The definitions of BOOSTL, DEPL, and ARRL have been given above and require only iterations on the departure and arrival velocities to determine their values in the overall optimization scheme. The low-thrust payload mass fraction, MLE, can be determined as an integral part of minimizing J and apportioning the time spent in each phase. A method of system optimization (ref. 8), based on the near invariance of J with system parameters, has been found to be quite accurate, especially when the slight variation can be predicted and compensated. The underlying assumptions to this method are that the minimum value of J is invariant to μ_w, and the average thrust acceleration over a trajectory with a minimum J is also invariant to μ_w. The average thrust acceleration may be described by:

$$\bar{a} = (a_0 a_1)^{1/2} \tag{21}$$

and the initial acceleration by:

$$a_0 = \frac{2\eta\mu_w}{\alpha C} \tag{22}$$

where

C exhaust velocity

a_1 final acceleration = a_o/μ_1

An alternate expression for the average acceleration is:

$$\overline{a} = (J_T/T_P)^{1/2} \qquad (23)$$

where J_T has previously been defined as:

$$J_T = \int_o^T a^2\,dt = J_D + J_H + J_C$$

and T_P is the total propulsion time along the entire low-thrust trajectory including all phases:

$$T_P = T_D + T_{HP} + T_C \qquad (24)$$

The ratio of electric-propulsion payload mass (or net spacecraft mass as defined in this program) to its initial mass, DEPL(BOOSTL - WEJECT), is given by:

$$MLE = \mu_1 - \mu_W - \mu_T \qquad (25)$$

and the final mass ratio is given by:

$$\mu_1 = \frac{\mu_W}{\mu_W + \frac{\gamma^2}{\eta}} \qquad (26)$$

where

μ_W powerplant mass ratio

μ_T propellant tankage ratio = $k(1 - \mu_1)$

k tankage fraction (0.03 built-in)

η thrustor subsystem efficiency

γ^2 $\alpha J_T/2$

α powerplant specific mass

It is convenient to define the thrustor subsystem efficiency in the form of an analytical function whose derivative is continuous, thus:

$$\eta = \frac{B}{1 + (D/C)^2} \qquad (27)$$

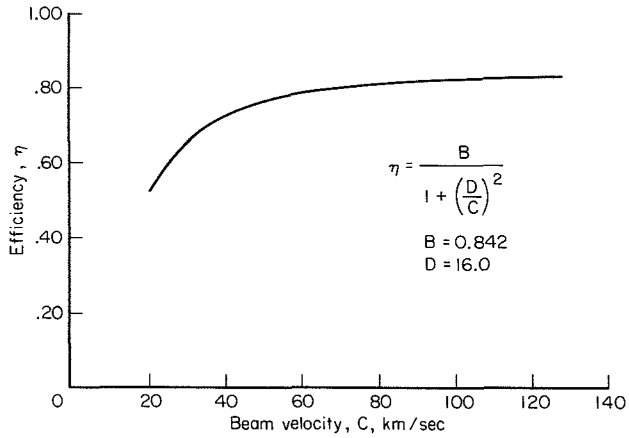


Figure 3.- Thrustor subsystem efficiency.

where

B constant (0.842 built-in)

D constant (16.0 built-in)

The best fit of B and D values to projections of references 9 and 10 is shown in figure 3, which includes a 90 percent power conditioning efficiency.

Optimum Power Level

To maximize payload, it is necessary to optimize the system parameters, exhaust velocity, and powerplant mass ratio. Setting the first variation of the payload mass ratio MLE equal to zero and using equations (23), (26), and (27) and the above relationships, the following expressions result for the optimum system parameters:

Exhaust velocity:

$$C = \left[\frac{2BT_P}{\alpha} + \frac{2BT_Pk}{\alpha} + D^2 - \frac{2T_P\gamma}{\alpha}\left(B + Bk + \frac{\alpha D^2}{2T_P}\right)^{1/2}\right]^{1/2} \tag{28}$$

Powerplant mass ratio:

$$\mu_W = \frac{\gamma + \gamma k + \frac{\gamma\alpha D^2}{T_PB}}{\left(B + Bk + \frac{\alpha D^2}{2T_P}\right)^{1/2}} - \frac{\gamma^2}{B} \tag{29}$$

The final mass ratio μ_1 and the payload fraction MLE may be found by direct substitution of μ_W and C into equations (26) and (27), giving:

$$\mu_1 = 1 - \frac{\gamma}{\left(B + Bk + \frac{\alpha D^2}{2T_P}\right)^{1/2}} \tag{30}$$

$$\text{MLE} = 1 + \frac{\gamma^2}{B} - \frac{2\gamma}{B}\left(B + Bk + \frac{\alpha D^2}{2T_P}\right)^{1/2} \tag{31}$$

The values of B, D, k, and α are presumably known; thus, the above optimum system equations require the total propulsion time T_P and the total energy parameter J_T which are functions of the heliocentric time T_H and the initial and final velocities V_1 and V_2. Hence, for maximum PAYLOAD, we need to determine the optimum V_1 and V_2 that maximize the payload of the combined heliocentric and planetocentric phases while seeking the best combination of T_D, T_H, and T_C. This is accomplished by incrementing the velocities in alternate fixed steps, DELV1, DELV2 (built-in values are both 0.5 km/sec) while iterating between the apportionment of time spent in each phase until the maximum overall payload is achieved. The optimum power level for the completely unconstrained case is given by:

$$\text{POWER} = \frac{\mu_W}{\alpha} \text{DEPL(BOOSTL - WEJECT)} \tag{32}$$

where DEPL(BOOSTL - WEJECT) represents the initial low-thrust system gross mass. The initial acceleration is:

$$\text{AZERO} = \frac{0.002\ \mu_w \eta}{\alpha C} \tag{33}$$

where μ_w and C are the optimum values found above.

Constrained Power Level

The preceding analysis has dealt with the case of fully optimized system parameters μ_w, T_P, C, and POWER. It often is necessary to determine the performance and requirements of a system that has a specified fixed power level. Through input of the desired powerplant characteristics ALPHA and POWER the mass and power level of the systems are constrained. The mass of the powerplant is given by:

$$\text{WPLANT} = \text{(ALPHA)POWER} \tag{34}$$

and the powerplant mass fraction is simply:

$$\mu_w = \frac{\text{WPLANT}}{\text{DEPL(BOOSTL - WEJECT)}} \tag{35}$$

From the previous definitions and equations (21), (22), (26), and (27), the following expression for exhaust velocity in terms of powerplant mass fraction results:

$$C = \left\{ 0.5 \left(1 + \frac{\gamma^2}{B\mu_w}\right) \left(\frac{B^2 J T \mu_w^{\ 2}}{\gamma^4}\right) \left[1 + \sqrt{1 - \frac{1}{TJ}\left(\frac{2D\gamma^2}{\gamma^2 + B\mu_w}\right)^2}\,\right] - D^2 \right\}^{1/2} \tag{36}$$

The required initial acceleration for this fixed power case is now:

$$A_{FP} = \frac{0.002\ \mu_w \eta}{\alpha C} \tag{37}$$

This change in initial acceleration, caused by a fixed μ_W and newly computed C, will affect the energy parameter J_T and the two assumptions underlying the previous method of system optimization. A technique of system optimization was therefore used which is based on the near invariance of trajectory characteristic length L with system parameters (ref. 11). In this technique, the characteristic length of a trajectory is assumed constant regardless of the type of propulsion system used to traverse its path. The form of this parameter, which is a measure of the energy requirements for the mission, is given by:

$$L = \frac{C^2}{A_o}\left[\left(1 - \sqrt{1 - \frac{A_o T_P}{C}}\right)^2 - \frac{A_o}{C}\,(T_T - T_P)R(\ell n)\left(1 - \frac{A_o T_P}{C}\right)\right] \tag{38}$$

where T_T is the total mission time. The constant R as derived (ref. 11) was 0.5. However, after inspection of numerous cases, the constant R used in this program was empirically set at 0.4, which causes L to more closely define both the optimum and constrained missions, and is identified as LPRIME (L'). Thus, L' is a function of C and T_P, since A_o depends on C. Ideally, one would hope to determine L' for the optimum power case and set it equal to the L' for the constrained case, thereby requiring only an iteration on T_P to determine the best C. Unfortunately, even L' varies with acceleration A_o, and, although slight, the variation is sufficient to cause unnecessary error in C and T_P and therefore low-thrust payload MLE. After some observation, the variation of characteristic length with acceleration, for the fixed-power case, was found to be simply:

$$L'_{FP} = L'_{OPT}\left(0.9 + 0.1\,\frac{A_{OPT}}{A_{FP}}\right) \tag{39}$$

where A_{OPT} and L'_{OPT} refer to the acceleration and length of the optimum power case, and A_{FP} and L'_{FP} refer to the fixed-power case. The method of solution is to first guess a T_P and solve equation (36) for C (with the known fixed μ_W). Next, determine the new A_{FP}, equation (37), and use equations (38) and (39) to determine a new value of T_P. Equation (36) is then solved for the new value of C. The final mass ratio is given by:

$$\mu_1 = 1 - \frac{A_{FP}T_P}{C} \tag{40}$$

and the payload mass ratio is given by:

$$MLE = \mu_1(1 + k) - \mu_W - k \tag{41}$$

Constrained Thrust Time With Fixed Power

In addition to the case of contrained power level, it is also realistic to specify a fixed upper bound on thrusting time. As for both optimum power and constrained power cases, the coast and thrust phases must still be optimally placed. The technique for system optimization of the fixed-thrust time with fixed-power case is similar to that of the fixed-power case. However, the trajectory characteristic length varies with both acceleration and thrust time in the following manner:

$$L'_{FTP} = L'_{FP}\left[0.85 + 0.15\left(\frac{A_{FP}}{A_{FTP}}\right)\left(\frac{\text{TIMEON}}{T_{FP}}\right)\right] \tag{42}$$

where A_{FTP} is the initial acceleration of the fixed-time, fixed-power case, TIMEON is the input constrained thrusting time upper limit, and T_{FP}, A_{FP}, and L'_{FP} are the thrust time, acceleration, and characteristic length found in the constrained-power, optimum-thrust-time case, which is solved prior to the constrained-power, constrained-time case. The procedure of solution is to guess a value of C, determine A_{FTP} and then compute L'_{FTP} by equation (42). Next, equation (38) is solved for the new value of C (knowing both T_P = TIMEON, which is input, and μ_W, which is computed from the constrained POWER input) and repeat the process until convergence. An excellent first guess for the exhaust velocity is:

$$C = C_{FP}\left(\frac{\text{TIMEON}}{T_{FP}}\right) \tag{43}$$

where the subscript FP refers to the previously solved fixed-power, optimum-time case. After determination of C, the low-thrust payload mass ratio computation proceeds in a manner similar to that of the previous case. The overall PAYLOAD optimization continues as the initial and final velocities are incremented and the phase times are apportioned with a subsequent iteration through the low-thrust system optimization, as described in the previous three subsections.

Powerplant Specific Mass as a Function of Power

An additional option may be exercised to investigate the effect of optimally sizing the powerplant to a launch vehicle - mission combination according to an assumed level of technology. Through the use of a functional relationship between power level and powerplant specific mass, the analyst can realistically determine the best compromise powerplant for a range of missions (ref. 12). Built into the code is the following empirical relationship, which is shown in figure 4:

$$\text{ALPHA} = (\text{WPLANT})\text{POWER}^{\text{PPK}} \tag{44}$$

where

WPLANT	constant describing the relationship (350.0 built-in)
PPK	constant defining the technology level as: -0.4 = state of art, -0.5 = nominal, -0.6 = advanced

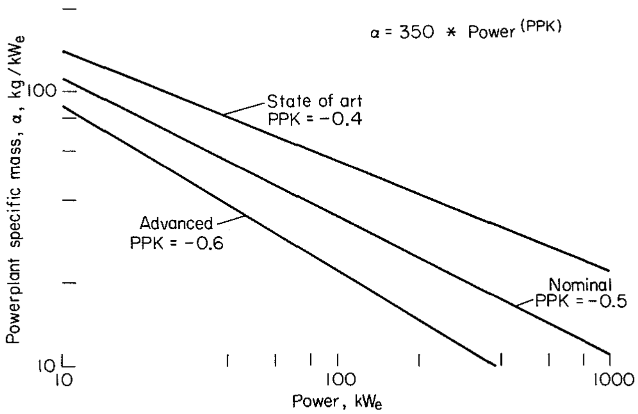


Figure 4.- Powerplant technology levels.

It is seen that ALPHA will increase as POWER decreases. The code will automatically recycle itself until it finds the optimum power level, and hence ALPHA, which will yield the maximum payload for a given launch weight on a particular mission (ref. 13). When using this option, ALPHA or POWER are not input, as they will be computed internally. The only input required is PPK and WPLANT (if the user wishes to override the built-in value of 350.0).

DISCUSSION

General User Comments

The program described in this report has been used extensively for a wide range of missions. The experience gained in using the code has led to modifications and improvements to facilitate its use by others. No initial guesses are required on the part of the user since all initial values and starting solutions are provided internally. Convergence is completely assured on any case that has a solution. On all other cases, the code repairs any damage done to its logic and proceeds with the next input case. This expedites the running of numerous cases with large ranges in parameters. Built into the code are automatic input loops on ALPHA, TIME, POWER, and EPST, which allow the analyst the flexibility to cover large ranges in these variables. Upon input of a range of parameters, it is advantageous to run cases in the order of increasing difficulty (i.e., TIME = 1000.0, 800.0, 600.0; ALPHA = 30.0, 40.0, 50.0). Because of built-in cutoffs, time is saved by eliminating all missions more difficult than the last one to fail (negative payload). Reasonable values of most parameters have been built in (see appendix A) which, of course, the analyst can override with his own desired input values. The input itself has been simplified through the use of colloquial variables such as the proper names of launch vehicles and planets (BIRD = 'ATLAS/CENTAUR', 'PLANET = SATURN', etc.) and the straightforward spelling of parameters to indicate their function such as MODE = FLYBY, ARRIVE = HIGH, LAUNCH = ESCAPE, etc. All proper names in the input should be enclosed by quote marks.

The program has been coded in FORTRAN IV and has been kept relatively simple so that the logic flow may be followed easily, thereby facilitating the inevitable changes to suit a user's particular needs. The program has been exercised on the IBM 360-50 computer and the storage requirements are minimal. The execution times on this computer range from 0.1 second (flyby with optimum power) to 0.5 second (orbiter with constrained power and constrained thrust time and with initial and final velocities to be optimized). Execution times on other computers are estimated to be 0.05 to 0.25 on the IBM 7094, and 0.02 to 0.1 on the IBM 360-75. These times represent a two to three order-of-magnitude reduction in the compute times of other existing programs on the same subject. Nor has accuracy been sacrificed, as correlation with exact mission simulation data is excellent (refs. 1, 14).

The output format has been selected to allow a one-line listing per case so that as many as 40 missions may be concisely filed on one page. The output is to the line printer and is sized for inclusion in loose-leaf notebooks. Appendix B contains the output parameters and their definitions. In addition to the conventional listing, a graph of the data may be obtained by stating on input PRINT = GRAPH. This allows a plot of net spacecraft mass versus mission time for a family of powerplant specific mass. Built into the program is a diagnostic feature that on input of PRINT = HELP will output various key parameters internal to the program in case of unforeseen problems (see line 233 of main program).

In addition to the options covered thus far there is another feature that may be useful. To compute the all high-thrust propulsion cases for purposes of comparison with the low-thrust missions, simply input ALPHA = 0.0 and the VA and VB equal to the hyperbolic excess velocities associated with the all-ballistic mission. Accordingly, the code will compute only the launch, departure, and arrival conditions with a coast trajectory assumed for the entire heliocentric phase. All planetocentric maneuvers will be calculated using the characteristics of the high-thrust systems that are either built-in or overridden by input.

To illustrate the requirements for deck make-up of a job, appendix C displays the IBM cards used for example problem 3. It will be noticed that the fourth card includes the subroutines MPX04F1 through F5, which are basic to this program. The fifth card includes subroutines MOX01UP and MOX01IN. Subroutine MOX01UP is a graph or plot routine available to IBM 7094 users under the name UMPLOT. It has been modified to run on the IBM 360 series and requires the four program calls PLOT1 through 4. Subroutine MOX01IN is a data input routine that is similar to, and may be replaced by, IBM's NAMELIST input routine. The CALL INPUT within the program should be changed to be READ statements. The present input routine allows cases to be stacked by simply placing an asterisk card between each set of input. Only those input quantities which are to be changed need be added after the asterisk. All data may be punched on the cards in free form. To familiarize potential users with the code, a series of example problems are included in appendix D. A complete listing of the program FORTRAN statements is given in appendix E.

As with any program, there are certain limitations and restrictions inherent to the operation of the code described here. These are set forth in the following paragraphs along with some suggested extensions to its application.

Limitations

The simulation of a particular mission is limited by the amount of precomputed and stored data. The trajectory data, within the code, for Mercury and Venus do not include the variation with initial and final velocities, and there are no data stored for Pluto as yet. Jupiter swingby electric-propulsion data have not yet been included in the program and would represent a very useful extension of this research tool. Users of the program who find a need for data such as the above may conveniently store the information as outlined in the analysis section. Of course, the accuracy of any simulated mission is dependent on the accuracy of the stored data, which requires detailed trajectory computations and efficient curve fits. Inevitably, some missions will require extrapolations of the stored information, and the proper form of the representative curves will afford greater confidence in the result.

Extensions of the Program

If more refined simulation is desired, one may consider the coupling of this level 1 code with a more accurate level 2 trajectory program. The mission may then be recomputed using a detailed trajectory subroutine (ref. 15) with the level 1 parameters as an initial starting solution. This method allows the user various levels of analyses and gives him the flexibility of trading accuracy for time. The execute times for this scheme are greatly reduced since in the lower level of analyses the trajectory data has already been computed, and in the higher level excellent initial solutions are available for the optimization of system and trajectory parameters such as specific impulse, powerplant mass fraction, thrust acceleration, operating time, and departure and arrival velocities.

An integral part of overall mission simulation should include the definition of the propulsion system hardware. Although a simple relationship between power level and system mass is built-in, a more rigorous treatment of system analysis may be provided through the coupling of this present code with a systems and hardware definition program. Within such a code, the system may be detailed into subsystem modules, including thrustor and power conditioning mating; thermodynamic cycle calculations; radiator weight and area analysis; apportionment of accessory equipment, pumps, plumbing, etc.; reactor characteristics, shield weight breakdown; and geometric configuration design and weight summary. There would be, of course, feedback loops and optimizations between various subsystems, which may be subject to mission constraints such as distance from Sun, operating time, ambient temperature, power level, diameter of launch vehicle, etc. When fully developed, the mathematical modeling of the powerplant characteristics would allow the interplay necessary to an overall low-thrust mission simulation tool.

National Aeronautics and Space Administration
Moffett Field, Calif. 94035, Nov. 24, 1969

APPENDIX A

INPUT PARAMETERS

Variable name	Description
TIME	Total mission time, days
NT	Number of missions times input (NT = 1 built in)
ALPHA	Powerplant specific mass, kg/kWe
NA	Number of alphas input (NA = 1 built in)
LAUNCH	Type of launch trajectory desired = ESCAPE, will launch booster payload to escape = PARK, will launch booster payload to parking orbit
RP1	Radius of parking orbit if LAUNCH = PARK, Earth radii
EPSD	Eccentricity of parking orbit (0.0 built in)
BIRD	Proper name of launch vehicle selected (must be enclosed in quotes): = 'SATURNV' 'SATURNV/CENTAUR' 'SATURNI/CENTAUR' 'SIC/S4B' 'SIC/S4B/CENTAUR' 'TITAN3F', same as Titan 3X(1207) 'TITAN3F/CENTAUR' 'TITAN3D/CENTAUR', same as (1205) 'TITAN3D/AGENA' 'ATLAS/CENTAUR' 'ATLAS/AGENA' 'INPUT BOOST DATA', used if characteristics of launch vehicle are to be input
TARGET	Proper name of target or planet (must be enclosed in quotes): = 'MERCURY' 'VENUS' 'MARS' 'JUPITER' 'SATURN' 'URANUS' 'NEPTUNE' 'PLUTO' 'COMET HALEY', rendezvous 'EXTRA-ECLIPTIC', 1.0 AU rendezvous
ANGLE	Angle of inclination to the ecliptic if TARGET = 'EXTRA-ECLIPTIC', degrees
MODE	Type of mission (need not be input if TARGET = 'COMET HALEY' or TARGET = 'EXTRA-ECLIPTIC') = FLYBY - flyby = ORBIT - orbiter
POWER	Electrical power level, if constrained, kWe
NP	Number of powers input (NP = 1 built in)

RP2	Radius of capture orbit, if orbiter, planetary radii
EPST	Eccentricity of capture orbit (0.0 built in)
NET	Number of capture eccentricities input (NET = 1 built in)
DEPART	Thrust level of departure stage if launch = PARK = HIGH, ballistic-escape stage = LOW, electric stage, spiral escape
DISP	Specific impulse of departure stage, sec (DISP = 450.0 built in)
DSIGMA	Tank inert fraction of high-thrust departure stage (DSIGMA = 0.137 built in)
DINERT	Fixed inert mass of high-thrust departure stage, kg (DINERT = 0.0 built in)
ARRIVE	Thrust level of capture stage if MODE = ORBIT = HIGH, ballistic-capture stage = LOW, electric stage, spiral capture
AISP	Specific impulse of ARRIVAL stage, sec (AISP = 300.0 built in)
ASIGMA	Tank inert fraction of high-thrust ARRIVAL stage (ASIGMA = 0.10 built in)
AINERT	Fixed inert mass of high-thrust arrival stage, kg (AINERT = 0.0 built in)
D	Constant in thrustor-efficiency function, km/sec (D = 16.0 built in)
B	Constant in thrustor-efficiency function (B = 0.842 built in)
TANK	Low-thrust propellant tankage fraction (TANK = 0.03 built in)
DELV1	Increment size on departure hyperbolic velocity optimization, km/sec (DELV1 = 0.5 built in)
DELV2	Increment size on arrival hyperbolic velocity optimization, km/sec (DELV2 = 0.5 built in)
VA	Departure hyperbolic excess velocity if constrained
VB	Arrival hyperbolic excess velocity if constrained
TIMEON	Electric propulsion thrusting time upper limit if constrained, hours (TIMEON = 9999999.9 built in)
ENERGY	Source of electric power: = ATOMIC, nuclear electric (built in) = SOLAR, solar cell (no data built in yet)
WPLANT	Constant in alpha-power relationship, kg (WPLANT = 350.0 built in) (see eq. (44))
PPK	Constant in alpha-power relationship (PPK = 0.0 built in) (see eq. (44))
PAYUP	Tabular values of launch vehicle performance to be input if BIRD = 'INPUT BOOST DATA'; maximum of 16 values, kg (PAYUP = 16×0.0 built in)
VC	Tabular values of launch vehicle performance corresponding to input values of PAYUP; maximum of 16 values, km/sec (VC = 16×7.75 built in)
WEJECT	Interstage mass, low thrust start-up equipment, etc., discarded after launch vehicle injection, kg (WEJECT = 0.0 built in)

MATCH	Method of planetoheliocentric trajectory matching = SPHERE (sphere of influence, built in) = ASYMPT (asymptotic velocity matching)
PRINT	Output control = DATA built in yields standard output = GRAPH yields standard plus graph = HELP yields debug diagnostic

Under PRINT = GRAPH the following may be input:

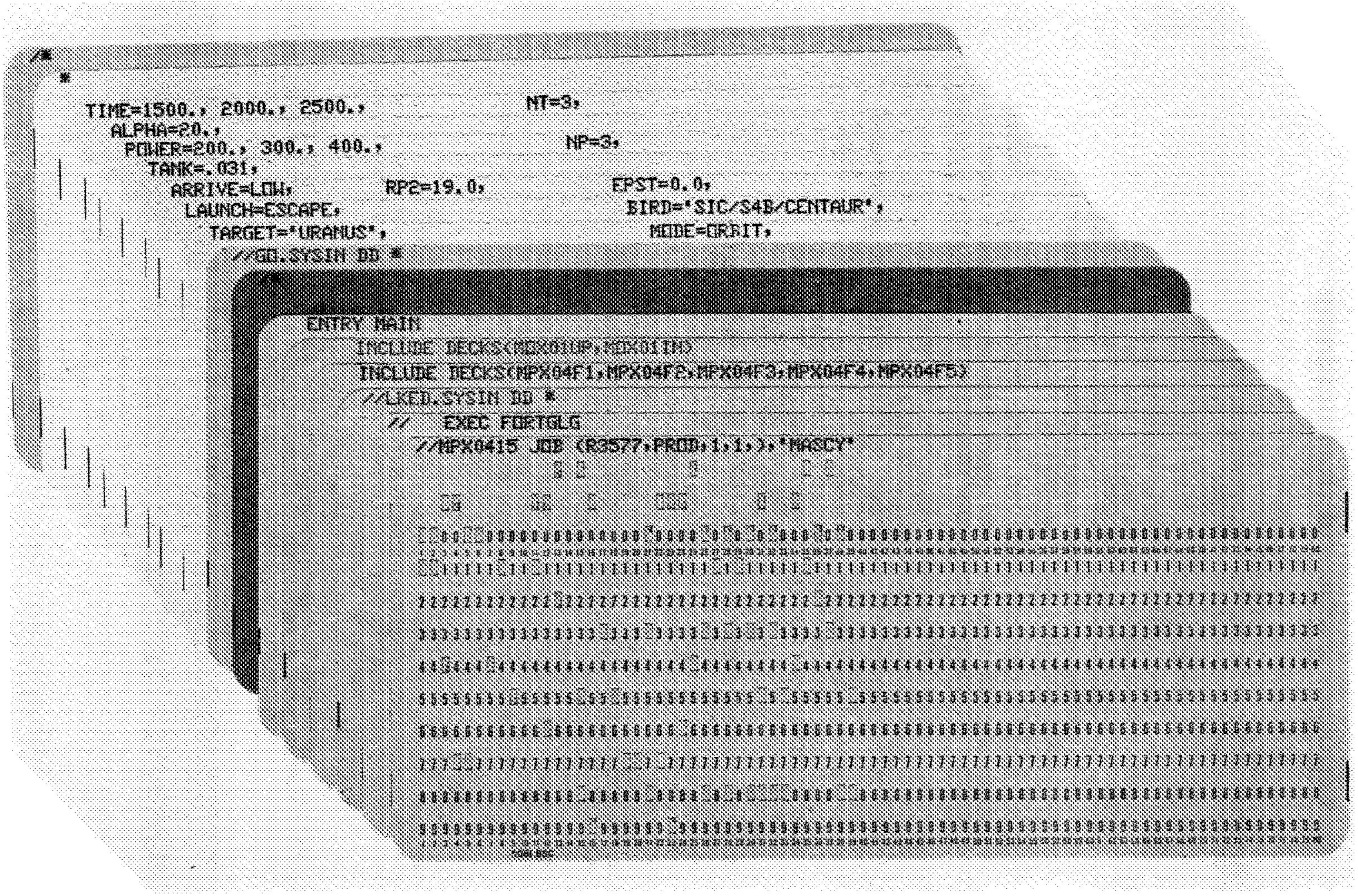
XMAX	Maximum trip time on abscissa, days (XMAX = 3200.0 built in)
XMIN	Minimum trip time on abscissa, days (XMIN = 0.0 built in)
YMAX	Maximum payload on ordinate, kg (YMAX = 70000.0 built in)
YMIN	Minimum payload on ordinate, kg (YMIN = 0.0 built in)
NHL	Number of horizontal grid lines ((NHL = 7 built in)
NVL	Number of vertical grid lines (NVL = 8 built in)
NSBH	Number of carriage spaces between horizontal lines (NSBH = 5 built in)
NSBV	Number of carriage spaces between vertical lines (NSBV = 10 built in)
NAME	Proper name of analyst (must be in quotes)

APPENDIX B

OUTPUT PARAMETERS

Variable name	Description	Units
TIME	Total mission time	days
ALPHA	Powerplant specific mass	kg/kWe
PAYLOAD	Net spacecraft mass	kg
MUP	Propellant mass fraction, low thrust	
MUW	Powerplant mass fraction, low thrust	
MLE	Payload mass fraction, low thrust	
DEPL	Departure payload mass fraction, high thrust.	
ARRL	Arrival payload mass fraction, high thrust	
POWER	Electrical power supplied to thrustor system	kWe
C	Exhaust velocity, low thrust	km/sec
T POW	Thrusting time, low thrust	hours
VINF 1	Hyperbolic excess velocity, Earth departure	km/sec
VINF 2	Hyperbolic excess velocity, Planet arrival	km/sec
BOOSTL	Launch vehicle injected payload	kg
TC	Capture time, low thrust	days
TH	Heliocentric time, low thrust	days
ETA	Thrustor subsystem efficiency p_j/p_e	

APPENDIX C - SAMPLE DECK MAKEUP



```
/*
 *
   TIME=1500., 2000., 2500.,                     NT=3,
     ALPHA=20.,
       POWER=200., 300., 400.,                       NP=3,
          TANK=.031,
             ARRIVE=LOW,        RP2=19.0,               EPST=0.0,
               LAUNCH=ESCAPE,                             BIRD='SIC/S4B/CENTAUR',
                  TARGET='URANUS',                          MODE=ORBIT,
                    //GO.SYSIN DD *
                      /*
                         ENTRY MAIN
                              INCLUDE DECKS(MDX01UP,MDX01IN)
                              INCLUDE DECKS(MPX04F1,MPX04F2,MPX04F3,MPX04F4,MPX04F5)
                              //LKED.SYSIN DD *
                                //   EXEC FORTGLG
                                  //MPX0415 JOB (R3577,PROD,1,1,),'MASCY'
```

APPENDIX D

EXAMPLE PROBLEMS

Example 1 shows the input parameters and output variables of a simple Saturn flyby mission. The optimum power level is shown to decrease with increasing ALPHA and to decrease with increasing mission time. The optimized hyperbolic excess velocity increases with increased ALPHA. The BOOSTL is the mass injected on a hyperbolic escape trajectory by the ATLAS/AGENA launch vehicle.

Example 2, a Jupiter orbiter, shows the method of overriding the built-in characteristics of the high-thrust capture stage by specifying AISP and ASIGMA. Note that the capture orbit characteristics are those of an ellipse with periapsis, RP2 = 2.0 Jupiter radii and eccentricity, EPST = 0.9. The exhaust velocity C of the electric stage is shown to decrease with increasing ALPHA. For this mission, the hyperbolic velocities at both departure and arrival, VINF1 and VINF2, respectively, have been optimized to yield maximum payload.

Example 3 indicates the method of constraining the electric power level of the low-thrust propulsion system by input of the desired level of POWER. The constrained power levels are shown in the appropriate output column. The low-thrust propellant tankage fraction has also been input, TANK = 0.031. Note that when a single variable is input such as one ALPHA, there is no need to input the quantity of that variable such as NA = 1.

Example 4 shows that mode need not be input when TARGET = 'EXTRA-ECLIPTIC'. The printout in the center of the page indicates that it is a rendezvous type mission, that is, the probe arrives at the desired inclination to the ecliptic (ANGLE = 45.0) at 1.0 AU and remains in a circular orbit with those conditions.

Example 5 uses a desired mass in Earth orbit by specifying LAUNCH = PARK, and BIRD = 'INPUT BOOST DATA'. In this case, the fixed initial mass of 50,000 kilograms is input by PAYUP = 50000.0. Note that in all cases the output shows that BOOSTL = 50000.0. Departure from the parking orbit is by a high-thrust vehicle, DEPART = HIGH, whose input characteristics are those of an assumed nuclear stage, specific impulse DISP = 800.0 seconds, hydrogen tankage fraction DSIGMA = 0.20, and fixed inerts plus nuclear engine DINERT = 7000.0 kg.

Example 6 constrains the departure hyperbolic excess velocity VA = 4.0 kilometers per second. Note the output column VINF1. Also, in this example, the capture orbit is circular (RP2 = 16.0 planet radii); therefore, the eccentricity, EPST = 0.0, need not be input.

Example 7 utilizes the built-in power-alpha relationship, equation (44). The nominal technology selected for this example requires WPLANT = 350.0 and

PPK = -0.5. Note the POWER column outputs the power level best suited for this launch vehicle-departure mode that conforms to the above constraint. The ALPHA column shows the powerplant specific mass corresponding to this power relationship. Neither POWER nor ALPHA should be input under this option.

Example 8 illustrates the use of the program in nondimensional parameters. Through the input LAUNCH = PARK and BIRD = NO BOOST, the code will initiate all missions from Earth orbit and the payload will be normalized to Earth orbital mass. The PBAR column gives the ratio of POWER divided by PAYLOAD in units of kilowatts/kilograms. For example, a mission time of 2000 days and a powerplant specific mass of 20 kg/kWe yields a payload mass fraction of 0.0869 and a PBAR = 0.0580. If we desired our Earth orbital mass to be 10,000 kg, then our payload would be 869 kg and the primary electrical power required would be 50.3 kWe [(0.0580)(869)]. Similarly, for an orbital mass of 20,000 kg, payload would be 1738 kg and power would be 100.6 kWe.

Example 9 depicts a very useful output format. Through the input PRINT = GRAPH, the results of the mission analysis is graphically portrayed following the standard columnar printout. The plot shows mission time in days along the abscissa or x-axis and net spacecraft mass (payload) in kilograms along the ordinate or y-axis. The maximum and minimum values of these parameters are controlled by the inputs YMAX, YMIN, XMAX, XMIN. The number of horizontal and vertical grid spaces may also be changed by input as described in appendix A. The family of alphas is plotted with the symbol corresponding to ALPHA divided by 10, thus 3, 4, 5 refer to ALPHA = 30, 40, 50 kg/kWe. The conditions of launch, departure, and arrival are shown in the upper left corner as well as the power level. The word FIGURE is output for labeling convenience on the bottom left and the date of the computer run is automatically printed on the bottom right corner. The name of the analyst may be inscribed on the bottom right corner by the input NAME = 'user's name'.

```
TARGET='SATURN',                           MODE=FLYBY,
LAUNCH=ESCAPE,                             BIRD='ATLAS/AGENA',
ALPHA=10., 20., 30.,                       NA=3,
TIME=1000., 1200., 1400., 1600.,           NT=4,
*
```

```
                                                  EARTH     TO    SATURN             FLYBY

                                                       ATLAS/AGENA       LAUNCH TO    ESCAPE

                                                            DEPART     HIGH

TIME  ALPHA  PAYLOAD   MUP  MUW  MLE  DEPL  ARRL  POWER      C    T POW  VINF1  VINF2  BOOSTL    TC   TH      ETA

1000.  10.0    356.  .231 .197 .565 1.000 1.000   12.4    77.6  12126.   0.0    0.0     630.    0. 1000.  .808
1000.  20.0    256.  .319 .261 .410 1.000 1.000    8.2    52.5  12126.   0.5    0.0     625.    0. 1000.  .770
1000.  30.0    187.  .368 .302 .319 1.000 1.000    5.9    41.9  12126.   1.5    0.0     587.    0. 1000.  .735

1200.  10.0    391.  .199 .175 .621 1.000 1.000   11.0    85.7  14257.   0.0    0.0     630.    0. 1200.  .814
1200.  20.0    302.  .277 .235 .480 1.000 1.000    7.4    58.3  14257.   0.0    0.0     630.    0. 1200.  .783
1200.  30.0    238.  .326 .275 .389 1.000 1.000    5.6    46.6  14257.   1.0    0.0     611.    0. 1200.  .753

1400.  10.0    413.  .179 .160 .656 1.000 1.000   10.1    92.7  16348.   0.0    0.0     630.    0. 1400.  .818
1400.  20.0    332.  .250 .216 .527 1.000 1.000    6.8    63.4  16348.   0.0    0.0     630.    0. 1400.  .792
1400.  30.0    272.  .300 .256 .435 1.000 1.000    5.3    50.6  16348.   0.5    0.0     625.    0. 1400.  .765

1600.  10.0    428.  .166 .150 .680 1.000 1.000    9.4    99.0  18406.   0.0    0.0     630.    0. 1600.  .821
1600.  20.0    352.  .232 .202 .558 1.000 1.000    6.4    67.9  18406.   0.0    0.0     630.    0. 1600.  .798
1600.  30.0    295.  .281 .242 .469 1.000 1.000    5.1    54.2  18406.   0.0    0.0     630.    0. 1600.  .774
```

Example 1.

```
TARGET='JUPITER',                          MODE=ORBIT,
LAUNCH=ESCAPE,                             BIRD='TITAN3F/CENTAUR',
ARRIVE=HIGH,          RP2=2.0,             EPST=.9,
AISP=310.0,                                ASIGMA=.11,
ALPHA=30.0,  40.0,  50.0,                  NA=3,
TIME=1000.0, 1200.,  1300.,  1400.,        NT=4,
*
```

```
                                                  EARTH     TO    JUPITER            ORBITER

                                                       TITAN3F/CENTAUR   LAUNCH TO    ESCAPE

                                                       DEPART     HIGH          ARRIVE    HIGH

TIME  ALPHA  PAYLOAD   MUP  MUW  MLE  DEPL  ARRL  POWER      C    T POW  VINF1  VINF2  BOOSTL    TC   TH      ETA

1000.  30.0   2540.  .211 .206 .576 1.000 0.585   51.7    50.0  14025.   1.5    5.5    7533.    0. 1000.  .764
1000.  40.0   2279.  .222 .225 .547 1.000 0.553   42.4    43.6  14025.   1.5    6.5    7533.    0. 1000.  .742
1000.  50.0   2077.  .225 .240 .529 1.000 0.536   35.1    39.4  14025.   2.0    7.0    7322.    0. 1000.  .723

1200.  30.0   2870.  .188 .183 .623 1.000 0.599   47.0    54.8  16513.   1.0    5.0    7688.    0. 1200.  .776
1200.  40.0   2624.  .198 .200 .595 1.000 0.585   37.7    47.7  16513.   1.5    5.5    7533.    0. 1200.  .757
1200.  50.0   2425.  .201 .211 .582 1.000 0.553   31.9    43.0  16513.   1.5    6.5    7533.    0. 1200.  .740

1300.  30.0   2997.  .181 .177 .637 1.000 0.612   45.2    56.9  17740.   1.0    4.5    7688.    0. 1300.  .780
1300.  40.0   2753.  .192 .193 .610 1.000 0.599   36.3    49.5  17740.   1.5    5.0    7533.    0. 1300.  .762
1300.  50.0   2561.  .194 .203 .597 1.000 0.570   30.6    44.6  17740.   1.5    6.0    7533.    0. 1300.  .746

1400.  30.0   3101.  .170 .166 .659 1.000 0.612   42.6    59.1  18958.   1.0    4.5    7688.    0. 1400.  .784
1400.  40.0   2864.  .186 .186 .622 1.000 0.599   35.8    51.1  18958.   1.0    5.0    7688.    0. 1400.  .767
1400.  50.0   2676.  .190 .197 .607 1.000 0.585   29.7    46.1  18958.   1.5    5.5    7533.    0. 1400.  .751
```

Example 2.

D-5

```
TARGET='URANUS',                         MODE=ORBIT,
LAUNCH=ESCAPE,                           BIRD='SIC/S4B/CENTAUR',
ARRIVE=LOW,         RP2=19.0,            EPST=0.0,
TANK=.031,
POWER=200., 300., 400.,                  NP=3,
ALPHA=20.,
TIME=1500., 2000., 2500.,                NT=3,
*
```

```
                                        EARTH     TO     URANUS            ORBITER

                                           SIC/S4B/CENTAUR    LAUNCH TO    ESCAPE

                                           DEPART     HIGH          ARRIVE     LOW

TIME   ALPHA   PAYLOAD    MUP   MUW   MLE   DEPL   ARRL   POWER      C     T POW   VINF1   VINF2   BOOSTL    TC   TH      ETA

1500.   20.0    1499.   .583  .290  .109 1.000  1.000   200.0    55.1   21762.    6.0    0.0    13776.    10. 1490.   .776
1500.   20.0    1300.   .576  .333  .072 1.000  1.000   300.0    59.7   21754.    4.0    0.0    17992.     9. 1491.   .786
1500.   20.0     820.   .543  .399  .041 1.000  1.000   400.0    67.7   21751.    3.0    0.0    20048.     9. 1491.   .797

2000.   20.0    4733.   .525  .210  .248 1.000  1.000   200.0    56.2   28174.    3.5    0.0    19058.    19. 1981.   .779
2000.   20.0    5106.   .473  .277  .235 1.000  1.000   300.0    68.8   28162.    2.0    0.0    21697.    18. 1982.   .799
2000.   20.0    4832.   .412  .359  .217 1.000  1.000   400.0    84.7   28159.    1.5    0.0    22312.    17. 1983.   .813

2500.   20.0    7472.   .457  .184  .344 1.000  1.000   200.0    62.9   34446.    2.0    0.0    21697.    30. 2470.   .791
2500.   20.0    7904.   .378  .264  .347 1.000  1.000   300.0    83.9   34434.    1.0    0.0    22763.    29. 2471.   .812
2500.   20.0    7514.   .317  .347  .326 1.000  1.000   400.0   105.8   34430.    0.5    0.0    23038.    29. 2471.   .823
```

Example 3.

```
TARGET='EXTRA-ECLIPTIC',
ANGLE=45.0,
ALPHA=10., 20., 30.,                     NA=3,
TIME=400., 500., 600., 700.,             NT=4,
LAUNCH=ESCAPE,                           BIRD='TITAN3D/CENTAUR',
POWER=50.0,
*
```

```
                                        EARTH     TO     EXTRA-ECLIPTIC     RENDEZVU

                                           TITAN3D/CENTAUR    LAUNCH TO    ESCAPE

                                                   DEPART     HIGH

TIME   ALPHA   PAYLOAD    MUP   MUW   MLE   DEPL   ARRL   POWER      C     T POW   VINF1   VINF2   BOOSTL    TC   TH      ETA

 400.   10.0    1238.   .519  .134  .332 1.000  1.000    50.0    33.8    8928.    5.0    0.0     3734.     0.  400.   .688
 400.   20.0     738.   .519  .268  .198 1.000  1.000    50.0    33.8    8928.    5.0    0.0     3734.     0.  400.   .688
 400.   30.0     238.   .519  .402  .064 1.000  1.000    50.0    33.8    8928.    5.0    0.0     3734.     0.  400.   .688

 500.   10.0    1654.   .487  .116  .383 1.000  1.000    50.0    36.7   11160.    4.0    0.0     4323.     0.  500.   .708
 500.   20.0    1154.   .487  .231  .267 1.000  1.000    50.0    36.7   11160.    4.0    0.0     4323.     0.  500.   .708
 500.   30.0     654.   .487  .347  .151 1.000  1.000    50.0    36.7   11160.    4.0    0.0     4323.     0.  500.   .708

 600.   10.0    2052.   .459  .103  .424 1.000  1.000    50.0    39.7   13392.    3.0    0.0     4838.     0.  600.   .724
 600.   20.0    1552.   .459  .207  .321 1.000  1.000    50.0    39.7   13392.    3.0    0.0     4838.     0.  600.   .724
 600.   30.0    1052.   .459  .310  .217 1.000  1.000    50.0    39.7   13392.    3.0    0.0     4838.     0.  600.   .724

 700.   10.0    2419.   .410  .099  .479 1.000  1.000    50.0    45.0   15624.    2.5    0.0     5055.     0.  700.   .748
 700.   20.0    1919.   .410  .198  .380 1.000  1.000    50.0    45.0   15624.    2.5    0.0     5055.     0.  700.   .748
 700.   30.0    1419.   .410  .297  .281 1.000  1.000    50.0    45.0   15624.    2.5    0.0     5055.     0.  700.   .748
```

Example 4.

```
TARGET='SATURN',                                  MODE=ORBIT,
LAUNCH=PARK,                                      BIRD='INPUT BOOST DATA',
PAYUP=50000.0,
DEPART=HIGH,                                      RP1=1.05,
DISP=800.0,          DSIGMA=.20,                  DINERT=7000.0,
ARRIVE=LOW,                                       RP2=20.0,
ALPHA=10.0, 20.0, 30.0,                           NA=3,
TIME=1000., 1500., 2000., 2500.,                  NT=4,
*
```

```
                                                EARTH     TO     SATURN            ORBITER

                                                     INPUT BOOST DATA  LAUNCH TO   PARKING

                                                     DEPART      HIGH          ARRIVE      LOW

TIME   ALPHA   PAYLOAD   MUP  MUW  MLE  DEPL  ARRL   POWER     C     T POW  VINF1  VINF2  BOOSTL    TC   TH     ETA

1000.  10.0    6987.  .391 .263 .334 0.418 1.000   551.0    75.6  14624.   3.0    0.0   50000.     9.  991.  .806
1000.  20.0    3354.  .475 .299 .212 0.316 1.000   236.1    50.3  14644.   6.0    0.0   50000.    11.  989.  .765
1000.  30.0    1628.  .520 .324 .140 0.232 1.000   125.1    39.8  14661.   8.0    0.0   50000.    13.  987.  .725

1500.  10.0   11742.  .261 .208 .524 0.448 1.000   465.0   100.1  21283.   1.5    0.0   50000.    26. 1474.  .821
1500.  20.0    8219.  .342 .254 .393 0.418 1.000   266.1    67.4  21309.   3.0    0.0   50000.    28. 1472.  .797
1500.  30.0    5992.  .396 .284 .308 0.389 1.000   184.5    53.2  21329.   4.0    0.0   50000.    30. 1470.  .772

2000.  10.0   14101.  .204 .173 .617 0.457 1.000   395.6   118.5  27846.   0.5    0.0   50000.    50. 1950.  .827
2000.  20.0   11047.  .272 .218 .502 0.440 1.000   240.1    80.8  27887.   2.0    0.0   50000.    54. 1946.  .810
2000.  30.0    8975.  .323 .250 .417 0.430 1.000   179.2    64.1  27905.   2.5    0.0   50000.    55. 1945.  .793

2500.  10.0   15457.  .171 .150 .674 0.459 1.000   343.5   134.2  34378.   0.0    0.0   50000.    83. 2417.  .830
2500.  20.0   12750.  .231 .193 .569 0.448 1.000   216.3    92.0  34428.   1.5    0.0   50000.    87. 2413.  .817
2500.  30.0   10864.  .275 .223 .494 0.440 1.000   163.6    73.4  34457.   2.0    0.0   50000.    90. 2410.  .804
```

Example 5.

```
TARGET='NEPTUNE',                                 MODE=ORBIT,
LAUNCH=ESCAPE,                                    BIRD='TITAN3D/AGENA',
ARRIVE=LOW,                                       RP2=16.0,
ALPHA=20., 30., 40.,                              NA=3,
TIME=3200., 3000., 2800.,    NT=3,
VA=4.0,
*
```

```
                                                EARTH     TO     NEPTUNE           ORBITER

                                                     TITAN3D/AGENA     LAUNCH TO   ESCAPE

                                                     DEPART      HIGH          ARRIVE      LOW

TIME   ALPHA   PAYLOAD   MUP  MUW  MLE  DEPL  ARRL   POWER     C     T POW  VINF1  VINF2  BOOSTL    TC   TH     ETA

3200.  20.0     734.  .396 .259 .333 1.000 1.000    28.5    90.2  42358.   4.0    0.0    2203.    52. 3148.  .816
3200.  30.0     493.  .483 .279 .224 1.000 1.000    20.5    68.5  42358.   4.0    0.0    2203.    52. 3148.  .798
3200.  40.0     314.  .555 .286 .142 1.000 1.000    15.8    55.3  42358.   4.0    0.0    2203.    52. 3148.  .777

3000.  20.0     657.  .424 .265 .298 1.000 1.000    29.2    86.0  40286.   4.0    0.0    2203.    45. 2955.  .814
3000.  30.0     412.  .516 .281 .187 1.000 1.000    20.7    64.7  40286.   4.0    0.0    2203.    45. 2955.  .793
3000.  40.0     232.  .593 .284 .106 1.000 1.000    15.6    51.6  40286.   4.0    0.0    2203.    45. 2955.  .768

2800.  20.0     570.  .457 .271 .259 1.000 1.000    29.9    81.4  38190.   4.0    0.0    2203.    38. 2762.  .811
2800.  30.0     322.  .556 .281 .146 1.000 1.000    20.6    60.3  38190.   4.0    0.0    2203.    38. 2762.  .787
2800.  40.0     145.  .639 .276 .066 1.000 1.000    15.2    47.4  38190.   4.0    0.0    2203.    38. 2762.  .756
```

Example 6.

```
TARGET='JUPITER',                              MODE=FLYBY,
LAUNCH=PARK,                                   BIRD='TITAN3F      ',
DEPART=LOW,
WPLANT=350.0,                                  PPK=-.5,
TIME=800., 1000., 1200., 1400., 1600., 1800., 2000.,       NT=7,
*
```

```
                                           EARTH     TO     JUPITER            FLYBY

                                               TITAN3F           LAUNCH TO    PARKING

                                                   DEPART      LOW

TIME  ALPHA  PAYLOAD   MUP  MUW  MLE  DEPL  ARRL   POWER      C     T POW  VINF1  VINF2  BOOSTL    TC   TH     ETA

 800.  24.4   5552.  .371 .293 .325 1.000 1.000   205.0    45.3  11760.   0.0    0.0   17088.    0.  653.  .749

1000.  26.5   6603.  .334 .270 .386 1.000 1.000   173.9    50.5  15158.   0.0    0.0   17088.    0.  785.  .765

1200.  28.2   7265.  .311 .254 .425 1.000 1.000   154.2    55.0  18657.   0.0    0.0   17088.    0.  909.  .776

1400.  29.5   7706.  .297 .243 .451 1.000 1.000   141.1    59.1  22267.   0.0    0.0   17088.    0. 1024.  .785

1600.  30.5   8010.  .287 .235 .469 1.000 1.000   132.0    63.1  26006.   0.0    0.0   17088.    0. 1127.  .791

1800.  31.2   8224.  .281 .229 .481 1.000 1.000   125.4    66.9  29889.   0.0    0.0   17088.    0. 1216.  .796

2000.  31.9   8376.  .277 .225 .490 1.000 1.000   120.7    70.7  33933.   0.0    0.0   17088.    0. 1291.  .801
```

Example 7.

```
TARGET='URANUS',                               MODE=ORBIT,
LAUNCH=PARK,                                    BIRD='NO BOOST',
DEPART=HIGH,                                   RP1=1.10,
DISP=420.,                                     DSIGMA=.12,
ARRIVE=HIGH,                                   RP2=2.0,           EPST=.9,
ALPHA=10., 20., 30., 40., 50.,                 NA=5,
TIME=1600., 1800., 2000.,                      NT=3,
*
```

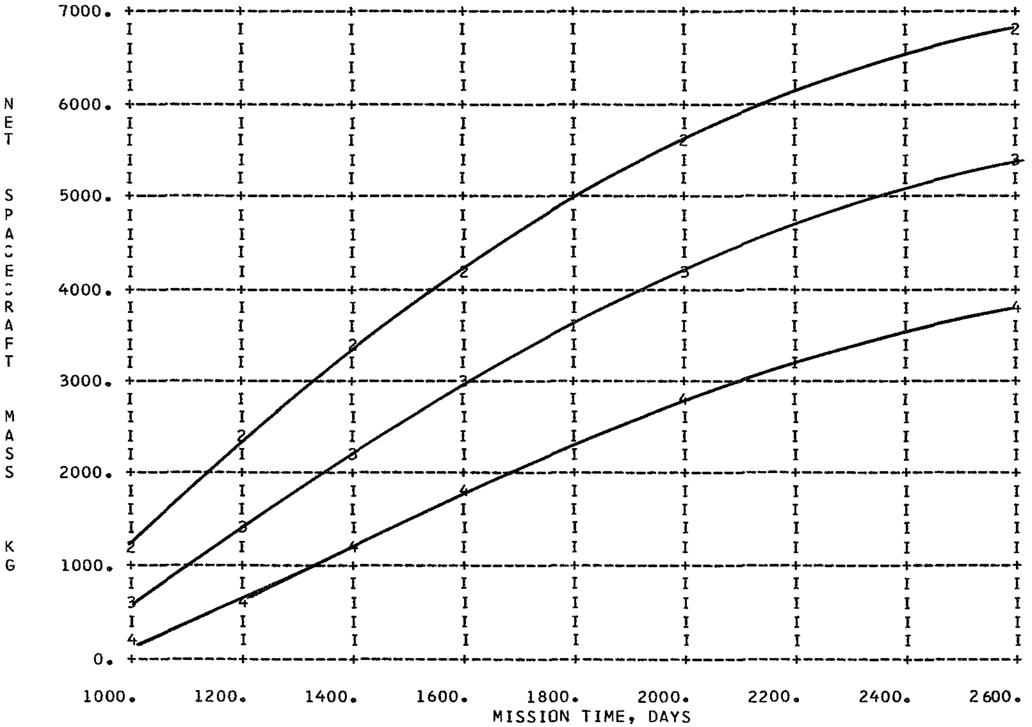
```
                                           EARTH     TO     URANUS             ORBITER

                                               NO BOOST          LAUNCH TO    PARKING

                                               DEPART     HIGH          ARRIVE    HIGH

TIME    ALPHA   PAYLOAD  MUP   MUW    MLE    DEP L  ARR L   PBAR      C    T POW  VINF1  VINF2    TC    TH     ETA

1600.   10.0   .1031   .407 .2604 0.3208  0.392  0.820  0.0990   93.0  22931.   1.5    2.0    0.0 1600.  .818
1600.   20.0   .0478   .510 .2854 0.1896  0.355  0.710  0.1059   60.3  22931.   3.0    4.0    0.0 1600.  .787
1600.   30.0   .0226   .550 .2990 0.1345  0.301  0.560  0.1324   47.6  22931.   4.5    6.0    0.0 1600.  .756
1600.   40.0   .0107   .568 .3127 0.1026  0.238  0.439  0.1734   40.7  22931.   6.0    7.5    0.0 1600.  .729
1600.   50.0   .0048   .556 .3282 0.0988  0.217  0.225  0.2949   37.2  22931.   6.5   10.5    0.0 1600.  .711

1800.   10.0   .1274   .361 .2473 0.3811  0.399  0.838  0.0774  101.6  25460.   1.0    1.5    0.0 1800.  .822
1800.   20.0   .0702   .461 .2794 0.2460  0.369  0.773  0.0735   66.5  25460.   2.5    3.0    0.0 1800.  .796
1800.   30.0   .0400   .514 .2953 0.1751  0.338  0.675  0.0833   52.0  25460.   3.5    4.5    0.0 1800.  .769
1800.   40.0   .0229   .540 .3082 0.1359  0.301  0.560  0.1013   44.1  25460.   4.5    6.0    0.0 1800.  .744
1800.   50.0   .0131   .548 .3211 0.1145  0.238  0.479  0.1170   39.4  25460.   6.0    7.0    0.0 1800.  .723

2000.   10.0   .1475   .321 .2328 0.4363  0.403  0.838  0.0637  109.6  27958.   0.5    1.5    0.0 2000.  .824
2000.   20.0   .0907   .419 .2708 0.2975  0.382  0.799  0.0570   72.2  27958.   2.0    2.5    0.0 2000.  .803
2000.   30.0   .0579   .476  2898 0.2198  0.355  0.743  0.0591   56.4  27958.   3.0    3.5    0.0 2000.  .779
2000.   40.0   .0374   .509 .3033 0.1728  0.320  0.675  0.0650   47.6  27958.   4.0    4.5    0.0 2000.  .757
2000.   50.0   ,0242   .525 .3153 0.1436  0.301  0.560  0.0785   42.2  27958.   4.5    6.0    0.0 2000.  .736
```

Example 8.

```
TARGET='SATURN',                          MODE=ORBIT,
LAUNCH=PARK,                              BIRD='TITAN3F     ',
DEPART=LOW ,                              RP1=1.05,
ARRIVE=HIGH,                              RP2=2.0,             EPST=.9,
TIME=1000., 1200., 1400., 1600., 2000., 2600.,        NT=6,
ALPHA=20., 30., 40.,                      NA=3,
TIMEON=10000.,                            POWER=200.,
PRINT=GRAPH,                              NAME='MASCY',
YMAX=7000.,         YMIN=0.0,             XMAX=2600.,          XMIN=1000.,
*
```

```
                                                 EARTH     TO     SATURN             ORBITER

                                                      TITAN3F          LAUNCH TO   PARKING

                                                      DEPART      LOW            ARRIVE    HIGH

TIME  ALPHA  PAYLOAD   MUP  MUW  MLE  DEPL  ARRL   POWER      C     T POW  VINF1  VINF2  BOOSTL    TC   TH     ETA

1000.  20.0   1284.  .582 .234 .167 1.000 0.451   200.0    40.3  15414.   0.0    8.5   17088.    0.  917.   .727
1000.  30.0    557.  .516 .351 .118 1.000 0.278   200.0    43.4  15536.   0.0   11.5   17088.    0.  906.   .741
1000.  40.0    159.  .450 .468 .068 1.000 0.136   200.0    47.1  15675.   0.0   14.5   17088.    0.  893.   .755

1200.  20.0   2391.  .516 .234 .234 1.000 0.597   200.0    47.6  18319.   0.0    6.0   17088.    0. 1092.   .756
1200.  30.0   1338.  .461 .351 .174 1.000 0.451   200.0    50.8  18450.   0.0    8.5   17088.    0. 1080.   .766
1200.  40.0    586.  .407 .468 .113 1.000 0.305   200.0    54.6  18598.   0.0   11.0   17088.    0. 1067.   .776

1400.  20.0   3417.  .455 .234 .297 1.000 0.674   200.0    55.2  21230.   0.0    4.5   17088.    0. 1264.   .777
1400.  30.0   2173.  .413 .351 .224 1.000 0.569   200.0    58.4  21360.   0.0    6.5   17088.    0. 1252.   .783
1400.  40.0   1153.  .371 .468 .150 1.000 0.451   200.0    62.1  21506.   0.0    8.5   17088.    0. 1239.   .790

1600.  20.0   4291.  .393 .234 .361 1.000 0.696   200.0    64.1  24183.   0.0    4.0   17088.    0. 1430.   .793
1600.  30.0   2936.  .373 .351 .264 1.000 0.650   200.0    66.0  24263.   0.0    5.0   17088.    0. 1423.   .795
1600.  40.0   1740.  .333 .468 .189 1.000 0.540   200.0    70.3  24438.   0.0    7.0   17088.    0. 1407.   .801

2000.  20.0   5610.  .319 .234 .438 1.000 0.750   200.0    80.2  30013.   0.0    2.5   17088.    0. 1762.   .810
2000.  30.0   4144.  .301 .351 .339 1.000 0.716   200.0    82.7  30119.   0.0    3.5   17088.    0. 1753.   .812
2000.  40.0   2761.  .275 .468 .249 1.000 0.650   200.0    87.0  30298.   0.0    5.0   17088.    0. 1737.   .814

2600.  20.0   6844.  .241 .234 .518 1.000 0.773   200.0   105.8  38817.   0.0    1.5   17088.    0. 2244.   .823
2600.  30.0   5315.  .227 .351 .415 1.000 0.750   200.0   109.1  38964.   0.0    2.5   17088.    0. 2232.   .824
2600.  40.0   3828.  .220 .468 .305 1.000 0.734   200.0   111.0  39047.   0.0    3.0   17088.    0. 2224.   .825
```

```
**********************************************SATURN          ORBITER *******************************
TITAN3F          LAUNCH TO  PARKING
 LOW   THRUST ESCAPE
HIGH   THRUST CAPTURE   RP2=  2.0  ECC=.90
POWER= 200. KWE                                            THRUST TIME UPPER LIMIT=10000.HOURS
```



```
FIGURE                                                                  MASCY          09/16/69
```

Example 9.

APPENDIX E - PROGRAM LISTINGS

```
C  MPX04F1   MAIN CONTROL PROGRAM FOR QUICKLY ANALYZING LOW THRUST MISSIONS
C
C
      LOGICAL MODE,FLYBY,ORBIT,ARRIVE,DEPART,HIGH,LOW
      LOGICAL LAUNCH,ESCAPE,PARK,MATCH, SPHERE, ASYMPT
      LOGICAL ENERGY,ATOMIC,SOLAR
      INTEGER DATA, GRAPH, HELP
      DIMENSION BIRD(4), VEHIK(3,13)
      DOUBLE PRECISION XLAUNC,ESCAP,PARKIN,RENDEZ
      DOUBLE PRECISION XMODE, ORBTR, FLBY, YLEVEL, YHIGH, XLEVEL
      DOUBLE PRECISION XHIGH,YLOW, XLOW
      DIMENSION T(20), ALPHA(20), THI(2), FTH(2), TTD(2), TTC(2)
      DIMENSION EPST(20) ,           POWERH(20),POWER(20)
      DIMENSION NSCALE(5),IMAGE(800) , DUMMY(1), CHAR(10)
      DIMENSION TIME(20)
      DIMENSION DAT(2),NAME(3)
      DIMENSION VC7(16), PAY7(16), VC(16), PAYUP(16)
      DIMENSION HOME(2),TARGET(4),PLAN(11)
      DIMENSION BDY(3,3,2)
      DATA  NAME/'MASCY        '/
      DATA PLAN/'MERC','VENU','EART', 'MARS','JUPI','SATU',
     1  'URAN', 'NEPT', 'PLUT','COME', 'EXTR'/
      DATA BLANK/'    '/
      DATA DUMMY/'0'/
      DATA NSCALE/1,0,0,0,0/
      DATA CHAR/'1','2','3','4','5','6','7','8','9' /
      DATA VEHIK/'NO B','OOST','    ',    'SATU','RNV ','    ',
     1  'SIC/','S4B/','CENT',     'SIC/','S4B ','    ',
     2     'TITA','N3F/','CENT',      'TITA','N3F ','    ',
     3     'INPU','T BO','OST ',           'SATU','RNV/','CENT',
     4      'SATU','RNI/','CENT',          'TITA','N3D/','AGEN',
     5       'ATLA','S/CE','NTAU',            'ATLA','S/AG','ENA ',
     6     'TITA','N3D/','CENT'/
      DATA ORBTR/'ORBITER '/
      DATA FLBY/ ' FLYBY  '  /
      DATA RENDEZ/'RENDEZVU'/
      DATA XHIGH/ ' HIGH   '/
      DATA XLOW/  '  LOW   ' /
      DATA  YHIGH/ '  HIGH  '  /
      DATA YLOW/  '  LOW   ' /
      DATA ESCAP/'ESCAPE'/
      DATA PARKIN/'PARKING'/
      DATA BIRD/'                '/
      DATA TARGET/'                '/
      DATA HOME/'EARTH   '/
      DATA BIRD/4HNO B,4HOOST/
      CALL DATE(DAT)
      DATA PAYUP/16*0.0/
      DATA  DATA,GRAPH,HELP/0,1,2/
      ORBIT=.TRUE.
      FLYBY=.FALSE.
      LOW=.TRUE.
      HIGH=.FALSE.
      ESCAPE=.TRUE.
      PARK=.FALSE.
      ATOMIC=.TRUE.
      SOLAR=.FALSE.
      ENERGY=ATOMIC
      SPHERE=.TRUE.
      ASYMPT=.FALSE.
      MATCH=SPHERE
      ARRIVE=HIGH
      NPO=0
      NGRAIN=0
      DEPART=HIGH
      LAUNCH=ESCAPE
      MODE=FLYBY
      NBIRD=1
      NPLAN2=0
      RP2=0.0
      GMEO=39.86E4
      GE=.00981
      DISP=450.
      DINERT=0.0
      DSIGMA=.137
      AISP=300.0
      AINERT=0.0
      ASIGMA=.10
      TC=8.64E4
      RAD=1.0/.01745329
      PY=180.0/RAD
      RGEO=6375.445
      EPSD=0.0
      WPLANT=350.0
      POWERH(1)=0.0
      POWER(1)=0.0
```

```
      ALPHA(1)=1.0
      PPK=0.0
      WEJECT=0.0
      TANK=.03
      L=1
      EPST(L)=0.0
      D=16.0
      B=.842
      NT=1
      NA=1
      NET=1
      NW=1
      NP=1
      NC=3
      NR=0
      JP=1
      AZERO=.5E-6
      AFINAL=1.E-6
      XMIN = 0.0
      YMIN=0.0
      XMAX=3200.0
      YMAX=70E3
      NHL=7
      NSBH=5
      NVL=8
      NSBV=10
      TIMEON=9999999.
      RT=.4
      VA=0.0
      VB=0.0
      SKIPA=1.0
      SKIPB=1.0
      DO 2 MB=1,16
2     VC(MB)=7.75 + MB*3
      DELV1=.5
      DELV2=.5
      RP1=1.05
      IPRINT=0
1     IF(ALPHA(1) .EQ. 0.0) GO TO 5
      WRITE(6,1002)
1002  FORMAT(1H1)
5     MPLAN2=NPLAN2
      MBIRD=NBIRD
6     CALL INPUT(6HNT    ,NT    ,6HNA    ,NA    ,6HD     ,D     ,
     16HTIME  ,TIME  ,6HALPHA ,ALPHA ,6HRP1   ,RP1   ,6HRP2   ,RP2   ,
     26HHOME  ,HOME  ,6HLOW   ,LOW   ,6HMODE  ,MODE  ,6HFLYBY ,FLYBY ,
     36HORBIT ,ORBIT ,6HHIGH  ,HIGH  ,
     *6HARRIVE,ARRIVE,6HDEPART,DEPART,6HTARGET,TARGET,6HEPSD  ,EPSD  ,
     A6HEPST  ,EPST  ,6HPRINT ,IPRINT,6HNET   ,NET   ,6HB     ,B     ,
     B6HDELV1 ,DELV1 ,6HDELV2 ,DELV2 ,6HDISP  ,DISP  ,6HAISP  ,AISP  ,
     D6HDSIGMA,DSIGMA,6HASIGMA,ASIGMA,6HBIRD  ,BIRD  ,6HLAUNCH,LAUNCH,
     E 6HESCAPE,ESCAPE,6HPARK  ,PARK  ,6HPPK   ,PPK   ,
     F6HVA    ,VA    ,6HVB    ,VB    ,6HVC    ,VC    ,6HPAYUP ,PAYUP ,
     G6HWPLANT,WPLANT,6HWEJECT,WEJECT,6HPOWER ,POWERH,6HNW    ,NW    ,
     H 6HNP    ,NP    ,              6HYMAX  ,YMAX  ,6HANGLE ,ANGLE ,
     I6HXMAX  ,XMAX  ,6HNHL   ,NHL   ,6HNSBH  ,NSBH  ,6HNVL   ,NVL   ,
     J6HNSBV  ,NSBV  ,6HXMIN  ,XMIN  ,6HYMIN  ,YMIN  ,6HTANK  ,TANK  ,
     K6HSKIP1 ,SKIPA ,6HSKIP2 ,SKIPB ,6HENERGY,ENERGY,6HTIMEON,TIMEON,
     L6HDINERT,DINERT,6HAINERT,AINERT,6HNAME  ,NAME  ,6HDATA  ,DATA  ,
     M6HGRAPH ,GRAPH ,6HHELP  ,HELP  ,6HMATCH ,MATCH ,6HSPHERE,SPHERE,
     N6HASYMPT,ASYMPT,6HATOMIC,ATOMIC,6HSOLAR ,SOLAR )
      IF(ALPHA(1) .EQ. 0.0) GO TO 7
      WRITE(6,1001)
1001  FORMAT(1H //)
7     DO 3  K=1,NT
3     T(K)=TIME(K)
      IF(PAYUP(2) .EQ. 0.0) GO TO 8
      DO 4 MB=1,16
      VC7(MB)=VC(MB)
4     PAY7(MB)=PAYUP(MB)
      GO TO 11
8     DO 9  MB=1,16
      VC7(MB)=VC(MB)
9     PAY7(MB)=PAYUP(1)
11    CONTINUE
      IF(VA .NE. 0.0) DELV1=0.0
      IF(VB .NE. 0.0) DELV2=0.0
      CALL PLOT1(NSCALE,NHL,NSBH,NVL,NSBV)
      CALL PLOT2(IMAGE,XMAX,XMIN,YMAX,YMIN,800)
      SKIP1=SKIPA
      SKIP2=SKIPB
      ARRML=1.0
      DEPML=1.0
      XMUL=1.0
      XMUW=0.0
      TIMON=TIMEON/24.
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      IF(LAUNCH) DEPART=HIGH
      XLAUNC=PARKIN
      IF(LAUNCH) XLAUNC=ESCAP
      XMODE=FLBY
      IF(MODE)XMODE=ORBTR
      YLEVEL=YHIGH
      IF(DEPART) YLEVEL=YLOW
      XLEVEL=XHIGH
      IF(ARRIVE) XLEVEL=XLOW
      IF(DEPART) SKIP1=0.0
      IF(ARRIVE) SKIP2=0.0
      DO 10  NPLAN1=1,11
      IF (HOME(1).EQ.PLAN(NPLAN1)) GO TO 20
 10   CONTINUE
 15   WRITE(6,16)
 16   FORMAT(2X,32HINPUT PLANET SPELLED INCORRECTLY)
      GO TO 1
 20   DO 30 NPLAN2=1,11
      IF (TARGET(1).EQ.PLAN(NPLAN2)) GO TO 40
 30   CONTINUE
      GO TO 15
 40   CONTINUE
      IF(NPLAN2.EQ.10 .OR. NPLAN2 .EQ. 11) GO TO 41
      GO TO 42
 41   MODE=FLYBY
      XMODE=RENDEZ
 42   CONTINUE
      DO 433  NBIRD=1,13
      DO 438  JW=1,3
      IF(BIRD(JW).NE. VEHIK(JW,NBIRD)) GO TO 433
 438  CONTINUE
      GO TO 435
 433  CONTINUE
      WRITE(6,436)
 436  FORMAT(2X,34HINPUT BOOST VEHICLE NOT IN STORAGE)
      GO TO 1
 435  IF(MPLAN2.EQ.NPLAN2.AND.MBIRD.EQ.NBIRD.AND.ALPHA(1).EQ..0)GOTO2004
 2005 WRITE(6,2000) HOME,TARGET,XMODE
 2000 FORMAT(1H ,40X,2A4,2X,2HTO,4X,4A4,2X,A8/)
      WRITE(6,2040) BIRD,XLAUNC
 2040 FORMAT(1H ,45X,4A4,2X,12HLAUNCH TO    ,A8/)
      IF (MODE) GO TO 2002
      WRITE(6,2001) YLEVEL
 2001 FORMAT(1H ,50X,6HDEPART,3X,A8/)
      GO TO 2011
 2002 WRITE(6,2003) YLEVEL,XLEVEL
 2003 FORMAT(1H ,45X,6HDEPART,3X,A8, 8X,6HARRIVE,3X,A8/)
 2011 IF(NBIRD.NE.1) GO TO 2030
      WRITE(6,2009)
 2009 FORMAT(1H ,4HTIME,3X,5HALPHA,2X,7HPAYLOAD,2X,3HMUP,2X,3HMUW,
     13X,3HMLE,3X,5HDEP L,2X,5HARR L,
     Z3X,4HPBAR,5X,1HC,4X,5HT POW,2X,5HVINF1,2X,5HVINF2,
     2  3X,2HTC,4X,2HTH,4X,3HETA/)
      GO TO 2004
 2030 WRITE(6,2031)
 2031 FORMAT(1H ,4HTIME,2X,5HALPHA,2X,7HPAYLOAD,3X,3HMUP,2X,3HMUW,
     12X,3HMLE,2X,4HDEPL,2X,4HARRL,
     Z2X,5HPOWER,5X,1HC,4X,5HT POW,2X,5HVINF1,2X,5HVINF2,2X,6HBOOSTL,
     2  3X,2HTC,2X,2HTH,5X,3HETA/)
 2004 CONTINUE
C   *****************************************************************ANALYSES
      K=1
 2016 JP=1
 2014 J=1
 2013 L=1
 2015 TOTAL1=0.0
      PAYSUM=10.0
      TLV1=0.0
      VINF1=VA
      VINF2=VB
      DMESH=2.0
 2012 A2=RP2/(1.0-EPST(L))
      A1=RP1/(1.0-EPSD)
      IF(DEPART) SKIP1=0.0
      IF(ARRIVE) SKIP2=0.0
 2044 NPASS=0
 2045 IF(VINF1.LT.0.0) GO TO 726
      IF(VINF2.LT.0.0) GO TO 728
 2050 IF(MATCH) NPASS=10
      CALL DPART          (DEPART,HIGH,LOW,DISP,GE,EPSD,RAD,DSIGMA,
     1RGEO,GMEO,RP1,DEPML,P,Q1,XJDBAR,DM,TDBAR,A1,VINF1,B,
     2   LAUNCH,NBIRD,BOOSTL,VC7,PAY7,DINERT)
      IF (MODE) GO TO 203
 202  CALL FLYBUY             (NPLAN2,THBAR,THPBAR,PTK,
     1  HA,HB,HC,VINF1,DELV1,ANGLE,GMEO,AZERO,VASS1,SKIP1,NPASS,ENERGY)
      Q2=1.0
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      Q=0.0
      CM=0.0
      TCBAR=0.0
      XJCBAR=0.0
      GO TO 114
  203 CALL ORBITR           (NPLAN2, THBAR, THPBAR, PTK, GM, RG,
     1  HA,HB,HC,VINF1,VINF2,DELV1,DELV2,AZERO,AFINAL,VASS1,VASS2,
     2SKIP1,SKIP2,NPASS,GMEO,ENERGY)
 3333 CALL ARRIV       (ARRIVE,NPLAN2,         P,Q,Q1,Q2,TCBAR,
     1 XJCBAR, CM, GM, EPST, TLTSI, AISP, GE,
     2  ASIGMA,RP2,A2,ARRML,VINF2 ,L,RG,B)
  114 AZUSED=AZERO
      AFUSED=AFINAL
      IF(IPRINT .EQ. 2) GO TO 113
      GO TO 112
  113 WRITE(6,9998) NPASS,VINF1,VINF2,TOTALL,BOOSTL,ALPHA(J),ARRML,
     1 XMUL,VASS1,VASS2,AZERO,AFINAL
 9998 FORMAT(2X,I2,2X,2F5.2,2X,2F10.4,2X,1F4.1,2X,2F7.5,2X,2F8.5,2X,
     12F15.10)
  112 IF(DEPML.LE.0.0) GO TO 720
      IF(ARRML .LE. 0.0) GO TO 722
      IF(BOOSTL .LE. 0.0    .AND.MODE .AND. .NOT. ARRIVE) GO TO 621
      IF(BOOSTL .LE. 0.0) GO TO 724
      IF(BOOSTL .LE. WEJECT .AND.MODE .AND. .NOT. ARRIVE) GO TO 621
      IF(BOOSTL.LE.WEJECT) GO TO 718
      IF(ALPHA(J).EQ.0.0) GO TO 690
C  *****************************************     MINIMUM  J  OPTIMIZATION
  115 THI(1)=0.45*T(K)
      PART2=Q1*DM*XJDBAR
      PART3=Q2*CM*XJCBAR
      PART6=1.0/(1.0-DM)
      PART7=1.0/(1.0-CM)
  116 DO 120  N=1,2
      IF(THI(N) .LE. 0.0) GO TO 716
      PART1=EXP(HA)*THI(N)**(HB+HC*ALOG(THI(N))-1.0)
      PART4=2.0*HC*ALOG(THI(N))
      PART5=1.0/((PART4+HB)*PART1)
      TTD(N)=P*ABS(PART2*PART5)**PART6
      TTC(N)=Q*ABS(PART3*PART5)**PART7
      FTH(N) = T(K) - TTD(N) - TTC(N)
      THI(2) = FTH(1)
  120 CONTINUE
      IF (P.EQ.0.0.AND.Q.EQ.0.0) GO TO 128
      IF (THI(2).EQ.THI(1)) GO TO 129
       EMM = (FTH(2) - FTH(1)) / (THI(2) - THI(1))
      TH = (FTH(1) - EMM*THI(1)) / (1. - EMM)
      TH=ABS(TH)
      IF(ABS(1.-(TH/THI(1)))-.0001) 124,124,122
  122 CONTINUE
      THI(1)=TH
      GO TO 116
  128 THI(2)=T(K)
  129 TH=THI(2)
C  *****************************************     COMPUTATION  TD, TC, TH, TP
  124 TD = TTD(2)
      TCAP=TTC(2)
      VARYJ=.0001667*(ALPHA(J) - 5.0)
      IF(SKIP .EQ. 0.0 ) VARYJ=0.0
      XJH=EXP(HA+HB*ALOG(TH)+HC*ALOG(TH)*ALOG(TH))
      XJH=XJH*(1.0 + XJH*VARYJ)
      THP=THPBAR*(TH/THBAR)**PTK
      THP=THP*(1.0 + XJH*VARYJ)**(1/3)
      TP= TD + THP + TCAP
      XJD = 0.
      IF(P.EQ.0.0) GO TO 130
  131 XJD=XJDBAR*((TD/TDBAR)**DM)
  130 XJC=0.
      IF(Q.EQ.0.0) GO TO 135
  134 IF(TCAP .LE. 0.0) GO TO 133
      XJC=XJCBAR*((TCAP/TCBAR)**CM)
      GO TO 135
  133 TCAP=0.0
      XJC=0.0
  135 XJMIN = XJD + XJH + XJC
C  *****************************************     SYSTEM  ANALYSIS
  136 GAMMA = SQRT(ALPHA(J)*XJMIN / 2000.)
      GAMMA2=GAMMA*GAMMA
      Z=B*(1.0 + TANK) + (GAMMA2*D*D)/(.0864*XJMIN*TP)
      IF((GAMMA/(Z**0.5)).GT.1.0) GO TO 648
      XMU1 = 1. - GAMMA / (Z**0.5)
      C=SQRT(0.0864*XJMIN*TP/GAMMA2*Z*XMU1)
      XMUW=2.0*GAMMA/B*Z**.5 - GAMMA*(1.0+TANK)/Z**.5 - GAMMA2/B
      ETA=B/(1.0 + (D/C)**2)
      AZERO=2.E-3*XMUW*ETA/(ALPHA(J)*C)
      AFINAL=AZERO/XMU1
      TERMA= 1.0-AZERO*TP*8.64E4/C
```

```
      IF(TERMA .LE. 0.0) GO TO 648
      TERMB=(1.0-SQRT(TERMA))**2
      TERMC=AZERO*(T(K)-TP)*(RT/C)*ALOG(TERMA)*8.64E4
      CL=(C*C/AZERO)*(TERMB-TERMC)
      AOPT=AZERO
      CLOPT=CL
      TOPT=TP
      IF(POWERH(1) .NE. 0.0 .AND. PPK .EQ. 0.0) GO TO 137
      IF(NPASS.LE.2) GO TO 2050
      XMUL = 1. - 2.*GAMMA*(Z**0.5)/B + (GAMMA2/B)
      GO TO 651
 648  IF(P .EQ. 1.0) GO TO 650
      TOTALL=.00001 + .00001*(VINF1 + VINF2)
      GO TO 630
C  *********************************************  SPECIFIED POWERPLANT
 137  WPLANT     =ALPHA(J)*POWERH(JP)
      XMUW=WPLANT     /((BOOSTL-WEJECT)*DEPML)
      IF(XMUW .GT. 1.0) GO TO 712
      GAMMA2=ALPHA(J)*XJMIN/2000.
      CCA=.5 + .5*GAMMA2/(B*XMUW)
      MT=0
 501  CCB=B*B*XJMIN*TP*.0864*XMUW*XMUW/(GAMMA2*GAMMA2)
      MT=MT + 1
      CCD=D*D/(CCA*CCA*CCB)
      IF(CCD.GT.1.0) GO TO 648
      CSQUA =CCA*CCB*(1.0 + SQRT(1.0-CCD))
      IF(CSQUA.LT.(D*D)) GO TO 648
      CSQUAR=CSQUA-(D*D)
      C=SQRT(CSQUAR)
      ETA=B/(1.0 + (D/C)**2)
      AZERO=2.E-3*XMUW*ETA/(ALPHA(J)*C)
      CL=CLOPT*(.9 + .1*(AOPT/AZERO))
 505  TERMA= 1.0-AZERO*TP*8.64E4/C
      IF(TERMA .LE. 0.0) GO TO 648
      IF(TP.EQ.T(K)) GO TO 516
      TERMB=(1.0-SQRT(TERMA))**2
      TERME=-C*(1.-SQRT(TERMA))*8.64E4/SQRT(TERMA)
      TERMG=ALOG(TERMA) + (T(K)-TP)*AZERO*8.64E4/(C*TERMA)
      TERMD=TERME-TERMG*RT*C*8.64E4
      TERMH=(T(K)-TP)*ALOG(TERMA)
      TERMF=CL-(C*C/AZERO)*TERMB + TERMH*RT*C*8.64E4
      TP1=TP - TERMF/TERMD
      IF(SKIP .EQ. 0.0) GO TO 650
      IF(ABS(1.-TP1/TP) .LE. .001) GO TO 510
      TP=TP1
      IF(TP .GT. T(K)) TP=T(K)
      GO TO 505
 510  IF(MT .GT. 1) GO TO 515
      TP=TP1
      GO TO 501
 515  ETA= B / (1. + (D/C)**2)
      AZERO=2.E-3*XMUW*ETA/(ALPHA(J)*C)
      AFP=AZERO
      TP=TP1
      TERMA= 1.0-AZERO*TP*8.64E4/C
      IF(TERMA .LE. 0.0) GO TO 648
      TERMB=(1.0-SQRT(TERMA))**2
      TERMC=AZERO*(T(K)-TP)*(RT/C)*ALOG(TERMA)*8.64E4
      AFINAL=AZERO/TERMA
      CL=(C*C/AZERO)*(TERMB-TERMC)
      CLFP=CL
      TPFP=TP
      IF(TIMON  .LE. TP) GO TO 520
 516  IF(NPASS.LE.2) GO TO 2050
      GO TO 650
C   *********************************************CONSTRAINED THRUSTING TIME
 520  MTT=0
      C=C*TIMON/TP
521   ETA=B/(1. + (D/C)**2)
      AZERO=2.E-3*XMUW*ETA/(ALPHA(J)*C)
      CL=CLFP*(.85 + .15*(AFP/AZERO)*(TIMON/TPFP))
      TP=TIMON
 525  MTT=MTT + 1
      CC2=C
      MTTT=0
 530  MTTT=MTTT + 1
      ETA=B/(1. + (D/C)**2)
 535  CD=C*C + D*D
      ZA=2.E-3*XMUW*B/ALPHA(J)
      TERMM=1.0 - TP*ZA*8.64E4/CD
      IF(TERMM .LE. 0.0) GO TO 648
      TERMR=(1. - SQRT(TERMM))**2
      FOFC=CL - CD*C*TERMR/ZA + RT*8.64E4*C*(T(K)-TP)*ALOG(TERMM)
      TERMN=-(3.0*C*C + D*D)*TERMR/ZA
      TERMO=-2.*C*C*TP*8.64E4*(1.0-1.0/SQRT(TERMM))/CD
      TERMS=C*C*8.64E4*TP*2.0*ZA/(TERMM*CD*CD)
```

```
      TERMQ=ALOG(TERMM) + TERMS
      TERMP=RT*8.64E4*(T(K)-TP)*TERMQ
      FDOTC=TERMN + TERMO + TERMP
      CC1=C - FOFC/FDOTC
      IF(ABS(1. - CC1/C) .LE. .001) GO TO 540
      C=CC1
      IF(C .LT. D) GO TO 648
      GO TO 530
  540 C=CC1
      ETA=B/(1. + (D/C)**2)
      ABEFOR=AZERO
      AZERO=2.E-3*XMUW*ETA/(ALPHA(J)*C)
      CL=CLFP*(.85 + .15*(AFP/AZERO)*(TIMON/TPFP))
      IF(ABS(1.-AZERO/ABEFOR) .LE. .001) GO TO 555
      GO TO 525
  555 ETA=B/(1. + (D/C)**2)
      AZERO=2.E-3*XMUW*ETA/(ALPHA(J)*C)
      CL=CLFP*(.85 + .15*(AFP/AZERO)*(TIMON/TPFP))
      XMU1=1. - AZERO*TP*8.64E4/C
      IF(XMU1 .LE. XMUW) GO TO 648
      AFINAL=AZERO/XMU1
      IF(NPASS .LE. 2) GO TO 2050
      GO TO 650
C    *********************************************   SYSTEM  PARAMETERS
  650 ETA =  B / (1. + (D/C)**2)
      XMU1=1. - AZERO*TP*8.64E4/C
      XMUL=XMU1*(1.0+ TANK) - XMUW - TANK
  651 ETA =  B / (1. + (D/C)**2)
      XMUP=1.0 - XMU1
      XMUT=TANK*XMUP
      TOTALL=DEPML*ARRML*(BOOSTL-WEJECT)*XMUL-AINERT
      IF(TOTALL.LE.0.0) TOTALL=.00001 + .00001*(VINF1 + VINF2)
      IF(XMUL.LT. 0.0) GO TO 630
      PBAR=XMUW*DEPML*(BOOSTL-WEJECT)/(ALPHA(J)*TOTALL)
      POWERR=PBAR*TOTALL
      IF(PPK.EQ.0.0) GO TO 630
  628 ALPHAC=WPLANT    *POWERR**PPK
      IF(ABS(1.0-ALPHA(J)/ALPHAC)-.000100)  630,630,629
  629 ALPHA(J)=ALPHAC
      GO TO 124
C  ****************************************    HYPERBOLIC VELOCITY OPTIMIZATION
  630 IF(P.EQ.1.0.AND.Q.EQ.1.0)  GO TO 700
C    CARD 630  SCREENS  FOR ORBITER LOW-LOW
  631 IF(MODE) GO TO 610
C  CARD 631  SCREENS FOR  ORBITERS
  632 IF(P.EQ.1.0) GO TO 700
C    CARD  632 SCREENS  FOR FLYBY LOW DEPART
  605 IF(ABS(1.0-TOTAL1/TOTALL).LE..00002) GO TO 660
      IF(TOTALL-TOTAL1) 602,660,600
  600 TOTAL1=TOTALL
      VINF1=VINF1+DELV1*DMESH
      AZ=AZUSED
      AF=AFUSED
      ALPHAX=ALPHA(J)
      GO TO 2050
  602 VINF1=VINF1-DELV1*DMESH
      AZERO=AZ
      AFINAL=AF
      IF(PPK .NE. 0.0) ALPHA(J)=ALPHAX
      NPASS=2
      GO TO 2045
  610 IF(P.EQ.0.0.AND.Q.EQ.1.0) GO TO 605
C    CARD 610 SCREENS FOR ORBITER HIGH-LOW
  611 IF(P.EQ.0.0.AND.Q.EQ.0.0) GO TO 615
C    CARD 611 SCREENS FOR ORBITER  HIGH-HIGH
      IF(ABS(1.0-TOTAL1/TOTALL).LE..00002) GO TO 660
  612 IF(TOTALL-TOTAL1) 613,660,614
C    CARD 612 HANDLES ORBITER LOW-HIGH
  614 TOTAL1=TOTALL
      VINF2=VINF2+DELV2*DMESH
      AZ=AZUSED
      AF=AFUSED
      ALPHAX=ALPHA(J)
      GO TO 2050
  613 VINF2=VINF2-DELV2*DMESH
      AFINAL=AF
      AZERO=AZ
      IF(PPK .NE. 0.0) ALPHA(J)=ALPHAX
      NPASS=2
      GO TO 2045
  615 IF(XMUL .LT. 0.0) GO TO 621
      IF(ABS(1.0-TLV1/TOTALL  ).LE..00002)GO TO 619
      IF(TOTALL-TLV1) 618,619,620
C    CARD 615  IS  FOR  ORBITER HIGH-HIGH FOR FIXED VINF2
  620 VINF1=VINF1 + DELV1*DMESH
      TLV1=TOTALL
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      AZ=AZUSED
      AF=AFUSED
      ALPHAX=ALPHA(J)
      GO TO 2050
  618 VINF1=VINF1-DELV1*DMESH
      AZERO=AZ
      AFINAL=AF
      IF(PPK .NE. 0.0) ALPHA(J)=ALPHAX
      NPASS=2
      GO TO 2045
  619 IF(ABS(1.0-TOTAL1/TOTALL).LE..00002)GO TO 660
      IF(TOTALL-TOTAL1) 622,660,621
C    CARD 619 IS FOR ORBITER HIGH-HIGH  WITH VARIATION ON VINF2
  621 TOTAL1=TOTALL
      VINF1A=VINF1
      VINF2A=VINF2
      AZ2=AZ
      AF2=AF
      ALPHAY=ALPHA(J)
      VINF1=VINF1A-2.0*DELV1*DMESH
      IF(VINF1.LE.VA) VINF1=VA
      VINF2=VINF2 + DELV2*DMESH
      AZERO=AZ
      AFINAL=AF
      TLV1=0.0
      GO TO 2044
  622 TLV1=TOTAL1
      VINF1=VINF1A
      VINF2=VINF2A
      AZERO=AZ2
      AFINAL=AF2
      IF(PPK .NE. 0.0) ALPHA(J)=ALPHAY
      NPASS=2
      GO TO 2045
  660 IF(DMESH.EQ.1.0) GO TO 700
      DMESH=1.0
      TLV1=0.0
      TOTAL1=0.0
      VINF1=VINF1-DELV1
      IF(VINF1.LE.VA) VINF1=VA
      VINF2=VINF2-DELV2
      IF(VINF2.LE.VB) VINF2=VB
      GO TO 2044
  670 POWERH(1)=POWERR
      POWER(1)=1.0
      GO TO 2015
  690 TOTALL=DEPML*ARRML*(BOOSTL-WEJECT)*XMUL-AINERT
C   BALLISTIC SYSTEM PRINTOUT
      WRITE(6,689) T(K),TOTALL,DEPML,ARRML,VINF1,VINF2,BOOSTL
  689 FORMAT(1H ,F5.0,7X,F10.3,15X,F5.3,1X,F5.3,25X,F4.1,3X,F4.1,2X,F7.0
     1)
      PAYSUM=10.0
      GO TO 805
  700 IF(XMUL.LT. 0.0) GO TO 730
      IF(VINF1.EQ.0.0)  VINF1=0.0
      IF(VINF2.EQ.0.0) VINF2=0.0
      IF(POWERH(1).EQ.0.0.AND.PPK.EQ.0.0.AND.TIMON.LE.TP) GO TO 670
      IF(POWER(1) .EQ. 1.0) POWERH(1)=0.0
      TP=TP*24.0
      TOTALL=DEPML*ARRML*(BOOSTL-WEJECT)*XMUL-AINERT
  691 IF(BOOSTL.NE.1.0) GO TO 693
C  ***************************************************************    PRINT OUT
      WRITE(6, 692)T(K),ALPHA(J),TOTALL,XMUP,XMUW,XMUL,DEPML,ARRML,
     1PBAR,C,TP,VINF1,VINF2,TCAP,TH,ETA
  692 FORMAT(1H ,F5.0,2X,F5.1,2X,F5.4,2X,F4.3,1X,F5.4,1X,F6.4,2X,F5.3,
     12X,F5.3,2X,F6.4,2X,F5.1,2X,F6.0,2X,F4.1,2X,F4.1,2X,
     2F5.1,1X,F5.0,2X,F4.3)
      GO TO 695
  693 WRITE(6, 694)T(K),ALPHA(J),TOTALL,XMUP,XMUW,XMUL,DEPML,ARRML,
     1POWERR,C,TP,VINF1,VINF2,BOOSTL,TCAP,TH,ETA
  694 FORMAT(1H ,F5.0,1X,F5.1,1X,F7.0,2X,F4.3,1X,F4.3,1X,F4.3,1X,F5.3,
     11X,F5.3,2X,F6.1,2X,F5.1,2X,F6.0,2X,F4.1,2X,F4.1,2X,F7.0,2X,
     2F4.0,1X,F5.0,2X,F4.3)
  695 IPC=ALPHA(J)/10.0+.05
      BCD=CHAR(IPC)
      NDATA=1
      TPLOT=T(K)
      TLPLOT=TOTALL
      CALL PLOT3(BCD,TPLOT,TLPLOT,NDATA)
  805 L=L + 1
      IF(L.GT.NET) GO TO 801
      GO TO 2015
  800 PAYSUM=-1.0
  801 L=1
  804 IF(PPK .NE. 0.0) GO TO 807
      J=J + 1
```

```
      IF(J.GT.NA) GO TO 802
      IF(ALPHA(J).GT.ALPHA(J-1).AND.PAYSUM.LT.0.0) GO TO 802
      GO TO 2013
802   J=1
806   JP=JP + 1
      IF(JP.GT.NP) GO TO 803
      IF(POWERH(JP) .GT. POWERH(JP-1) .AND. XMUW .GT.1.0) GO TO 803
      GO TO 2014
803   JP=1
807   K=K + 1
      IF(PPK .NE. 0.0) ALPHA(1)=1.0
      IF(K.GT.NT) GO TO 808
      IF(T(K).LT.T(K-1).AND.PAYSUM.LT.0.0) GO TO 808
      WRITE(6,809)
809   FORMAT(1H )
      GO TO 2016
808   K=1
      PAYSUM=10.0
      IF(IPRINT.EQ.1) GO TO 302
      GO TO 1
302   WRITE(6,300)TARGET,XMODE
300   FORMAT(1H1,45('*'),4A4,A8,30('*'))
304   WRITE(6,305)BIRD,XLAUNC
305   FORMAT(1X,4A4,2X,11HLAUNCH TO  ,A8)
      IF(LAUNCH) GO TO 318
      WRITE(6,306) YLEVEL
306   FORMAT(1X,A8,13HTHRUST ESCAPE)
307   IF(.NOT.MODE) GO TO 320
      WRITE(6,308) XLEVEL,RP2,EPST(L)
308   FORMAT(1X,A8,14HTHRUST CAPTURE,3X,4HRP2=,F5.1,2X,4HECC=,F3.2)
310   IF(PPK.NE.0.0) GO TO 311
      IF(POWERH(1).EQ.0.0) GO TO 313
      IF(TIMON .LE. TP) GO TO 324
      WRITE(6,323) POWERH(JP)
323   FORMAT(1X,6HPOWER=,F5.0,1X,3HKWE, 65X,19HOPTIMUM THRUST TIME)
      GO TO 317
324   WRITE(6,315) POWERH(JP),TIMEON
315   FORMAT(1X,6HPOWER=,F5.0,1X,3HKWE,49X,24HTHRUST TIME UPPER LIMIT=,
     1F6.0, 5HHOURS)
      GO TO 317
318   WRITE(6,319)
319   FORMAT()
      GO TO 307
320   WRITE(6,319)
      GO TO 310
  311 PPKDIF = 1.0 + PPK
      WRITE(6,312) WPLANT,PPKDIF
312   FORMAT(1X,11HPLANT MASS=,F5.0,8H*POWER**,F3.2)
      GO TO 317
313   WRITE(6,314)
314   FORMAT(1X,13HOPTIMUM POWER,67X,19HOPTIMUM THRUST TIME)
317   CALL PLOT4(31,31H     NET  SPACECRAFT  MASS   KG)
      WRITE(6,301)
301   FORMAT(45X,18HMISSION TIME, DAYS)
      WRITE(6,322) NAME,DAT
322   FORMAT(1X,6HFIGURE, 69X,3A4,2X,2A4)
151   GO TO 1
712   WRITE(6,713)
713   FORMAT(2X,21HXMUW GREATER THAN 1.0)
      GO TO 806
716   WRITE(6,717)
717   FORMAT(2X,38HTHI(N) LESS THAN 0.0,CHECK TIME INPUTS)
      GO TO 805
718   WRITE(6,719)
719   FORMAT(2X,23HBOOSTL LESS THAN WEJECT)
      GO TO 800
720   WRITE(6,721)
721   FORMAT(2X,14HNEGATIVE DEPML)
      GO TO 800
722   WRITE(6,723)
723   FORMAT(2X,14HNEGATIVE ARRML)
      GO TO 800
724   WRITE(6,725)
725   FORMAT(2X,15HNEGATIVE BOOSTL)
      GO TO 800
726   WRITE(6,727)
727   FORMAT(2X,19HVINF1 LESS THAN 0.0)
      GO TO 805
728   WRITE(6,729)
729   FORMAT(2X,19HVINF2 LESS THAN 0.0)
      GO TO 805
730   WRITE(6,731)
731   FORMAT(2X,13HNEGATIVE XMUL)
      GO TO 800
      END
```

```
C        MPX04F5              DEPART  E-9
C
C
       SUBROUTINE DPART   (DEPART,HIGH,LOW,DISP,GE,EPSD,RAD,DSIGMA,
     1RGEO,GMEO,RP1,DEPML,P,Q1,XJDBAR,DM,TDBAR,A1,VINF1,B,
     2   LAUNCH,NBIRD,BOOSTL,VC7,PAY7,DINERT)
       DIMENSION SIS4V(16), T3FCP(16), T3FCV(16), T3FV(16), T3FP(16)
       DIMENSION SVP(16), SVV(16), SIS4CP(16), SIS4CV(16), SIS4P(16)
       DIMENSION PAY7(16), VC7(16)
       DIMENSION SVCV(16), SVCP(16), SICV(16), SICP(16), T3DAV(16)
       DIMENSION T3DAP(16), ACV(16), ACP(16), AAV(16), AAP(16)
       DIMENSION T3DCV(16),  T3DCP(16)
       DATA SVV/7.0, 7.75, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.0, 15.5,
     1  16.0, 16.2, 16.3, 16.4, 16.8, 30.0  /
       DATA SVP /152000., 120000., 82000., 60000., 43000., 30500.,
     1 21000., 12800., 6900., 4000., 1300., 400., 130.,30., 0., 0. /
       DATA SIS4CV/7.,7.75,9., 10., 11., 12., 13., 14., 15., 16., 17.,
     1  18., 19., 20., 21., 30. /
       DATA SIS4CP/89000., 67000., 46000., 32000., 22800., 16000.,
     1 11700., 8200., 5800., 4000., 2700., 1700., 890., 370.,100.,0. /
       DATA SIS4V/7.,7.75, 9., 10., 11., 11.5, 12., 12.5, 12.8, 13.,
     1 13.2, 13.4, 13.5, 13.6, 13.8, 30. /
       DATA SIS4P/80000., 62000., 41000., 27500., 16600., 12300.,
     1  8400., 5400., 3800., 2800., 1970., 1140., 680., 250., 30.,0. /
       DATA T3FCV/7.,7.75, 9., 10., 11., 12., 13., 14., 15., 15.5,
     1  16., 16.5, 16.8, 17., 17.5, 30. /
       DATA T3FCP/30000., 23000., 15000., 10800., 7700., 5300., 3600.,
     1  2300., 1380., 990., 680., 375., 200., 90., 0., 0. /
       DATA T3FV/7., 7.75, 9., 10., 11., 11.5, 12., 12.2, 12.4, 12.6,
     1  12.8, 13., 13.1, 13.2, 13.4, 30.6  /
       DATA T3FP/ 25000., 18000., 10200., 6300., 3350., 2300., 1500.,
     1  1200., 900., 630., 370., 150., 70., 20., 0.0, 0. /
       DATA  SVCV / 7.0, 7.75, 9.0, 10., 12., 14., 16., 18., 20., 21.,
     1 22., 22.5, 23., 23.25, 24., 30.0/
       DATA SVCP / 152000.0, 120000.0, 82000.0, 62000.0, 34000.0,
     1 18000., 9300., 4500., 2100., 1300., 600., 340., 125., 50.,0.,0./
       DATA  SICV / 7.0, 7.75, 9.0, 10., 11., 12., 13., 13.5, 14., 14.5,
     1  15., 15.8, 16.4, 17., 17.2, 30.0 /
       DATA  SICP / 32200., 24000., 15000., 10440., 7080., 4760.0,
     1  3130., 2450., 1910., 1408., 1044., 454., 136., 10., 0.0, 0.0/
       DATA  T3DAV /  7.0, 7.75, 9., 10., 11., 12., 12.5, 13., 13.5, 14.,
     1  14.4, 14.8, 15.2, 15.6, 16., 30.  /
       DATA  T3DAP / 15880., 12100., 7530., 4950., 3040., 1838., 1360.,
     1  1042., 741., 499., 317.,  186., 95.4, 45.4, 0.0, 0.0/
       DATA  ACV /7.0, 7.75, 9.0, 10., 10.5, 11., 11.4, 11.8, 12.2,
     1  12.4, 12.6, 12.8, 13., 13.3, 14., 30.0/
       DATA   ACP / 7260., 5360., 3250., 2130., 1680., 1295., 1000.,
     1  749.,  450., 330., 220., 118., 45., 10., 0.0, 0.0/
       DATA   AAV / 7.0, 7.75, 9., 10., 10.4, 10.8, 11.2, 11.6,
     1  12., 12.2, 12.4, 12.6, 12.8, 13., 14., 30.0/
       DATA   AAP  / 5000., 3600., 2000., 1160., 910., 700., 530., 380.,
     1   250., 192., 140., 80., 36., 17., 0.0,0.0/
       DATA T3DCV / 7.0, 7.75, 9.0, 10.0, 11., 12.0, 13.0, 14.,
     1 14.5, 15.0, 15.5, 16.0, 16.42, 17.0, 18.0, 30.0/
       DATA  T3DCP  /  21600.0, 17000.0, 11000.,  7800.,  5500., 3800.,
     1  2500., 1520., 1140., 790., 460., 240., 100., 50., 0.0, 0.0 /
       LOGICAL DEPART,HIGH,LOW
       LOGICAL LAUNCH, ESCAPE, PARK
       BOOSTL=1.0
       D1=0.0
       IF(LAUNCH) GO TO 820
       GO TO 821
  820  VBOOST=SQRT(VINF1*VINF1 + 120.1)
       GO TO 800
  821  E100=(RP1*6375. - 6560.)/(RP1 * 6375. + 6560.)
       A100 =(RP1*6375. + 6560.)/2.0
       BIRDV1=SQRT(GMEO*(1.+E100)/((1.-E100)*A100))-7.75
       BIRDV2=SQRT(GMEO*(1.+EPSD)/((1.-EPSD)*A1*RGEO))
     1        -SQRT(GMEO*(1.-E100)/((1.+E100)*A100))
       VBOOST=7.75 + BIRDV1 + BIRDV2
       GO TO 800
  800  GO TO (801,802,803,804,805,806,807,808,809,810,811,812,813),NBIRD
  801  BOOSTL=1.0
       VBOOST=7.75
       GO TO 841
  802  CALL TAINT(SVV   ,SVP   ,VBOOST,BOOSTL,16,2,NERR1,D1)
       GO TO 841
  803  CALL TAINT(SIS4CV,SIS4CP,VBOOST,BOOSTL,16,2,NERR1,D1)
       GO TO 841
  804  CALL TAINT(SIS4V ,SIS4P ,VBOOST,BOOSTL,16,2,NERR1,D1)
       GO TO 841
  805  CALL TAINT(T3FCV ,T3FCP ,VBOOST,BOOSTL,16,2,NERR1,D1)
       GO TO 841
  806  CALL TAINT(T3FV  ,T3FP  ,VBOOST,BOOSTL,16,2,NERR1,D1)
       GO TO 841
  807  CALL TAINT(VC7,PAY7,VBOOST,BOOSTL,16,2,NERR1,D1)
```

```
      GO TO 841
  808 CALL TAINT( SVCV , SVCP ,VBOOST,BOOSTL,16,2,NERR1,D1)
      GO TO 841
  809 CALL TAINT(SICV , SICP  ,VBOOST,BOOSTL,16,2,NERR1,D1)
      GO TO 841
  810 CALL TAINT( T3DAV,T3DAP ,VBOOST,BOOSTL,16,2,NERR1,D1)
      GO TO 841
  811 CALL TAINT(    ACV,    ACP,VBOOST,BOOSTL,16,2,NERR1,D1)
      GO TO 841
  812 CALL TAINT(    AAV,    AAP,VBOOST,BOOSTL,16,2,NERR1,D1)
      GO TO 841
  813 CALL TAINT(T3DCV,T3DCP  ,VBOOST,BOOSTL,16,2,NERR1,D1)
      GO TO 841
  841 IF(LAUNCH) GO TO 505
      GO TO 504
  504 IF(DEPART) GO TO 503
      GO TO 501
  501 CONTINUE
      TLTSI=0.0
      VJET=DISP*GE
      EPS=EPSD
      TLTSR=TLTSI/RAD
      VINF=VINF1
      SIGMA=DSIGMA
      RD=RGEO
      GP=GMEO
      AS=RP1/(1.-EPS)
      PS=AS*RD*(1.-EPS*EPS)
      RLTS=PS/(1.+EPS*COS(TLTSR))
      VSU=SQRT((GP/(AS*RD))*(1.+2.*EPS*COS(TLTSR)+EPS*EPS)/(1.-EPS*EPS))
      DVI=SQRT((VINF**2)+(2.*GP/(RLTS)))-VSU
      BMFST=EXP((-DVI)/VJET)
      BPROP=(1.+SIGMA)*BMFST-SIGMA -DINERT/BOOSTL
      DEPML=BPROP
  505 P=0.0
      Q1=1.0
      XJDBAR=0.0
      DM=0.0
      TDBAR=0.0
      GO TO 596
  503 C=100.0
      D=20.0
      TC=8.64E4
      TDBAR=30.
      TDBAR=TDBAR*TC
      T=200.0*TC
      GP=GMEO
      EPS=EPSD
      RD=RGEO
      A1=RP1/(1.-EPS)
      AD=A1*RD
      VC=SQRT(GP/(A1*RD))
      U1=.9
  430 IF(U1.GT.1.0) U1=.999999
      P1=1.84*VC*((AD*AD*C/(GP*TDBAR))**.25)/C
      P2=(1.0/U1-1.0)**.25
      P3=(1.0/U1-1.0)**.75
      FU=ALOG(U1)+VC/C-(P1)*P2
      FUDOT=1.0/U1+P1/(P3*U1*U1*4.0)
      U2=U1-FU/FUDOT
      ETA=1./(1.+(D/C)**2)
      UALPHA=(1.0-U2)*1000.*C*C/(2.*ETA*TDBAR)
      IF(ABS(1.-(U1/U2))-.0001) 431,431,432
  432 U1=U2
      GO TO 430
  431 XJDBAR=2.0*ETA*UALPHA*1000.*(1.-U2)/U2
      U1=.9
  230 IF(U1.GT.1.0) U1=.999999
      P1=1.84*VC*((AD*AD*C/(GP*T))**.25)/C
      P2=(1.0/U1-1.0)**.25
      P3=(1.0/U1-1.0)**.75
      FU=ALOG(U1)+VC/C-(P1)*P2
      FUDOT=1.0/U1+P1/(P3*U1*U1*4.0)
      U2=U1-FU/FUDOT
      ETA=1./(1.+(D/C)**2)
      UALPHA=(1.0-U2)*1000.*C*C/(2.*ETA*T)
      IF(ABS(1.-(U1/U2))-.0001) 231,231,232
  232 U1=U2
      GO TO 230
  231 XJ=2.0*ETA*UALPHA*1000.*(1.-U2)/U2
      DM=(ALOG(XJDBAR/XJ))/(ALOG(TDBAR/T))
      IF(DM  .LT.0.0) GO TO 240
      DM=0.0
      XJDBAR=0.0
  240 TDBAR=TDBAR/TC
      P=1.0
      Q1=TDBAR**(-DM)
    1 CONTINUE
  596 RETURN
      END
```

```
C       MPX04F4                   FLYBY
C
C
        SUBROUTINE FLYBUY      (NPLAN2,THBAR,THPBAR,PTK,
       1  HA,HB,HC,VINF1,DELV1,ANGLE,GMEO,AZERO,VASS1,SKIP1,NPASS,ENERGY)
        LOGICAL ENERGY,ATOMIC,SOLAR
        D1=0.0
        C1=0.0
        C3=0.0
        VASS1=VINF1
        NPASS=NPASS + 1
        IF(SKIP1.EQ.0.0) GO TO 202
        IF(NPASS .GE. 10) GO TO 195
C     ********************************************   ASYMPTOTIC MATCHING
        XASS1=VINF1*VINF1*.25/SQRT(GMEO*AZERO)
        GOFX1=2.0*(XASS1+.651630)*(XASS1+4.113609)*(XASS1+1.214342)/(
       1  (XASS1+4.169068)*(XASS1+1.303312)*(SQRT(XASS1+1.0)))
  201   VASS1=GOFX1*(GMEO*AZERO)**.25
  202   GO TO (301,302,303,304,305,306,307,308,309,310,311),NPLAN2
  195   VASS1=SQRT(VINF1*VINF1 + 2.0*GMEO/(145.0000*6375.0))
C   **********************************  SPHERE OF INFLUENCE MATCHING
        GO TO 202
  301   THBAR=70.0
C   MERCURY
        HA=56.365662
        HB=-20.123871
        HC=1.848905
        DELV1=0.0
        THPBAR=43.796
        PTK=1.291965
        GO TO 500
  302   THBAR=50.0
C   VENUS
        HA=42.662186
        HB=-15.007878
        HC=1.328273
        DELV1=0.0
        THPBAR=27.5
        PTK=1.0
        GO TO 500
C   EARTH
  303   GO TO 1
C   MARS

  304   GO TO 1
  305   THBAR=300.0
C   JUPITER
        HA=56.788559
        HB=-15.133818
        HC=1.030477
        C1=-.002046
        C3=1.505424
        THPBAR=150.89
        PTK=1.056036
        GO TO 500
  306   THBAR=600.0
C   SATURN
        HA=54.259232
        HB=-13.236733
        HC=.827999
        C1=-.001736
        C3=1.368783
        THPBAR=321.034
        PTK=.887848
        GO TO 500
  307   THBAR=600.0
C   URANUS
        HA=40.394104
        HB=-8.366853
        HC=.438166
        C1=-.001075
        C3=1.439463
        THPBAR=329.991
        PTK=.907105
        GO TO 500
  308   THBAR=1500.
C   NEPTUNE
        HA=44.884598
        HB=-8.931028
        HC=.445309
        C1=-.000705
        C3=1.512190
        PTK=1.274
        THPBAR=786.
        GO TO 500
C   PLUTO
  309   GO TO 1
```

```
  310 THBAR=500.0
C  HALLEY'S  COMET RENDEZVOUS
      HA=-51.464508
      HB=18.605637
      HC=-1.553296
      C1=-.001243
      C3=.993871
      PTK=1.0
      THPBAR=450.0
      GO TO 500
  311 DIHI=2.0*57.29578*ARSIN(VASS1/59.54)
C  EXTRA-ECLIPTIC  RENDEZVOUS
      IF(DIHI .GT. ANGLE) DIHI=ANGLE
      DILO=ANGLE-DIHI
      VINC=DILO/10.0
      IF(.NOT. ENERGY) GO TO 411
      THBAR=400.0
      THPBAR=372.
      PTK=1.
      HA=.338472
      HB=2.247731
      HC=-.41
      C1=.0713
      C3=.335
      FACTOR=C1*VINC**C3
      GO TO 501
  411 HA=5.0
      HB=-1.004368
      HC=-.000119
      C1=2.315532
      C3=.443572
      THPBAR=180.+DILO
      THBAR=300.0
      PTK=1.0
      HA=HA+C1*VINC**C3
      GO TO 502
    1 WRITE(6,100)
  100 FORMAT(1H ,22HPLANET DATA NOT STORED)
  500 FACTOR=C1*VASS1**C3
  501 HC=HC+FACTOR
  502 RETURN
      END
```

```
C        MPX04F2               ORBITER
C
C
      SUBROUTINE ORBITR       (NPLAN2, THBAR, THPBAR, PTK, GM, RG,
     1 HA,HB,HC,VINF1,VINF2,DELV1,DELV2,AZERO,AFINAL,VASS1,VASS2,
     2SKIP1,SKIP2,NPASS,GMEO,ENERGY)
      LOGICAL ENERGY,ATOMIC,SOLAR
      D1=0.0
      C1=0.0
      C2=0.0
      C3=0.0
      C4=0.0
  203 GO TO (401,402,403,404,405,406,407,408,409),NPLAN2
  401 THBAR=80.
C  MERCURY
      HA=37.226028
      HB=-11.546978
      HC=.971943
      DELV1=0.0
      DELV2=0.0
      THPBAR=56.161
      PTK=1.156017
      GM=2.18E4
      RSPHER=46.
      RG=2420.
      GO TO 500
  402 THBAR=100.0
C  VENUS
      HA=42.995316
      HB=-14.002761
      HC=1.163274
      DELV1=0.0
      DELV2=0.0
      THPBAR=60.
      PTK=1.0
      GM=3.2485E5
      RSPHER=101.
      RG=6.05E3
      GO TO 500
C  EARTH
  403 GO TO 1
C  MARS
  404 GO TO 1
```

```
 405   THBAR=400.0
C  JUPITER
       HA=56.546051
       HB=-13.704782
       HC=.843276
       C1=-.0017318
       C3=1.258404
       THPBAR=257.175
       PTK=.895741
       RG=7.14E4
       RSPHER=674.
       GM=1.2671E8
       GO TO 500
 406   THBAR=700.
C  SATURN
       HA=46.593872
       HB=-9.870175
       HC=.525386
       C1=-.001485
       C3=1.145093
       THPBAR=437.583
       PTK=.908804
       RG=6.04E4
       RSPHER=905.
       GM=3.792E7
       GO TO 500
 407   THBAR=1200.
C  URANUS
       THPBAR=740.
       PTK=.88825
       HA=52.340347
       HB=-10.660658
       HC=.549718
       C1=-.001056
       C3=1.056167
       RG=2.35E4
       RSPHER=2210.
       GM=5.788E6
       GO TO 500
 408   THBAR=2000.
C  NEPTUNE
       HA=58.582687
       HB=-11.742033
       HC=.598062
       C1=-.000748
       C3=1.123747
       THPBAR=1220.
       PTK=.748
       RG=2.23E4
       RSPHER=3900.
       GM=6.8E6
       GO TO 500
C  PLUTO
 409   GO TO 1
 1     WRITE(6,100)
 100   FORMAT(2H , 22HPLANET DATA NOT STORED)
 500   VASS1=VINF1
       VASS2=VINF2
       NPASS=NPASS + 1
       IF(SKIP1.EQ.0.0) GO TO 499
       IF(NPASS .GE. 10) GO TO 195
C    ******************************************   ASYMPTOTIC MATCHING
       XASS1=VINF1*VINF1*.25/SQRT(GMEO*AZERO)
       GOFX1=2.0*(XASS1+.651 630)*(XASS1+4.113 609)*(XASS1+1.214342)/(
      1  (XASS1+4.169068)*(XASS1+1.303312)*(SQRT(XASS1+1.0)))
 201   VASS1=GOFX1*(GMEO*AZERO)**.25
 499   IF(SKIP2.EQ.0.0) GO TO 501
       IF(NPASS .GE. 10) GO TO 196
       XASS2=VINF2*VINF2*.25/SQRT(GM*AFINAL)
       GOFX2=2.0*(XASS2+.651 630)*(XASS2+4.113 609)*(XASS2+1.214342)/(
      1    (XASS2+4.169068)*(XASS2+1.303312)*(SQRT(XASS2+1.0)))
       GO TO 198
C   ***********************************  SPHERE OF INFLUENCE MATCHING
 195   VASS1=SQRT(VINF1*VINF1 + 2.0*GMEO/(145.0000*6375.0))
       GO TO 499
 196   VASS2=SQRT(VINF2*VINF2 + 2.0*GM/(RSPHER *RG))
       GO TO 501
 198   VASS2=GOFX2*(GM*AFINAL)**.25
 501   FACTOR=C1*(VASS1 + VASS2)**C3
       HC=HC+FACTOR
       RETURN
       END
```

```
C       MPX04F3                  ARRIVE
C
C
      SUBROUTINE ARRIV (ARRIVE,NPLAN2,         P,Q,Q1,Q2,TCBAR,
     1 XJCBAR, CM, GM, EPST, TLTSI, AISP, GE,
     2  ASIGMA,RP2,A2,ARRML,VINF2 ,L,RG,B)
      LOGICAL MODE,FLYBY,ORBIT,ARRIVE,DEPART,HIGH,LOW
      DIMENSION EPST(20)
      RAD=1.0/.01745329
      IF (ARRIVE) GO TO 100
      GO TO 200
  100 C=100.0
      D=20.0
      TC=8.64E4
      TCBAR=30.0
      TCBAR=TCBAR*TC
      T=200.0*TC
      EPS=EPST(L)
      GP=GM
      A2=RP2/(1.-EPS)
      AD=A2*RG
      VC=SQRT(GP/(A2*RG))
      U1=.9
  430 IF(U1.GT.1.0) U1=.999999
      P1=1.84*VC*((AD*AD*C/(GP*TCBAR))**.25)/C
      P2=(1.0-U1)**.25
      P3=(1.0-U1)**.75
      FU=ALOG(U1)+VC/C-(P1)*P2
      FUDOT=1.0/U1+P1/(P3*U1*U1*4.0)
      U2=U1-FU/FUDOT
      ETA=1./(1.+(D/C)**2)
      UALPHA=(1.0-U2)*1000.*C*C/(2.*ETA*TCBAR)
      IF(ABS(1.-(U1/U2))-.0001) 431,431,432
  432 U1=U2
      GO TO 430
  431 IF(U2 .GE. 1.0) U2=.999998
      XJCBAR=2.0*ETA*UALPHA*1000.*(1.-U2)/U2
      U1=.9
  230 IF(U1.GT.1.0) U1=.999999
      P1=1.84*VC*((AD*AD*C/(GP*T))**.25)/C
      P2=(1.0-U1)**.25
      P3=(1.0-U1)**.75
      FU=ALOG(U1)+VC/C-(P1)*P2
      FUDOT=1.0/U1+P1/(P3*U1*U1*4.0)
      U2=U1-FU/FUDOT
      ETA=1./(1.+(D/C)**2)
      UALPHA=(1.0-U2)*1000.*C*C/(2.*ETA*T)
      IF(ABS(1.-(U1/U2))-.0001) 231,231,232
  232 U1=U2
      GO TO 230
  231 IF(U2 .GE. 1.0) U2=.999999
      XJ=2.0*ETA*UALPHA*1000.*(1.-U2)/U2
      CM=(ALOG(XJCBAR/XJ))/(ALOG(TCBAR/T))
      IF(CM  .LT.0.0) GO TO 240
      CM=0.0
      XJCBAR=1.0
  240 TCBAR=TCBAR/TC
  500 Q=1.0
      Q2=TCBAR**(-CM)
      GO TO 114
  200 Q2=1.0
      Q=0.
      CM=0.0
      TCBAR=0.0
      XJCBAR=0.0
      GP=GM
      EPS=EPST(L)
      TLTSI=0.0
      VJET=AISP*GE
      TLTSR=TLTSI/RAD
      VINF=VINF2
      SIGMA=ASIGMA
      AS=RP2/(1.-EPS)
      PS=AS*RG*(1.-EPS*EPS)
      RLTS=PS/(1.+EPS*COS(TLTSR))
      VSU=SQRT((GP/(AS*RG))*(1.+2.*EPS*COS(TLTSR)+EPS*EPS)/(1.-EPS*EPS))
      DVI=SQRT((VINF**2)+(2.*GP/(RLTS)))-VSU
      BMFST=EXP((-DVI)/VJET)
      BPROP=(1.+SIGMA)*BMFST-SIGMA
      ARRML=BPROP
      GO TO 114
   19 WRITE(6,221)
  221 FORMAT(1H ,22HPLANET DATA NOT STORED)
  114 RETURN
      END
```

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