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Standardized Spacecraft

- A Methodology for Decision Making -

AMS Report No. 1199

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ABSTRACT

As the space program matures, more and more attention is being focused on ways to reduce the costs of performing space missions. Standardization has been suggested as a way of providing cost reductions. This report is concerned primarily with the question of standardization at the system level; in particular, the question of the desirability of spacecraft standardization for geocentric space missions is addressed. The spacecraft is considered to be a bus upon which mission oriented equipment, the payload, is mounted.

Three basic questions are considered namely:

- (a) Is spacecraft standardization economically desirable?
- (b) If spacecraft standardization is economically desirable, what standardized spacecraft configuration or mix of configurations and technologies should be developed? and
- (c) If standardized spacecraft are to be developed, what power levels should they be designed for?

The intent of this paper is to describe a methodology which has been developed and which is necessary to follow if the above questions are to be answered and informed decisions made relative to spacecraft standardization. To illustrate the decision making problems and the need for the developed methodology and the data requirements, typical standardized spacecraft have been considered. Both standardized solar and nuclear powered spacecraft and mission specialized spacecraft have been conceptualized and performance and cost estimates have been made. These estimates are not considered to be of sufficient accuracy to allow decisions regarding spacecraft mix and power levels to be made at this time. The estimates are deemed of sufficient accuracy so as to demonstrate the desirability of spacecraft standardization and the methodology (as well as the need for the methodology) which is necessary to decide upon the best mix of standardized spacecraft and their design power levels.

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1. INTRODUCTION

As the space program matures, more and more attention is being focused on ways to reduce the costs of performing space missions [1-3]. Standardization [4] offers a way of substantially reducing overall costs. Standardization may take place, and to a considerable extent has already taken place, at the piece/part or component level and at the subsystem and system level. This report is concerned primarily with the question of standardization at the system level; in particular, the question of the desirability of spacecraft standardization for geocentric missions is addressed. The spacecraft is considered to be a bus upon which mission oriented equipment, the payload, is mounted. The spacecraft consists of the structure and thermal control subsystems, electrical power subsystem, attitude and velocity control subsystem, **and tracking**, telemetry and command subsystem.

Three basic questions are considered, namely:

- (a) Is spacecraft standardization economically desirable?
- (b) If spacecraft standardization is economically desirable, what standardized spacecraft configuration or mix of configurations and technologies should be developed? and
- (c) If standardized spacecraft are to be developed, what power levels should they be designed for?

Definitive answers to the last two questions are not herein provided. The intent of this paper is to describe a methodology which has been developed, and which is necessary to follow, if informed decisions relative to spacecraft standardization are to be made. To illustrate the decision making problems and the need for the developed methodology and the data requirements, typical standardized spacecraft have been considered. Both standardized solar and nuclear powered spacecraft and mission specialized (non-standardized) spacecraft have been conceptualized and performance and cost estimates have been made. These estimates are not considered to be of sufficient accuracy to allow decisions regarding spacecraft mix and power levels to be made at this time. The estimates are deemed of sufficient accuracy so as to demonstrate the desirability of spacecraft standardization

and the methodology (as well as the need for the methodology) which is necessary to decide upon the best mix of standardized spacecraft and their design power levels.

To demonstrate the methodology a sub-set of the 1972 NASA Mission Model [5] has been considered. Conceptual designs of solar and nuclear powered [6] standardized spacecraft have been developed in light of the assumed mission model. Power subsystem cost estimates have been made and cost-estimating relationships (CERs) utilized [7] for estimating the costs of other spacecraft subsystems. The methodology considers the specific missions in detail (i.e., subsystem mass and power requirements, number and timing of flights, etc.), recurring and non-recurring costs, transportation charges in terms of spacecraft mass and geometry, learning effects, spacecraft spares, cost spreading, timing of expenditures, etc.

There are many possible alternatives relative to spacecraft design which can satisfy the mission model. It is naturally desired to select the "best" alternative. The task of comparing and selecting the best alternative is usually a very difficult process complicated by the fact that it is usually difficult to specify the attributes, and their relative importance, which define "best". Several attributes which are normally considered are the present value of costs and benefits, the specific timing of expenditures, the relationship of the expenditures to those of other on-going and new-start programs, the R & D schedule, uncertainties relating to cost, benefit, schedule and performance, resulting risk, etc. The current analysis and methodology are concerned with evaluating and comparing alternatives which provide an equal capability where capability is considered as the ability to perform a specified subset of projected geocentric space missions. Of primary concern is the present value of the cost of achieving the desired level of capability. The methodology to be discussed in the following pages selects the best alternative by minimizing the present value of the total cost for providing a specified level of capability. The benefits of achieving added capability are not considered. Consideration is also given to the selection of the best alternative under conditions of uncertainty and risk. The decision process is considered when there is uncertainty associated with the basic costs and performance levels of the alternatives. These uncertainties manifest

themselves as the variability in the computed present value of the total cost associated with the alternatives; that is, the present value of cost is a random variable which is a function of the basic cost and performance uncertainties. The problem of selecting a single alternative from amongst a set of alternatives under conditions of uncertainty is also discussed.

The conceptual equal capability decision problem, under conditions of certainty, is illustrated in Figure 1.1. Figure 1.1 illustrates the present value of the cost of achieving different levels of capability in terms of technology bases considered. For example, technology base 2 may encompass standardized nuclear powered spacecraft and mission specialized spacecraft, technology base 3 may encompass standardized solar powered spacecraft and mission specialized spacecraft, and technology base 1 may be a composite of standardized nuclear and solar powered spacecraft and mission specialized spacecraft. Each of the curves shown represents the set of most efficient alternatives, using the specified technology base for achieving any given level of capability. All other alternatives which draw on the same technology base will yield higher costs for achieving a specified capability and will thus show up as points to the right of the illustrated curves. The purpose of the analysis and evaluation of alternatives is to develop the curves of efficient alternatives based upon the different possible technology bases so that the best alternative and technology base can be selected. Note that, in general, the technology base which yields the minimum present value of cost alternative depends upon the desired level of capability.

Within a given technology base there exist many options. In the specific case under consideration, the options range from the basic spacecraft design configuration to the specific maximum power capability selected as the design point^{*} and the number of available power steps (i.e., the degree of modularization). The specific design attributes of the spacecraft result in a multi-dimensional parameter termed performance level

^{*}When using standardized spacecraft with modularized power subsystems, the power available will be equal to or greater than that required for a specific mission.

Figure 1.1 Capability - Cost Relationship in Terms of Technology Base

Figure 1.2 Determination of Optimum Performance Level

which has, as a minimum, the dimensions of power, mass, volume, stabilization accuracy, reliability, and many more. The relationship between performance level and present value of cost is illustrated conceptually in Figure 1.2. Note that, in general, there is a performance level which, for a given technology base and specified level of capability, minimizes the present value of cost. A mathematical model has been developed and used to evaluate the performance level (in a restricted sense) which will minimize the present value of cost for achieving a specified capability with a specified technology base. This will be described in detail in the following pages. Suffice it to say at this point that through the use of the developed mathematical model, the minimum present value of costs, denoted as C_1 , C_2 , C_3 , can be approximated.

Different technologies, which are in various stages of research and development, design and use, are being compared. When performing such a comparison it is important to consider the different levels of uncertainty and resulting risk associated with the different technologies and explicitly consider the risk in the decision making process. There are many areas of uncertainty which need to be considered including the mission requirements or desired level of capability, subsystem mass estimates, validity and accuracy of cost estimating relationships, design concepts, probability that standardized spacecraft will be employed on specific missions, power obtainable per unit mass, etc. These uncertainties imply that the well defined curves relating performance level and present value of cost, as illustrated in Figure 1.2, are not adequate when it is desired to explicitly take into account uncertainty and risk. Because of the uncertainties which exists, the "optimum" performance level and associated minimum present value of cost must be considered as illustrated in Figure 1.3 where the marginal probability distributions of performance level and minimum present value of cost are depicted. The impact of considering the uncertainties and the resulting probability distribution of minimum present value of cost is illustrated in Figure 1.4.

Figure 1.4 illustrates the probability distributions of the minimum present value of cost associated with each of the technology bases. These probability distributions can only be established by considering the basic

Figure 1.3 Effect of Uncertainties on Selection of Optimum Performance Level and Present Value of Cost

Figure 1.4 Probability of Present Value of Cost Resulting from the Use of Different Technology Bases at an Equal Capability Level

areas of uncertainty and establishing quantitative measures of these uncertainties [8-11]. The dotted lines in Figure 1.4 represent the most-likely values of the minimum present value of costs. In the absence of the probability distributions of minimum present value of cost it is clear that technology base T_1 is preferable to T_2 or T_3 . When considering the indicated probability distributions the choice is not too clear since there is a reasonable chance that the present value of cost of technology base 1 can exceed that associated with technology base 2 by a considerable amount.

The decision making process can be clarified in a number of ways as illustrated in Figures 1.5 and 1.6. Figure 1.5 represents each technology base as a single point in the risk (σ) - expected minimum present value of cost (m) plane. The risk, or variability, of the present value is represented by the standard deviation of the present value probability distribution. A frontier of best alternatives (Figure 1.5) can be established by noting that T_1 is preferable to T_3 since both alternatives have the same level of risk but the expected present value of cost of T_1 is less than that of T_3 (i.e., $\sigma_1 = \sigma_3$ and $m_1 < m_3$). Similarly it should be noted that the risk associated with T_4 is greater than that of T_2 but the expected present values of cost of T_2 and T_4 are equal (i.e., $\sigma_4 > \sigma_2$ and $m_4 = m_2$). In this latter situation, a conservative decision maker would normally choose alternative T_2 . This process can be repeated so that a frontier of best alternatives, can be created. The decision maker, having eliminated all inefficient alternatives, can then concentrate only on the efficient alternatives and exercise his risk avoidance preferences by intuitively trading-off risk and expected present value of cost resulting in the selection of the "best" alternative.

Figure 1.6 represents an alternate way of comparing alternatives which explicitly allows risk to be taken into account. Figure 1.6 illustrates the probability or chance that the present value of cost of alternative i will exceed that of alternative j by at least an amount Z . Note that when $Z = 0$ this is the probability of the present value of cost of alternative i exceeding that of alternative j . This

Figure 1.5 Risk - Expected Value Comparison to Establish Frontier of Best Alternatives

Figure 1.6 Probability That the Minimum Present Value of Cost Resulting From the Use of a Technology Base Will Exceed That Resulting From the Use of an Alternative Technology Base by More Than an Amount z

probability, in effect, allows the chance to be assessed of one alternative being better than other alternatives in terms of the degree of "betterness". In Figure 1.6, note that the curve of $C_1 \geq C_3 + Z$ is above that of $C_2 \geq C_3 + Z$ indicating that there is a greater chance that the present value of cost of T_1 will exceed T_3 than that of T_2 exceeding T_3 . Similar curves for C_j exceeding C_i can be drawn. This information quantifying the risk of one alternative relative to all other alternatives can then be used in the decision making processes.

A method is described for establishing the probability distributions of minimum present value of cost for the alternatives considered and for comparing these probability distributions.

2. STANDARDIZATION CONCEPTS

The goal of standardization is normally expressed as the reduction of the present value of the cost of performing a specified mission model. As discussed previously, the present value of cost can be considered as having two dimensions--the expected present value and the risk or standard deviation of present value. Standardization has the potential of reducing the present value of costs through reductions in non-recurring (design, development, test, engineering and related investments) costs resulting from the need to develop fewer spacecraft than would otherwise be necessary if mission specialized spacecraft were utilized. Costs may also be reduced through larger "buys" and learning effects. On the other hand costs tend to increase because standardized spacecraft will not match mission requirements as closely as mission specialized spacecraft; for example, a finite degree of subsystem modularity will tend to yield spacecraft which, in general, have more capability than the missions require. This additional capability tends to increase unit recurring cost and transportation related costs. The economic methodology discussed in Section 4 allows all of these potential cost increases and decreases, including associated uncertainty and risk, to be placed in perspective and alternative courses of action to be compared taking into account the specific timing of costs and the present value of costs (both expected value and standard deviation or risk).

Several basically different standardization concepts are evident namely (a) non-standardization, (b) piece/part or subsystem standardization and (c) spacecraft standardization. Non-standardization implies either the development or design of new equipment for each mission or the use of previously developed equipment but with no provision made for previously purchasing additional equipment in anticipation of its future use and thereby reducing costs through larger buys. Piece/part or subsystem standardization implies the planned utilization of previously developed and procured equipments. This is analogous to drawing "black-boxes" out of inventory with the result that larger buys

are possible with resulting reductions in unit cost and the foregoing of additional development costs. Spacecraft standardization implies the development of a spacecraft which will be utilized on more than one mission. A standardized spacecraft may be considered as a bus upon which mission specialized equipment, the payload, is mounted. Standardized spacecraft may be modular in nature so as to more closely accommodate the specific requirements of a broad class of missions.

The remainder of this paper is concerned with the economic desirability of spacecraft standardization. Both mission specialized (i.e., non-standardized) and standardized spacecraft are considered. No consideration is given to the question of the desirability of piece/part or subsystem standardization.

A standardized spacecraft, or bus, is assumed to consist of the following subsystems:

- a. structure and thermal control
- b. telemetry, tracking and command (TT&C)
- c. electrical power supply (EPS)
- d. attitude and velocity control (AVCS), and
- e. propulsion

This provides a platform upon which the mission specialized equipment may be mounted. The concept of standardization through modularity is illustrated in Figure 2.1 based upon solar power technology. Figure 2.2 represents a typical solar powered standardized spacecraft configuration and Figure 2.3 illustrates the SEOS payload on this configuration. Figures 2.4 and 2.5 illustrate typical RTG and Radioisotope Brayton standardized spacecraft concepts, respectively, and Figures 2.6 and 2.7 illustrate typical payloads on these spacecraft.

The basic problem is to select the mix of spacecraft and the specific design power levels (modularity) which will minimize the present value of the cost associated with performing the mission model. The mix of spacecraft may consist of mission specialized spacecraft and various configurations of solar and nuclear powered standardized spacecraft. It is assumed that the standardized spacecraft will be capable of supplying

Figure 2.1. Single Design Standardized Solar-Powered Spacecraft

Figure 2.2 Typical Solar Powered Standardized Spacecraft Configuration
(From Ref. 12)

Figure 2.3 SEOS Mission Configuration
Using Solar Powered Standardized
Spacecraft Configuration

Figure 2.4 Typical RTG Standardized Spacecraft
(from Ref. 6)

Figure 2.5 Typical Radioisotope Brayton Standardized
Spacecraft (from Ref. 6)

Figure 2.6 Tracking and Data Relay Satellite System (TDRSS)
Deployed on RTG S/C (from Ref. 6)

Figure 2.7 Illustrative Application of Standard Brayton S/C to the EOS Mission

power at several different power levels through modularization. Therefore, one of the major tasks of the analysis is to determine the power levels that each spacecraft should be designed for so as to minimize the present value of cost. The specific maximum power design point and spacecraft assignment (or mission capture) problem is illustrated in a simplified form in Figure 2.8. Two alternatives or mixes of spacecraft are illustrated. It is assumed that the power subsystems are modularized so that spacecraft

Figure 2.8 Spacecraft Assignment and Power Level Determination Problem

#1 can provide three power levels and spacecraft #2 can provide two power levels. The alternatives indicated as B_1 and B_2 utilize the same spacecraft but designed for different maximum power capabilities. In order to determine which of the alternatives minimizes the present value of cost it is necessary to assess the variation in both non-recurring and recurring costs in terms of power level. Power level affects the power subsystem cost directly and other subsystem costs indirectly -- for example, an increase in power level increases power subsystem and hence spacecraft mass which in turn effects attitude and velocity control subsystem mass and hence cost. The number and timing of flights within each mission may significantly influence the alternative which minimizes the present value of cost. For example, if mission 1 consists of a relatively large number of flights, alternative A may be optimum (high non-recurring cost but low recurring cost since the non-standardized spacecraft provides the best match for mission 4 requirements). On the other hand, if mission 1 consists of a small number of flights then alternatives B_1 or B_2 may be more desirable than A.

The first step in the analysis is to show that there is at least one technology base which includes standardized spacecraft which can potentially reduce the present value of cost significantly below that achievable with a technology base consisting of only mission specialized spacecraft. Once this has been accomplished the next step is to determine the particular technology base which minimizes the present value of cost of performing the mission model. Because of the strong interrelationship of power capability and cost, this latter step requires the consideration of the maximum designed power capability of each standardized spacecraft concept within the assumed technology bases. The joint problem of spacecraft assignment to missions and maximum standardized spacecraft design power capability must be addressed simultaneously.

3. COST CONSIDERATIONS

As discussed previously an important evaluation measure is the present value of the cost of performing a mission model. Present value accounts for the timing of costs by discounting all future costs to the present by

$$PV = \sum_{i=1}^y \frac{CF_i}{(1+d/100)^i} \quad (3.1)$$

where PV is the present value which results from achieving a cash flow of CF_i in the i^{th} year for each year up to the planning horizon y at a cost of capital or discount rate or social rate of return, d (in percent). The present value is a single measure which represents the complete cash flow time history associated with each alternative.

For the case under consideration the cash flow consists of only negative terms, i.e., costs. The costs are total annual costs and include both non-recurring and recurring costs. Non-recurring costs are defined as all of the effort/activity related costs associated with designing, developing, manufacturing, and testing of a fully qualified prototype spacecraft. In addition, program peculiar support equipment (for example, aerospace ground equipment -- mechanical and electrical) are considered as non-recurring cost components. Recurring cost is defined as all the effort/activity related costs associated with fabrication/manufacturing, assembly, integration and test, of the spacecraft flight hardware. This category of cost also considers the effort related costs associated with the launch and orbital operations of the particular program.

Engineering type or point design cost estimates or estimates based upon cost estimating relationships (CER's) may be at the subsystem or system level. In the present methodology both point design and CER generated cost estimates are utilized. CER's are, in general non-linear multi-variable equations which relate subsystem costs (both recurring and non-recurring) to subsystem performance and physical characteristics. Typical CER's will be described in following pages. In order

to achieve realistic values of the present value of cost, it is important that the timing of all costs be specified. This implies that all costs be incurred as per the dictates of the mission model being considered. The appropriate non-recurring and recurring costs must be spread over time (i.e., it normally requires several years for the development of a spacecraft whereas, for a single launch, transportation charges accrue over a very short interval of time).

When comparing alternative spacecraft strategies it is necessary to consider all related costs (i.e., all costs components which might be affected by the different alternatives to be considered). This includes the spacecraft non-recurring and recurring costs, transportation charges and mission equipment or payload related costs. Mission equipment related costs need to be considered if different spacecraft design concepts and configurations effect mission equipment non-recurring and recurring costs in different amounts. For example, standardized nuclear powered spacecraft may use the waste heat from the thermal power source to create a temperature controlled environment within which much of the mission equipment may be located thereby removing the need for temperature control within the mission equipment. On the other hand, standardized solar powered spacecraft may require each mission equipment to provide it's own environmental control. The result is that the mission equipment costs associated with these two concepts may differ. The methodology to be described in Section 4 considers all related costs with the exception of the mission equipment related costs. The reason for this omission is that as of the time of this writing there is insufficient detail pertaining to mission equipment differences to allow cost differences to be ascertained. If and when these cost differences can be established they can easily be incorporated within the developed methodology.

As discussed previously, the quantitative consideration of uncertainties and their effect on costs and resulting risk form an integral part of an analysis which is concerned with comparing alternative courses of action from amongst which the "best" alternative is to be selected. There are many areas of uncertainty in the analysis of standardized spacecraft, several of which pertain to:

- a. Mission requirements - The mission requirements consist of a set of missions, traffic (number of flights as a function of time) projections, mission equipment specification including type of sensors, geometry, mass, power requirements, etc. There are many areas of uncertainty associated with the mission requirements which have major impacts upon cost, namely, the chance that any single mission will be performed, timing of the flights, traffic level, power requirements, mass, and many others.
- b. Technology - The comparison of standardized spacecraft should be based upon technologies which will be available in the 1980's. This requires a forecast of both solar and nuclear power technologies. Forecasts imply uncertainty!
- c. Cost Estimating Relationships - Cost estimating relationships attempt to relate cost to performance parameters and physical characteristics. To accomplish this, historical data is relied upon to establish the cost-performance-physical characteristics relationships. The significance of these relationships in the future is always uncertain since the use of CER's implies little or no technology change in the future. There is also an uncertainty associated with the use of CER's which are based upon current and past practices when considering a "mass" production environment as might be created through the use of standardized spacecraft.
- d. Subsystem mass estimates - There are uncertainties associated with subsystem mass estimates both of the standardized and non-standardized subsystems. The mass uncertainties effect costs since subsystem mass is one of the major performance parameters used in the cost-estimating relationships. Mass uncertainties also affect transportation charges which are directly proportional to mass.
- e. Standardized spacecraft utilization - The development of standardized spacecraft does not guarantee their utilization on the assumed missions. Changes in mission objectives may have significant impact on the applicability of standardized spacecraft for any given mission. Institutional decisions

will also affect the standardized spacecraft utilization. The net effect is that the probability that a standardized spacecraft will be employed on any specific mission will be somewhat less than unity. This introduces uncertainty in both recurring and non-recurring costs of performing the mission model.

The net effect of these uncertainties is to cause uncertainty in the annual costs, both recurring and non-recurring. These uncertainties are therefore reflected in the probability distribution of the present value of costs as discussed previously.

4. METHODOLOGY

It is desired to compare alternative approaches of spacecraft design in order to determine the best mix of spacecraft (i.e., those that should be developed) for satisfying the mission model. Since the different alternatives will undoubtedly have different cost patterns (with time), the alternatives are compared on a present value basis (see Equation 3.1). The economic analysis methodology which has been developed specifically for this purpose is described below and is illustrated in Figure 4.1. The detailed equations which comprise the mathematical model are presented in Appendix B.

The economic analysis methodology establishes the present value of the costs which result from performing a specified mission model with a specified spacecraft technology base (a technology base consists of one or more spacecraft design concepts and may encompass mission specialized spacecraft and standardized spacecraft and may include solar and nuclear power subsystem technologies). Therefore the economic analysis is also concerned with estimating the spacecraft and related costs associated with performing the mission model. The costs include the actual spacecraft recurring and non-recurring costs, the cost of spare or backup spacecraft, transportation charges (for both the required and spare spacecraft placements) and recurring (re-development) non-recurring costs. In order to establish spacecraft recurring and non-recurring costs it is necessary to size the spacecraft as per the requirements of the mission model and the assignment of different spacecraft to the various missions. The sizing consists of varying the power levels of the spacecraft which in turn affects spacecraft mass and spacecraft cost and transportation charges. The analysis considers both mission specialized and standardized spacecraft. In the former case the analysis makes use of cost estimating relationships (CERs) [7] for both the unit recurring and non-recurring costs whereas in the latter case the CER's are utilized for all subsystem costs with the exception of the power subsystem costs, nominal values of which are specified for each spacecraft configuration. Also

Figure 4.1 • The General Steps in the Economic Analysis

specified are partial derivatives which allow the spacecraft design to be scaled, in terms of power and its effect on subsystem masses, so as to minimize costs. The economic analysis determines the appropriate timing of all costs as determined by the mission model, establishes spacecraft assignments (to missions) and determines the maximum power capability which should be achieved for each spacecraft. In accomplishing this the methodology allows for the consideration of learning effects and cost spreading functions.

Since it is important to consider the total costs associated with each alternative, the present analysis considers the transportation charges (both Space Shuttle and upper stage, when necessary) and the cost of spares. Not included in the current analysis is the interaction between spacecraft design and the cost of mission oriented equipment.

A mathematical model has been developed and forms the heart of the economic analysis. The model, discussed in detail in Appendices A & B, and its overall relationship to the evaluation of standardized spacecraft are illustrated in Figure 4.1. The specific functions performed by the model are now described. A basic input to the mathematical model is the specification of the mission model. This specification consists of the following two parts: (i) the delineation of the missions which are to be considered as candidates for spacecraft standardization, the number of flights required per year per mission and the percentage of spares required for each mission, and (ii) the detailed specification (see Appendix A) of the spacecraft subsystems, primarily in the areas of power and mass, for mission specialized spacecraft. The power requirements are exclusive of the power required for thermal control, battery charging and power conditioning. The power required for these latter functions is considered separately so that the power subsystem requirements can vary depending upon the power subsystem technology (solar or nuclear) which is employed in the standardized spacecraft.

Transportation data must be specified for both the Space Shuttle and upper stages. This data consists primarily of the average Space Shuttle and upper stage utilization factors, maximum payload capability (mass and length), cost, gross mass of upper stages, and

the identification of which upper stage will be considered for each mission. The specification of a number of upper stages with different capabilities is possible so that capability can be matched to mission requirements and appropriate transportation charges obtained.

The required data pertaining to mission specialized spacecraft has been described under the mission model data. Other data is necessary and relates to recurring and non-recurring cost spreading functions, the time interval over which costs are to be spread, expected useful life of spacecraft design technology, etc.

For each standardized spacecraft concept it is necessary to specify a set of nominal parameters. These relate to subsystem mass at the estimated maximum (nominal design point) power level^{*}, nominal or maximum design point power capability, number of power steps and maximum possible power level to which spacecraft can be scaled. In order for the spacecraft to be scaled to other maximum power levels it is necessary to specify a number of sensitivity coefficients or partial derivatives, namely the change in each subsystem mass per unit mass change of other subsystems and the change in power subsystem mass per watt change in maximum electric power. Power subsystem unit recurring and non-recurring costs and their partial derivatives with respect to power must be specified. Applicable cost spreading functions, number of years over which costs are to be spread, cumulative average learning rates, etc. must also be specified. For the standardized spacecraft, the power subsystems are treated separately from other subsystems. Therefore power subsystem learning rates may differ from spacecraft learning rates, technology life may differ from spacecraft technology life and several different power subsystems may be specified over which a common learning experience may be achieved.

* The optimum maximum power level is not known a-priori, it can only be estimated. The mathematical model determines the "optimum" power level as part of the spacecraft assignment analysis (this is discussed in following paragraphs pertaining to the "Mix-Optimizer").

These data are validated by the model and the set of mathematical computations is initiated. The first step in the analysis is to establish which spacecraft should be assigned to each mission and at the same time to determine what maximum design power capability should be achieved by each spacecraft type (this is the basic problem illustrated in Figure 2.8). These computations are performed in the "mix optimizer" which is described in following paragraphs. Suffice it to say at this point that the mix optimizer, through the use of a heuristic algorithm which utilizes, among other parameters, CER's and the partial derivatives of subsystem mass to other subsystem mass changes and power subsystem mass to maximum electric power capability, determines the spacecraft assignment and desired design power levels. It should be noted that it is desirable to perform the assignment and power level determination by minimizing the present value of cost of performing the mission model. This is not done in the current mix optimizer which considers basically only the recurring costs and hence can only lead to "near optimal" and not true optimal solutions. The basic problem is the additional complexity and increased computation time which would result from the inclusion of non-recurring costs and present value computations in the optimization computations. (Research is continuing in this area to try to remove this restriction).

Once the mix optimizer has established which spacecraft (i.e., the specific standardized or mission specialized) should be assigned to each mission and the maximum power capability of each standardized spacecraft, the mathematical model can thence proceed to establish the annual cash flow and present value associated with performing the specified mission model. Basically, a single set of computations is performed but with minor variations for mission specialized spacecraft and standardized spacecraft. The first step in these computations is the determination of the timing of events (i.e., number of flights) as per the mission model. The model thence determines the unit recurring cost and non-recurring cost for each spacecraft type. Unit recurring costs are established for each mission. These costs are established through the use of CER's [7] which have the general form

$$C_j = K_{1,j} + K_{2,j}X_j + K_{3,j}Y_j^{K_{4,j}} \quad (4.1)$$

where C_j is the cost of the j^{th} subsystem, the K terms are constants and X and Y are specific subsystem design parameters such as mass, power, specific impulse, etc. CER's are used for establishing the cost associated with the following subsystems for the mission-specialized spacecraft:

- a. structure and thermal control,
- b. telemetry, tracking and command,
- c. electrical power supply,
- d. attitude and velocity control, and
- e. propulsion.

For the standardized spacecraft the same CER's are used for all of the above subsystems with the exception that electrical power supply subsystem costs and their partial derivatives with respect to power are specified as part of the input data and are used to establish the electrical power supply subsystem cost.

The number of spacecraft must be modified to take into account the need for and use of spares. The mathematical model determines the number of spare spacecraft (by type) which must be acquired and when they should be acquired. Spares are determined on a mission by mission basis for those missions which, as per the results of the mix optimizer, utilize mission specialized spacecraft and across all missions which utilize each particular type of standardized spacecraft. The algorithm for establishing the number and allocation of spares is as follows. A spare spacecraft is purchased for each spacecraft type in the first year that the spacecraft type is flown. These spares are placed in inventory. When it is determined that the time has come to launch a spare, the spare is removed from inventory and flown and a new spare of the required type (and cost) acquired and placed in inventory. The spare, in essence, becomes an increase in the mission requirements. The specific timing of the utilization of a spare

spacecraft is a function of the number of flights of each spacecraft type and the specified (i.e., input data) percentage of spares desired for each spacecraft type. It should be noted that the initial number of standardized spacecraft spares acquired is related to the number of spacecraft types and not the number of missions whereas the initial number of mission oriented spacecraft spares is related to the number of missions for which mission oriented spacecraft are utilized -- this is potentially a significant advantage of standardization.

Both unit recurring and recurring non-recurring costs are adjusted for learning effects. The recurring non-recurring costs are redevelopment costs and are the result of finite technology life. The learning effect algorithm is based upon the assumption that these costs decrease with increased experience or quantity according to the following relationship:

$$\frac{\text{Cost of } N^{\text{th}} \text{ spacecraft}}{\text{1st Unit Cost}} = (N)^{\frac{[\log_{10}(\text{CALRS}) - \log_{10}(100)] / \log_{10}(2)}{10}} \quad (4.2)$$

where N is the number of spacecraft acquired and CALRS is the cumulative average rate (%). A similar equation is used for establishing the recurring non-recurring learning effects where N is thence the number of redevelopments which have taken place and the learning rate applies to the learning experienced from one development cycle to the next. The learning effects are illustrated in Figure 4.2.

The timing of the recurring non-recurring costs is a function of the specified technology life and the timing of spacecraft flights. Redevelopment costs are incurred at time intervals as specified by the technology life or the first year thereafter that a flight is required when no flight is required in the year determined by considering only the technology life.

So far in the analysis all costs have been assumed to occur instantaneously in time. Since actual costs, with the possible exception of transportation charges, do not occur instantaneously but actually are spread over a number of years, cost spreading must be performed. The cost spreading is performed using the following form of spreading function:

$$F(S) = (10B - 4)S^5 + (10A - 20B + 5)S^4 + (10B - 20A)S^3 + 10AS^2 \quad (4.3)$$

where $F(S)$ is the percentage of funds spent and S is the fraction of time through the program. A and B are constants which determine the basic shape of the spreading function^{*}. Typical cost spreading functions are illustrated in Figure 4.3. The model utilizes the cost spreading functions so as to spread the unit recurring and non-recurring costs into preceeding years. It is assumed in this cost spreading that unit recurring costs are spread backwards in time so that the last year of recurring cost (for a particular event) occurs in the year of the event. For the non-recurring costs, it is assumed that the backward spreading takes place such that the last year of cost (for a particular event) occurs in the year preceeding the event.

The final step prior to establishing the total annual cash flows is the determination of the transportation charges associated with each and all of the required spacecraft placements (including spares). For this computation it is assumed that a non-profit organization will operate the transportation system such that all launch and operating costs will be recovered in the form of user fees -- i.e., break-even. Since the transportation system may not be operated at 100% efficiency, that is it may operate with less than maximum loads on the average, the costs must be recovered on the basis of total delivered load. The purpose of the transportation cost model is to establish an estimate^{**} of the transportation charges which might be incurred by each mission in terms of the particular spacecraft design. The major areas to be highlighted are the differences in transportation costs which might result from differences in the mass

^{*}The constants A and B can be determined either by trial and error or by fitting the generalized cost spreading function to discrete data described in Appendix E.

^{**}Only an estimate of transportation charges can be made since they depend to a large extent upon the detailed Space Shuttle operations and mission models which are not explicitly modeled in this analysis.

Figure 4.2 Learning Effects

and configuration (length) of the alternative spacecraft design concepts. The transportation charge is the sum of the Space Shuttle charge (to low earth orbit) and the tug or other upper stage charge. The mathematical model utilizes an algorithm for establishing transportation charges which considers both spacecraft mass and length. The transportation charge is mission (orbit) dependent. The upper stage charge is assumed to vary directly with the ratio of spacecraft mass to payload delivery capability and inversely with average upper stage utilization (the fraction of the upper stage capability which is utilized on the average). The Space Shuttle transportation charge is similar except that both payload mass and length are considered. The payload, as seen by the Shuttle, consists of both the

Figure 4.3 Cost Spreading Functions: Percent of Funds Spent as a Fraction of the Time Through the Program [15]

upper stage (when required) and the spacecraft. The Space Shuttle charge is assumed to vary directly with the ratio of payload mass to payload delivery capability and inversely with average Space Shuttle utilization or directly with the ratio of payload length to Shuttle payload bay length and inversely with average Space Shuttle utilization, whichever is the greater.*

* The linear (mass and/or length) transportation charge algorithm is probably not reasonable from both NASA's and customer's points of view. The development of a more reasonable algorithm is necessary, complex, and beyond the scope of the current work efforts and will not be discussed further.

After the establishment of the transportation charges, all costs are added together on an annual basis. This then establishes the cash flow (costs) for performing the specified mission model with the specified technology base. Finally, the present value of costs is computed at several different discount rates. From a purely economic point of view, for the situation at hand, the best alternative or course of action (in this case, technology base) is that which minimizes the present value of costs.

With the overall concept of the mathematical model established attention can now be focused on the details of the "Mix Optimizer". The mix optimizer attempts to assign spacecraft to missions in a manner which minimizes the present value of the cost of performing the mission model. In order to accomplish this the mix optimizer also attempts to determine the maximum power capability which should be achieved by each spacecraft. As illustrated in Figure 2.8 the power capability and optimal assignment problems are interrelated since cost depends upon power capability and assignment depends upon cost.

The spacecraft assignment and power capability problem can be formulated in general but simplified terms as indicated below where it is desired to determine the set of values of the $a_{i,j}$ and $c_{j,k}$ arrays and the associated subscript values which minimizes C given the set of indicated constraints.

$$C = \text{Minimum} \left\{ \sum_j \left[\sum_k \left\{ \sum_i \alpha_i a_{i,j} (x_j + c_{j,k} D_{j,k}) \right\} + \beta_j b_j (Y_j + c_{j,k} E_{j,k}) \right] \right\} \quad (4.4)$$

subject to

$$a_{i,j} = 0 \text{ or } 1,$$

$$\sum_j a_{i,j} = 1 \text{ for each } i,$$

$$C_{j,k} = 0 \text{ or } 1,$$

$$\sum_k C_{j,k} = 1 \text{ for each } j,$$

$$\text{If } \sum a_{i,j} \geq 1 \text{ then } b_j = 1 \text{ otherwise } b_j = 0,$$

and $a_{i,j} = 0$ if the j^{th} spacecraft capabilities are not compatible with the i^{th} mission requirements. i, j and k are indices representing missions, spacecraft type and maximum design power capability, respectively. $a_{i,j} = 1$ when a particular spacecraft type is utilized for the i^{th} mission, otherwise $a_{i,j} = 0$. $b_j = 1$ when a particular spacecraft type is utilized for at least one mission; when a particular spacecraft type is not utilized, $b_j = 0$. x_j and y_j represent the recurring and non-recurring costs associated with the j^{th} spacecraft type at the nominal design power capability. $D_{j,k}$ and $E_{j,k}$ represent the unit recurring cost and non-recurring cost increments, respectively, associated with the k^{th} power increment relative to the nominal power capability. $C_{j,k}$ is an integer, 0 or 1, which insures that only a single power level will be considered at any one time for the j^{th} spacecraft. α_i is the present value and learning factor which accounts for the specific timing of the flights within the i^{th} mission and adjusts unit costs for learning effects. B_j is the present value factor which accounts for the specific timing of the non-recurring costs.

It should be noted that the α_i terms are interdependent. The interdependence is due to the learning effects which relate the unit recurring cost of a spacecraft to the total number of the same spacecraft (or power subsystems) produced. The total number produced is a function of the spacecraft assignments to all other missions. The interdependence of the α_i terms is also due to the consideration of spares, the number

and timing of which depends upon the spacecraft assignment to other missions.

The β_j terms, because of the timing of the recurring non-recurring costs are, although not readily apparent, dependent upon the assignment of spacecraft to missions. The specific missions and the timing of flights determines, as discussed previously, the timing of the recurring non-recurring costs.

It should be noted that if learning effects and recurring non-recurring costs are not considered (actually assumed in the heuristic assignment algorithm discussed below), the system of equations described above reduces to a non-linear integer programming problem. At this point then there are three approaches which might be followed to solving the assignment and power capability problem namely the integer programming approach, the brute force approach of solving for the cost of all possible combinations, and the heuristic algorithm approach. This latter approach, which is actually a compromise between the other approaches, has been taken.

As a result of the above interrelationships the determination of the optimum spacecraft mix, assignment and power subsystem capability has not been attempted. Instead, a heuristic algorithm has been developed for achieving reasonable near-optimal solutions. This algorithm, which simultaneously selects appropriate spacecraft, determines performance levels, and assigns spacecraft to missions, is illustrated in summary form in Figure 4.4. Since the ultimate goal of the mix optimizer is to minimize the present value of the cost of satisfying the mission model, the mix optimizer decisions are made on the basis of a cost analysis.

A principle to be noted with respect to the various approximations incorporated in the mix optimizer is that absolute accuracy of the cost approximations is not crucial provided the approximations preserve the ranking of alternatives which would result if equation 4.4 and associated constraints were solved exactly.

The assignment and power optimization algorithm illustrated in Figure 4.4 also incorporates a number of compromises in order to achieve

Figure 4.4 Mix Optimizer Logic

Figure 4.4 Mix Optimizer Logic (continued)

realistic computer execution times and costs. The algorithm does not check every combination of power levels and spacecraft-mission assignments and therefore cannot guarantee a global minimization of the present value of costs. The algorithm however provides a mechanism for originating sensible spacecraft mission assignments and spacecraft power levels and continues to refine the choices until no further savings in cost can be found.

The algorithm consists of two steps. The first step establishes an initial spacecraft-mission assignment and power subsystem maximum power capability for the mission model. The second step consists of perturbing the initial configuration by re-assigning spacecraft to missions and adjusting the spacecraft power subsystem capabilities in ways which reduce the present value of cost estimate.

The procedure for arriving at the initial configuration is based upon the supposition that a cost effective mix of standardized spacecraft would comprise spacecraft specially suited to different portions of the range of power requirements of the mission model. For this reason a standardized spacecraft power subsystem capability is initially permitted to "float" until the spacecraft captures a mission. The spacecraft will then tend to have its power design point fixed at an initial level where it is cost effective.

The procedure for implementing the first step of the mix optimizer, as shown in Figure 4.4, considers the missions for assignment in order from highest to lowest power requirements. To compare the costs of performing a mission with different spacecraft, the power subsystem capabilities of all standardized spacecraft which have not received any assignments are first optimized over all unassigned compatible missions. This step gives a rough estimate of a plausible power subsystem capability by looking ahead at all the missions to be assigned. The cost to fly the highest power unassigned mission only is then examined for all compatible spacecraft and the mission is assigned to the spacecraft yielding the lowest cost. Once the standardized spacecraft receives its first mission assignment the power subsystem capability is fixed for

the remainder of the initial assignment step. The other spacecraft continue to have variable power capabilities until they become economically advantageous for mission assignment. The option to use a mission specialized spacecraft is always included in the cost comparisons.

Mission/spacecraft compatibility takes into account several factors. Mission stabilization requirements must be met by the spacecraft and the power requirements must be in the designable power range of the spacecraft power subsystem. If desired, missions may also be dedicated (assigned) to particular spacecraft by indicating, through the input data, a predetermined commitment.

The second step of the mix optimizer improves the assignment configuration arrived at by the first step by alternately executing two processes. The first process is to optimize the power subsystem capability for each standardized spacecraft with assignments by considering only the costs of the missions assigned to the spacecraft. The second process is to examine each mission and determine the cost to perform it using each compatible spacecraft including mission specialized spacecraft. Each mission is then assigned to the spacecraft providing the lowest cost. The two processes are iterated until the total cost estimate to perform all the missions cannot be significantly reduced, at which point the mix optimization is completed.

Several compromises were made to institute a procedure which would seek cost effective combinations of spacecraft/mission assignments and spacecraft maximum power capabilities and which executes reasonably quickly on the computer. It is assumed (in the mix optimizer) that discounting, cost spreading and learning effects would have but minor effects on the relative ranking of alternatives and could be omitted from the initial approximate cost analysis performed for the purpose of spacecraft assignment. Ignoring their effects, the cost of performing the mission model can be represented as the sum of the spacecraft development costs, recurring costs and transportation costs. For a standardized spacecraft, the costs can be expressed as

$$\text{COST} = \text{development costs} + \sum_{\substack{\text{assigned} \\ \text{missions}}} (\text{first unit recurring cost/mission})$$

$$\times (\text{no. of S/C produced for mission}) +$$

$$\sum_{\substack{\text{assigned} \\ \text{missions}}} (\text{transportation cost per flight/mission}) \quad (4.5)$$

$$\times (\text{no. of S/C flown})$$

where the summations are over all the missions which utilize (i.e., are assigned to) the particular spacecraft.

The number of spacecraft produced and the number flown differ only by the number of spares remaining at the end of the mission model time horizon which are not flown, typically a small fraction of the mission flights. The number of flights of a given mission is given, to a good approximation, by

$$\text{FLIGHTS} = (\text{no. of scheduled flights}) \times \left(1 + \frac{\text{percentage of spares}}{100}\right) \quad (4.6)$$

Therefore

$$\begin{aligned} \text{COST} = & \text{development costs} + \sum_{\substack{\text{assigned} \\ \text{missions}}} (\text{first unit recurring cost/mission}) \\ & + (\text{transportation cost per flight/mission}) \times (\text{FLIGHTS}) \end{aligned} \quad (4.7)$$

As power subsystem maximum power capability is varied the power subsystem and other support subsystem mass and costs vary. The effect of mass variations is also considered in the computation of transportation charges. All mass variations are assumed to be linearly related to power level changes and other subsystem mass changes. The

sensitivity coefficients relating to power subsystem mass change per unit change of power (K_1), support subsystem mass change per unit mass change in other subsystem mass (K_2) and power subsystem change in both recurring and non-recurring cost per unit change of power (K_3 and K_4 , respectively) are all specified as part of the input data set for each standardized spacecraft in the technology base (see Appendix A). As a result the following general form of relationships are used to establish the spacecraft recurring and non-recurring costs as the maximum power capability is varied.

$$\text{Power Subsys. Unit Rec. Cost} = \text{nominal cost} + \Delta P \times K_3$$

$$\text{Power Subsys. Non-Rec. Cost} = \text{nominal cost} + \Delta P \times K_4$$

$$\text{Support}^* \text{ Subsys. Unit Rec. Cost} = f_R(\text{nominal mass} + \Delta P \times K_1 \times K_2) \quad (4.8)$$

$$\text{Support}^* \text{ Subsys. Non-Rec. Cost} = f_N(\text{nominal mass} + \Delta P \times K_1 \times K_2)$$

In the above equations, ΔP represents the variation of power level from the nominal maximum power capability and f_R and f_N represent the functional relationships (CERs) which are used to establish unit recurring and non-recurring costs in terms of system parameters.

For mission specialized spacecraft, the cost is

$$\text{COST} = \text{development cost} + (\text{unit recurring cost} + \text{transportation cost}) \times \text{FLIGHTS} \quad (4.9)$$

The mission model total cost is established by summing the costs associated with each spacecraft used.

* TT&C, AVCS, etc. The actual computations actually take into account the mass variation of all other subsystems which result from a change in power level.

An important assumption is that reasonable spacecraft assignments can be made without the consideration of development (non-recurring) costs. The purpose of the approximation is to reduce computer execution time and cost by allowing decisions to be made on the basis of recurring and transportation cost estimates. As the analysis has sophisticated to include redevelopment (recurring non-recurring) costs and relationships between performance parameters and development costs, this approximation has become increasingly less accurate.

For a given set of spacecraft-mission assignments it is evident that the mission model present value of cost is minimized by minimizing the costs associated with each spacecraft individually. For a given spacecraft-mission assignment mix the standardized spacecraft power subsystem capabilities can be optimally chosen by examining each standardized spacecraft separately and choosing the power level which minimizes the recurring and transportation costs of the missions associated with it. It is also important to note that for a group of spacecraft with fixed power capabilities the total cost is minimized by minimizing the costs associated with the individual missions. Changes in the standardized spacecraft-mission assignments can likewise be evaluated on the basis of the recurring and transportation costs alone since all the development costs are assumed to be fixed. If the costs to fly a mission with standardized and mission specialized spacecraft are compared, the development costs of the mission specialized spacecraft must be included since the introduction of a new spacecraft is being considered. It should be noted that standardized spacecraft development costs cannot easily be allocated to missions since the allocation depends on the number of missions which are to be assigned to the spacecraft which in turn depends upon the costs.

Although savings due to reduced development costs may be achieved through the elimination of a standardized spacecraft from consideration, the algorithms to search for these cases were too complex to merit implementation in this version of the methodology. This capability is achieved, however, by using the complete cost model to

evaluate different spacecraft-mission assignments selectable through input data manipulation. For example individual spacecraft configurations can be deleted from the **input**. data set and the effect on present value noted.

The mathematical model has been programmed and utilized to perform the previously described computations. It transforms the set of input data, based upon analyses of mission models and spacecraft configurations, into the cash flow requirements and present value of cash flow. These results can be reviewed, the input data set modified, and the effect of input data changes observed. In other words, the model can be used to evaluate both the nominal situation and to perform sensitivity analyses. The sensitivity analyses can lead to the determination of sensitivity coefficients (Figure 4.5) by varying parameters one at a time or in combination. The resulting coefficients need not be treated as constants--this will depend upon the range of uncertainty or variability of the pertinent input parameters. It is important to point out that sensitivity coefficients by themselves provide little or no insight into the importance of the variables. The importance of the variables can only be ascertained by considering the sensitivity of the result to variations in the pertinent variables over the possible range of variation of the variables. Referring to Figure 4.5 it can be seen that for small variations of the variables, PV is more sensitive to variations in X_1 than X_2 . On the other hand, if it is possible that S_2 can vary over a wide range, then PV is more sensitive to variations in X_2 than X_1 .

The sensitivity coefficients, together with subjective estimates of the range of variation (i.e., uncertainty) of the variables and the probability distribution of the variables within the range of uncertainty, can provide important insights into the risk associated with the development of a technology base. Risk is measured as the probability that the present value of cost associated with a specified technology base will exceed various levels. A procedure for developing quantitative measures of risk is indicated below.

Figure 4.5 Sensitivity Coefficients

Consider a function, $f(x,y)$, which possesses derivatives of all orders at a point x_0, y_0 . $f(x,y)$ may be expanded in a Taylor's series given by

$$f(x,y) = f(x_0, y_0) + [(x-x_0) \frac{\partial}{\partial x} + (y-y_0) \frac{\partial}{\partial y}] f(x,y) \Big|_{x_0, y_0} + \frac{1}{2!} [(x-x_0) \frac{\partial}{\partial x} + (y-y_0) \frac{\partial}{\partial y}]^2 f(x,y) \Big|_{x_0, y_0} + \dots \quad (4.14)$$

Letting $\Delta x = x - x_0$, $\Delta y = y - y_0$ and neglecting higher than first order terms

$$f(x,y) = f(x_0, y_0) + \frac{\partial f(x,y)_{x_0, y_0}}{\partial x} \Delta x + \frac{\partial f(x,y)_{x_0, y_0}}{\partial y} \Delta y \quad (4.15)$$

For the case at hand, $f(x,y)$ is the minimum present value of cost, PV , and $f(x,y)_{x_o, y_o}$ is the minimum present value of cost associated with the nominal values x_o, y_o of the variables associated with the present value (Refer to Figure 1.3). The partial derivatives represent the sensitivity coefficients of the present value; that is, the change in present value caused by a change in the value of the variable. The present value can therefore be expressed as

$$PV = PV_o + \sum_i \left. \frac{\Delta PV}{\Delta x_i} \right|_o \Delta x_i \quad (4.16)$$

where PV is the minimum present value of cost as determined at the nominal value of all the X_i variables. If the ΔX_i are considered as random variables, i.e., specified as ranges of uncertainties and probabilities associated with the values within the range of uncertainty, then PV is a random variable. Given subjective estimates pertaining to the probability distributions of the ΔX_i , the probability distribution of PV can be determined through the use of Monte Carlo techniques. When this is done the $\frac{\Delta PV}{\Delta X_i}$ terms may be treated in a truly general form by establishing the sensitivity coefficients in terms of the magnitude of the ΔX_i excursions (this eliminates the usual assumption regarding constant sensitivity coefficients).

Under certain conditions an analytic approach can be followed to determine the probability distribution of PV . It should be noted that, according to the Central Limit Theorem [16], the probability distribution of PV becomes normal, independent of the form of the ΔX_i probability distributions if i (the number of variables) becomes large and no one variable is dominant. When this is true, and the sensitivity coefficients can be assumed to be constant (at least over the range of uncertainty of the ΔX_i), then

$$\overline{PV} = PV_o + \sum_i \left. \frac{\Delta PV}{\Delta x_i} \right|_o \overline{\Delta x_i} \quad (4.17)$$

and

$$\sigma_{PV}^* = \sqrt{\sum_i \left[\left. \frac{\Delta PV}{\Delta x_i} \right|_o \sigma_i \right]^2} \quad (4.18)$$

where $\overline{PV}$ is the expected value of PV, $\overline{\Delta x_i}$ is the expected value of Δx_i , σ_{PV} is the standard deviation of PV and σ_i is the standard deviation of Δx_i . Thus, the probability distribution of PV is normally distributed with an expected value $\overline{PV}$ and standard deviation σ_{PV} .

Having established the probability distribution of the present value of the cost of each specified technology base, the probability of the present value of technology base x exceeding that of technology base y by more than at least a specified amount can now be determined. This can be accomplished by letting $z = x - y$ and computing the probability distribution of z . Under the assumption that both x and y are normal and independent

$$p(z) = \frac{1}{\sqrt{2\pi} \sigma_z} \exp\left[-\frac{(z-m_z)^2}{2\sigma_z^2}\right] dz \quad (4.19)$$

where $\sigma_z^2 = \sigma_x^2 + \sigma_y^2$

and $m_z = m_x - m_y$

by letting $t = \frac{z-m_z}{\sigma_z}$, the probability that z exceeds a specified amount K can be computed from

* assuming independent variables

$$P(z \geq K) = \frac{1}{\sqrt{2\pi}} \int_{\frac{K-m_z}{\sigma_z}}^{\infty} \exp[-t^2/2] dt \quad (4.20)$$

This is the normalized Gaussian function whose values are tabulated in Table 4.1 in terms of $(K-m_z)/\sigma_z$. Thus the curves illustrated in Figure 1.6 can be established allowing the chance that the present value of cost of one technology base to exceed that of an alternate technology base by more than a specified amount to be established.

Table 4.1 Probability that x Exceeds y by More Than an Amount K			
$P(z \geq K) = \frac{1}{\sqrt{2\pi}} \int_{\frac{K-m_z}{\sigma_z}}^{\infty} \exp[-t^2/2] dt$			
$\frac{K-m_z}{\sigma_z}$	$P(z \geq K)$	$\frac{K-m_z}{\sigma_z}$	$P(z \geq K)$
0	.50000	1.6	.05480
.1	.46017	1.7	.04457
.2	.42074	1.8	.03593
.3	.38209	1.9	.02872
.4	.34458	2.0	.02275
.5	.30854	2.1	.01786
.6	.27425	2.2	.01390
.7	.24196	2.3	.01072
.8	.21186	2.4	.00820
.9	.18406	2.5	.00621
1.0	.15866	2.6	.00466
1.1	.13567	2.7	.00347
1.2	.11507	2.8	.00256
1.3	.09680	2.9	.00187
1.4	.08076	3.0	.00135
1.5	.06681		

5. TYPICAL COMPARISON OF ALTERNATIVES

The previous pages have described a methodology and an implemented capability which have been developed so that the economics of spacecraft standardization can be better understood and informed decisions made regarding standardization. The current level of capability allows the economic merits of a specific mix of standardized spacecraft to be evaluated and compared with spacecraft based upon current design practices (i.e., mission specialized spacecraft). The current level of capability also allows for the comparison of alternative mixes or designs of standardized spacecraft and determines the optimum power design level for each of the spacecraft. Spacecraft are assigned to missions in an optimal fashion based upon the desire to minimize the present value of costs associated with performing a specified mission model. The methodology also allows for the explicit consideration of uncertainty and resulting risk and the incorporation of quantitative risk considerations in the decision making process. The economic analysis, as described previously, considers recurring and non-recurring costs, learning effects, cost spreading, transportation charges, spacecraft spares and their associated transportation charges, and the specific timing of all expenditures as constrained by mission requirements. The economic analysis also allows the standardized spacecraft designs to be varied about the nominal design point in order to minimize the present value of costs (this spacecraft "sizing" optimization results in the determination of the power levels which the standardized spacecraft should be designed for). The result of the economic analysis is a determination of total annual costs, the present value of costs and savings, spacecraft assignment to missions, and the sizing of standardized spacecraft.

To demonstrate the methodology and capability, the standardized spacecraft design concepts previously discussed have been utilized, together with preliminary cost estimates and a mission model (consisting of ten missions from the NASA 1971-72 mission model). It must be emphasized that no attempt is being made at this time, because of the preliminary nature of the basic data both relating to spacecraft design

and costs and the mission model, to draw conclusions relative to the desirability of standardized nuclear and solar powered spacecraft. The intent is only to demonstrate the methodology and capability by the means of an example.

The economic analyses require the specification of a mission model so that the annual costs and present value of costs of performing the mission model with mission specialized and standardized spacecraft can be evaluated. The specification requires the definition of the mission specialized (non-standardized) spacecraft in terms of subsystem mass, power requirements, etc., and the number of spacecraft required as a function of time. The details of the data requirements are given in Appendix A and the set of data used in the typical analysis is given in Appendix C. Many different mission models have been espoused (for both NASA and non-NASA missions). Because of the degree of detail available, the missions included in the 1971-72 NASA mission model (as described in depth in References 5 and 13) have been used in the economic analyses. Forecasts of the missions to be performed as part of the planned space activities during the 1980-1990 time period were studied [6,12] in order to define the requirements for the diverse applications and thereby arrive at realistic criteria for conceptual spacecraft designs.

The mission model was analyzed and it was found that considerable commonality existed for a majority of the missions in the power ranges of 100-500 watts and 500-2000 watts. These missions, a subset of which are summarized in Tables 5.1 and 5.2, generally are in the categories of communication or earth observations and typically are performed in 1400 km circular orbits or in geosynchronous orbits. To evaluate the economics of standardization, the subset of missions indicated in Tables 5.1 and 5.2 were selected and the specific requirements in terms of attitude control, station keeping, etc. were evaluated and various standardized spacecraft configured (see References 6 and 12). The detailed characteristics of these missions are given in detail in Appendix C (sections II and IV of the typical computer output data) and definitions of terms are given in Appendix A. Typical major subsystem requirements are given in Table 5.3.

Table 5.1 Characteristics of 10 Study Missions					
No.	Mission	No. of Flights	Orbit Characteristic	Power, watts	Mission Payload mass, kg.
1	Explorer Upper Atmospheric Sampling Lower Magnetosphere measurements	12	Elliptical 1800/180 km 28° to 90° inclination	100	45.4
2	Geopause Precision Laser Ranging to Earth and Low Earth Orbit Proof Mass Satellites	7	Circular 20,000 km polar	100 to 400	68.0
3	Tracking and Data Relay Satellite (TDRS) Continuous Communication Service for Shuttle and Unmanned Spacecraft	10	Geo-stationary	430	99.3
4	Synchronous Meteorological Satellite (SMS) Continuous Meteorology Observations	14	Geo-stationary	300	113.4
5	TIROS-O Operational Meteorological Satellite (5th gen.)	3	Circular 1300 km near-polar sun-sync	200	111.1
6	Earth Observatory Satellite (EOS) R&D Earth Remote Sensing Satellite	8	Circular 926 km near-polar sun-sync	1200	412.8
7	Synchronous Earth Observatory Satellite (SEOS)	5	Geo-stationary	1500	408.2
8	Earth Resources Satellite (ERS) Operational Earth Resources Satellite	14	Circular 1716 km near-polar sun-sync	1200	140.6
9	Disaster Warning Satellite (DWS) Emergency Communication Satellite	6	Geo-stationary	900	226.8
10	System Test Satellite (STS)	8	Geo-stationary	600	142.9

Table 5.2 Orbital Characteristics of Missions

Low-Altitude Sun-Synchonous Orbits	Geostationary Orbits	Other Orbits
TIROS	TDRS	Explorer (highly
EOS	SMS	eccentric low earth)
ERS	SEOS	Geopause (high
	DWS	altitude circular
	STS	polar)

In a study [6] performed for the AEC/NASA Space Nuclear Systems Division, Fairchild Industries performed a preliminary design effort on standardized nuclear-powered spacecraft. Several of the conclusions from this study are as follows:

- Analysis of the 1971-72 NASA mission model for the post-1979 time period revealed that many different missions can be divided into just a few groupings of common power, weight, and size.
- Two standard radioisotope-powered spacecraft, using present-day technology, can satisfy 80-90 percent of the unmanned, earth-orbit missions listed in the NASA mission model for the 1979-90 period. The spacecraft provide structure, thermal control, electrical power, attitude and velocity control (AVCS), and tracking, telemetry and command (TTC) subsystems. The only

Table 5.3 Major Subsystem Requirements	
Subsystem	Requirement
Electrical Power	<ul style="list-style-type: none"> • +28 volt DC, $\pm 2\%$ regulation. • Power requirement satisfied by modularized subsystem to satisfy specific mission needs.
Attitude Control	<ul style="list-style-type: none"> • Three-axis stabilization with spin stabilization as possible alternate. • 0.1° standard accuracy with improved accuracy available for special mission requirements.
Reaction Control	<ul style="list-style-type: none"> • Orbit change ΔV capability = 357 meters/sec. • Attitude torque capability for momentum dumping.
TT&C Subsystem	<ul style="list-style-type: none"> • Up to 10^6 BPS rate for housekeeping and moderate mission data transmission requirements. • Dual redundant system with remote add on modules for flexibility and interface minimization.
Thermal Control Subsystem	<ul style="list-style-type: none"> • Maintain support system modules between -10°C and $+40^\circ\text{C}$.
Structure	<ul style="list-style-type: none"> • Flexible concept for adapting wide variety of mission payloads to standardized structure and support systems.

missions excepted are those few which exceed either the weight-carrying capacity or the attitude control accuracy of the spacecraft as currently designed.

- Two nuclear power system designs, one for each spacecraft can satisfy all the missions served. The systems are a radioisotope thermoelectric generator and a radioisotope Brayton system (as a result of more recent studies [14] a radioisotope organic rankine system is being considered. For each spacecraft mission, power is provided as required in modular steps, either by addition of complete RTG's to provide power up to 4500 watts (e) or by adding fuel capsules to the Brayton system to cover the range from 500 to 2000 watts (e). Both systems can use the same standardized heat source.
- Waste heat from the nuclear generators can be used to maintain spacecraft equipment temperatures within acceptable limits for all altitudes, sun angles, and equipment duty cycles. This is the key factor which permits standardization of the entire spacecraft despite the wide variety of missions encountered.

As a result of the analysis, Fairchild Industries established two general spacecraft configurations as illustrated in Figures 2.4 and 2.5. It must be emphasized that these designs are based upon analysis and intuition -- that is no attempt was made to optimize the spacecraft design from the point of view of minimizing the present value of the costs associated with performing the missions as postulated in the mission model.

The following analysis is based upon three standardized spacecraft concepts namely a solar powered spacecraft as illustrated in Figures 2.1 and 2.2, a radioisotope-thermoelectric (RTG) powered spacecraft as illustrated in Figure 2.4 and a radioisotope-Brayton (RB) or organic rankine cycle powered spacecraft as illustrated in

Table 5.4 Technology Base Specification				
Technology Base	Spacecraft Concepts			
	Mission Specialized	Standardized		
		Solar	RTG *	RB **
0	✓			
1	✓		✓	
2	✓			✓
3	✓	✓		
4	✓		✓	✓
5	✓	✓	✓	
6	✓	✓		✓
7	✓	✓	✓	✓
* Radioisotope thermoelectric generator ** Radioisotope Brayton Cycle generator				

Figure 2.5. The basic question is should these three spacecraft concepts be developed, implemented and used and at what power levels should they be developed? To answer these questions eight different technology bases may be defined as shown in Table 5.4. Each technology base has a different mix of spacecraft concepts available (i.e., developed) to it. For example, technology base 0 can draw upon mission specialized spacecraft only (standardized spacecraft not available); technology base 7 can draw upon mission specialized spacecraft and the three standardized spacecraft concepts; etc. As discussed previously in section 4.0, the developed methodology determines, within a specified technology base, the optimal assignment of spacecraft to missions and the power design levels, which combine to minimize the present value of the cost of performing the specified mission model.

Typical results of an analysis of technology base 7 are illustrated in Figures 5.1 through 5.7. It should be noted that in the current model^{*} the non-recurring costs are not within the optimization loop. Therefore the optimum spacecraft mix can not be directly ascertained across all of the technology bases. In order to accomplish the optimization across the technology bases it is necessary to determine the optimum alternative within each technology base and thence determine the technology base which yields the minimum present value of costs. For the indicated results, spacecraft 1 refers to the standardized spacecraft employing RTG technology, spacecraft 2 refers to the standardized spacecraft employing RB technology and spacecraft 3 refers to the standardized spacecraft employing solar technology.

Figure 5.1 illustrates the standardized spacecraft power subsystem development (non-recurring) and first unit recurring costs. These are the input data values as specified at the nominal power level scaled to the "optimal" design power level within the specified technology base, as determined by minimizing the present value of costs. Figure 5.2 illustrates the spacecraft assignment and specific power levels for both the maximum design power level and the actual power provided for and required for each mission. The spacecraft assignments are as follows: spacecraft 1 to missions 2, 3, 4 and 5, spacecraft 2 to missions 7 and 10 and spacecraft 3 to missions 6, 8 and 9. Note that no standardized spacecraft have been assigned to mission 1. This mission can best be performed by a mission specialized spacecraft. It should also be noted that the mission power requirement is a function of whether solar or nuclear power is utilized (nuclear power minimizes the need for batteries and battery charging and reduces the need for thermal control using electrical power). It can be seen that the maximum power capability of spacecraft 1 is never actually required. The maximum power has been selected so as to minimize the present value of cost across the missions as illustrated in Figure 2.8.

^{*} An attempt is currently being made to eliminate this shortcoming by bringing the non-recurring cost inside the optimization loop. The problem is to accomplish this without a substantial increase in computer computation time.

Figure 5.1

Standardized power subsystem/spacecraft

unit cost information

- power subsystem first unit development cost (\$ millions) -
- power subsystem first unit recurring cost (\$ millions) -
- number of power supply modules available -
- power supply type -

			spacecraft
1	2	3	
22.40,	36.91,	2.89,	
1.33,	3.24,	1.41,	
3 ,	4 ,	6 ,	
1 ,	2 ,	3 ,	

Figure 5.2

Standardized spacecraft/mission power information

- spacecraft max power (watts) -
- power allocated for mission (watts) -
- mission power requirement (watts) -
- ratio of power modules used to number available -

spacecraft type	mission									
	1	2	3	4	5	6	7	8	9	10
1	0.0,	411.9,	411.9,	411.9,	411.9,	0.0,	0.0,	0.0,	0.0,	0.0,
	0.0,	137.3,	411.9,	274.6,	274.6,	0.0,	0.0,	0.0,	0.0,	0.0,
	0.0,	100.0,	301.0,	273.0,	167.0,	0.0,	0.0,	0.0,	0.0,	0.0,
	0/0,	1/3,	3/3,	2/3,	2/3,	0/0,	0/0,	0/0,	0/0,	0/0,
2	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	1364.0,	0.0,	0.0,	1364.0,
	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	1364.0,	0.0,	0.0,	682.0,
	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	1364.0,	0.0,	0.0,	545.0,
	0/0,	0/0,	0/0,	0/0,	0/0,	0/0,	4/4,	0/0,	0/0,	2/4,
3	0.0,	0.0,	0.0,	0.0,	0.0,	1199.0,	0.0,	1199.0,	1199.0,	0.0,
	0.0,	0.0,	0.0,	0.0,	0.0,	1199.0,	0.0,	1199.0,	999.2,	0.0,
	0.0,	0.0,	0.0,	0.0,	0.0,	1199.0,	0.0,	1199.0,	899.8,	0.0,
	0/0,	0/0,	0/0,	0/0,	0/0,	6/6,	0/0,	6/6,	5/5,	0/0,

Figure 5.3 illustrates how spacecraft-mission optimal assignment is modified as basic parameters are changed. Specifically, Figure 5.3 illustrates the spacecraft assignment when the power subsystem recurring cost of spacecraft 2 is decreased by 10%. Note the change in spacecraft assignment (refer to Figure 5.2) for mission 9.

Figure 5.4 summarizes the unit recurring cost for the spacecraft as per their assignment and configuration for each mission. The costs vary from mission to mission and reflect the number of power subsystem modules required for each mission. The costs shown are the equivalent of first unit costs and do not, as yet, take into account learning effects. Also illustrated are the spacecraft development costs. Figure 5.5 illustrates the standardized spacecraft recurring and non-recurring costs (not including the power subsystem non-recurring costs) and their time phasing as dictated by mission requirements. The indicated recurring costs take into account the number of flights required each year and learning effects and include the cost of spares but do not include transportation charges. Note that recurring non-recurring costs are indicated. Their timing is determined by the anticipated technology life, changing requirements and flight requirements. Learning effects are also applied to these recurring non-recurring costs.

Figure 5.6 illustrates the recurring and non-recurring costs for the mission specialized spacecraft for each of the missions which have not been "captured" by standardized spacecraft. Learning effects on both recurring costs and recurring non-recurring costs are taken into account. The learning effects are based only upon the flights within each mission--i.e., there is, in the mission specialized spacecraft case, no learning from mission to mission. Figure 5.7 indicates the total annual costs for performing the specified mission model. The costs are spread in time as per the previously described cost spreading functions and includes both the standardized and mission specialized spacecraft costs, transportation charges and spares (including their transportation charges as required). Note the drop off in cost in the last few years--this results from the fact that a finite time period is considered beyond which no flights are scheduled (i.e., a finite time horizon). Therefore costs are not spread forward into the last few years of the analysis. This, however, because it occurs so far out in time and because relative results are of prime importance, introduces but little error into the analysis.

Figure 5.3 Effect of Decreasing Cost of Spacecraft
2 Power Subsystem by 10%

Standardized spacecraft/mission power information

- spacecraft max power (watts) -
- power allocated for mission (watts) -
- mission power requirement (watts) -
- ratio of power modules used to number available -

		mission									
spacecraft type		1	2	3	4	5	6	7	8	9	10
69	1	0.0,	411.9,	411.9,	411.9,	411.9,	0.0,	0.0,	0.0,	0.0,	0.0,
		0.0,	137.3,	411.9,	274.6,	274.6,	0.0,	0.0,	0.0,	0.0,	0.0,
		0.0,	100.0,	391.0,	273.0,	167.0,	0.0,	0.0,	0.0,	0.0,	0.0,
		0/0,	1/3,	3/3,	2/3,	2/3,	0/0,	0/0,	0/0,	0/0,	0/0,
	2	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	1364.0,	0.0,	1364.0,	1364.0,
		0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	1364.0,	0.0,	1023.0,	682.0,
		0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	1364.0,	0.0,	818.0,	545.0,
		0/0,	0/0,	0/0,	0/0,	0/0,	0/0,	4/4,	0/0,	3/4,	2/4,
	3	0.0,	0.0,	0.0,	0.0,	0.0,	1199.0,	0.0,	1199.0,	0.0,	0.0,
		0.0,	0.0,	0.0,	0.0,	0.0,	1199.0,	0.0,	1199.0,	0.0,	0.0,
		0.0,	0.0,	0.0,	0.0,	0.0,	1199.0,	0.0,	1199.0,	0.0,	0.0,
		0/0,	0/0,	0/0,	0/0,	0/0,	6/6,	0/0,	6/6,	0/0,	0/0,

Figure 5.4

Standardized spacecraft unit costs
 - first unit recurring cost/mission -
 (\$ millions)

spacecraft type	mission									
	1	2	3	4	5	6	7	8	9	10
1	0.0	7.69	8.57	8.13	8.13	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	10.61	0.0	0.0	8.99
3	0.0	0.0	0.0	0.0	0.0	9.49	0.0	9.49	9.26	0.0

- first unit development cost -
 (\$ millions)

spacecraft		
1	2	3
37.18	42.42	46.68

Figure 5.5

Standardized spacecraft yearly costs

(prior to cost spreading)

- recurring cost -

- development cost -

- power subsystem development cost -

(\$ millions)

year

spacecraft
type

	1	2	3	4	5	6	7	8	9	10
1	0.0	0.0	0.0	0.0	0.0	0.0	22.30	14.79	21.22	20.60
	0.0	0.0	0.0	0.0	0.0	0.0	37.18	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	22.40	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.91	0.0	17.00
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.42	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.91	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	43.75	24.12	15.81	15.56
	0.0	0.0	0.0	0.0	0.0	0.0	46.68	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	2.80	0.0	0.0	0.0
	11	12	13	14	15	16	17	18		
1	26.69	13.30	32.22	12.92	19.06	12.72	12.65	12.25		
	0.0	18.44	0.0	0.0	0.0	0.0	12.24	0.0		
	0.0	15.58	0.0	0.0	0.0	0.0	12.60	0.0		
2	0.0	24.18	0.0	23.55	0.0	15.97	7.22	0.0		
	0.0	0.0	0.0	21.04	0.0	0.0	0.0	0.0		
	0.0	0.0	0.0	25.67	0.0	0.0	0.0	0.0		
3	22.79	14.93	14.97	7.44	29.30	35.35	14.38	14.30		
	0.0	23.15	0.0	0.0	0.0	0.0	15.36	0.0		
	0.0	2.30	0.0	0.0	0.0	0.0	2.01	0.0		

Figure 5.6

Non-standardized spacecraft+ yearly costs
(prior to cost spreading)

- recurring cost -
- development cost -

(\$ millions)

(years)

mission	1	2	3	4	5	6	7	8	9	10
1	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	16.14 62.45	7.59 0.0	7.41 0.0	7.28 0.0

(years)

mission	11	12	13	14	15	16	17	18
1	7.17 46.55	14.09 0.0	6.94 0.0	6.88 0.0	6.82 39.20	6.78 0.0	13.43 0.0	6.66 0.0

Figure 5.7

Standardized plus non-standardized spacecraft
 total annual costs
 (cost spreading included)
 (\$ millions)

year	1	2	3	4	5	6	7	8	9	10
annual cost	0.0	0.0	8.56	50.50	140.95	142.78	115.65	118.28	115.79	138.91
year	11	12	13	14	15	16	17	18		
annual cost	126.88	132.29	114.68	111.11	115.07	103.69	53.59	29.04		

Figure 5.8

Standardized plus non-standardized spacecraft
 present value of costs
 (\$ millions)

discount rate (%)	0.0	5.0	8.0	10.0	12.0
present value	1617.8	1015.3	787.9	671.8	576.9

The final result of the analysis is illustrated in Figure 5.8 where the present value of costs, at several different discount rates, is shown. Note that the present value of cost at a discount rate of zero is the straight sum of all future costs (without discounting).

The above results can be obtained for each technology base as indicated in Table 5.4 and the best technology base selected based upon the minimization of the present value of the cost of performing the mission model. This is Tabulated in Table 5.5 where it can be seen that technology

Table 5.5 Present Value Comparison of Technology Bases	
Technology Base	Present Value (at 10% discount rate) (\$ million)
Ø	1430.2
1	935.8
2	568.5
3	564.0
4	638.3
5	629.5
6	625.1
7	671.8

base #3 yields the minimum present value of cost and is therefore the preferred choice. This preference is based upon expected values. As discussed previously, it is important, particularly when comparing different technology bases, to establish the probability distribution of the present value of cost and compare the likelihood of the present value of cost of each technology base exceeding that of other technology bases. The methodology to accomplish this was described in Section 4.0. An example is now presented in the hope of clarifying the methodology. To accomplish this four parameters are considered as uncertainty variables namely

- the unit recurring cost associated with the standardized power subsystem at the nominal power level (XCSTPR),*

* FORTRAN variable name used in the mathematical model; see Appendix A.

- the change in power subsystem cost per watt change in electric power (XDCSTR),
- the non-recurring cost of the standardized power subsystem (XCSTPN), and
- the change in non-recurring cost of the standardized power subsystem per watt change in electric power (XDCSTN).

These uncertainty variables are considered for each spacecraft (power subsystem). It should be noted that there exist many potential uncertainty variables, only four of which are considered here for illustrative purposes only.

The sensitivity coefficients associated with these four variables for technology base #7 are presented in Table 5.6.* Similar coefficients have been established for each technology base. These values have been obtained by perturbing the nominal input data and determining its effect on present value. Also illustrated in Table 5.6 are the assumed (for illustrative purposes only) ranges of uncertainty of each of the variables and associated uncertainty profiles. The uncertainty profiles [9, 11], or probability distributions, of the input variables are illustrated at the bottom of Table 5.6.

*The negative values obtained for the sensitivity coefficients associated with XDCSTR and XDCSTN are due to the relationship these variables have to the power subsystem cost and the designed maximum power capability. The power subsystem recurring cost is given by

$$PRCST = XCSTPR + XDCSTR \cdot \Delta P$$

and the non-recurring cost by

$$PNRS = XCSTPN + XDCSTN \cdot \Delta P$$

where

ΔP = Nominal maximum power capability -
designed maximum power capability.

Then it is true that:

$$\frac{\partial PRCST}{\partial XDCSTR} = \Delta P \quad \text{and} \quad \frac{\partial PNRS}{\partial XDCSTN} = \Delta P$$

$\partial PV / \partial PRCST$ and $\partial PV / \partial PNRS$ are in general positive quantities since increasing power subsystem cost will generally increase the present value of cost. Thus, if ΔP is negative, which is the case for the particular power subsystems shown, then $\partial PV / \partial XDCSTR$ and $\partial PV / \partial XDCSTN$, the sensitivity coefficients, will be negative.

Table 5.6 Example of Risk Analysis Input Data for Technology Base #7

Spacecraft	Variable	Derived Sensitivity Coefficient	Assumed Range ** of Uncertainty	Uncertainty ⁺ Profile
1	XCSTPR	+0.10	-10% to +20%	1
	XDCSTR	-0.01	-10% to +10%	2
	XCSTPN	+0.24	- 5% to +20%	3
	XDCSTN	-0.01	- 5% to +20%	4
2	XCSTPR	+0.20	-10% to +20%	2
	XDCSTR	-0.05	-10% to +10%	2
	XCSTPN	+0.36	- 5% to +20%	2
	XDCSTN	-0.06	- 5% to +20%	2
3	XCSTPR	+0.20	-10% to +20%	4
	XDCSTR	-0.05	-10% to +10%	2
	XCSTPN	+0.04	-10% to +20%	4
	XDCSTN	-0.01	-10% to +20%	1

* Units are \$10⁶ of present value per 1% change in nominal value of variable

** Units are % variation relative to nominal value

⁺ Uncertainty profiles:

Figure 5.9 Probability that the Present Value of Technology Base X Exceeds that of Technology Base Y By More Than Amount K

Equations 4.17 and 4.18 are utilized to establish the expected present value of cost and the standard deviation of the present value for each of the technology bases. The sensitivity coefficients, ranges of uncertainty and uncertainty profiles (i.e., resulting values of $\Delta \bar{x}_i$ and σ_i) as indicated in Table 5.6 yield the results shown in Figure 5.9. In reviewing the results it must be kept in mind that only four of the large number of input variables have been treated as uncertainty (probabilistic) variables and that the ranges of uncertainty have been considered as quite small. This leads to unrealistically small values for the standard deviation of present value.

Figure 5.9 illustrates the probability that the present value of technology base #2 will exceed that of technology base #3 by more than the indicated amount k . Conversely it illustrates the probability that the present value of technology base #3 exceeds that of technology base #2 by more than the indicated amount. There is a 27% chance that the present value of technology base #2 will exceed that of technology base #3 (i.e., $K = 0$) and a 73%

chance of the alternate situation arising. Thus the decision maker is given the quantitative risk measure which is the result of the considered uncertainties. In other words the decision maker must decide if he should pursue the development of technology base #3 or technology base #2. For the illustrative case there is about a 25% chance that the present value of technology base #3 will exceed that of technology base #2 and a 75% chance of the reverse being true. There is little chance that the present value of technology base #3 will exceed that of technology base #2 by more than \$5 million. Since this latter amount is small compared to the expected values it reasonably may be concluded that technology base #3 should be pursued.

However, all too frequently the situation illustrated in Figure 5.10 is encountered where two hypothetical technology bases are considered. Technology base A has a lower expected and most likely present value of cost than that of technology base B. Without the explicit consideration of uncertainty and the development of the present value probability distributions, technology base A would be selected for development. After the explicit consideration of uncertainty the probability of the present value of the cost of technology base A exceeding that of technology base B can be established as shown in Figure 5.11. Quite frequently the situation arises such that the risk associated with technology base A relative to base B are too large and even though $\overline{PV}_A < \overline{PV}_B$, technology base B is selected for development. This type of decision results from the decision maker exercising his risk aversion preferences after viewing the risk data as per Figures 5.10 and 5.11. In other words there is an intolerably high probability that the present value of technology base A will exceed that of technology base B by a very large amount. A subjective tradeoff must be made between the difference in expected present values and the chance that the present value of technology base A will exceed that of technology base B by an intolerable amount.

Figure 5.10 Generalized Problem of Decision Making Under Conditions of Uncertainty

Figure 5.11 Probability That PV_A Exceeds PV_B By At Least K

6. SUMMARY

An economic analysis methodology has been developed and its use demonstrated for answering the following basic questions:

- (a) Is spacecraft standardization economically desirable?
- (b) If spacecraft standardization is economically desirable, what standardized spacecraft configuration or mix of configurations and technologies should be developed? and
- (c) If standardized spacecraft are to be developed, what power levels should they be designed for?

The methodology develops the present value of the costs of performing a specified mission model drawing upon a specified technology base of standardized and mission specialized spacecraft. Within a specified technology base spacecraft power and related capabilities are varied so that a near optimal determination of power capability and spacecraft-mission assignment is accomplished. This results in the establishment of the minimum present value of cost approach, within each specified technology base, to satisfying mission requirements and at the same time establishing the spacecraft which should be developed within each technology base and their power capabilities. The present value of the costs of the optimal choice within each technology base can then be compared so that the best overall approach to satisfying mission requirements can be established.

As part of the evaluation and comparison procedure it is necessary to consider mission, performance and cost uncertainties and the resultant risk. This is particularly true for the case at hand where the different technology bases draw upon systems which are in different stages of research, development, design and use. The developed methodology illustrates how quantitative subjective assessments of the uncertainty associated with the values of key input variables can be utilized to establish quantitative risk measures such as the probability that the present value of the cost will exceed various specified values. Therefore the various possible alternatives can be compared from the point of view of the chance that the present value of each alternative will exceed that of other alternatives. The decision maker may thence exercise his risk aversion preferences.

The methodology is based upon the formulation and use of a mathematical model which considers both recurring and non-recurring costs and their timing as dictated by the specified mission model. The determination of both recurring and non-recurring costs considers both point estimates of cost and CER generated values. Point estimates are used for the power subsystems and CERs for all supporting subsystems. This approach tends to minimize CER induced errors since support subsystems are quite similar even though power subsystems may differ significantly. The determination of recurring and non-recurring costs also considers learning effects, cost spreading, spare spacecraft, transportation charges, etc. A major element of the mathematical model and the overall methodology is the consideration of spacecraft power capability as a variable, initial values of which are estimated and input to the model. Through the use of linear scaling laws the mathematical model allows the spacecraft capability to be varied so that the optimal performance (power) capability can be established.

The results obtained to date indicate that spacecraft standardization can be economically attractive relative to the continued development of mission specialized spacecraft.* This is indicated by the very significant differences in the present value of costs (typically on the order of \$500 million when considering 10 NASA missions) of all of the alternatives considered (Table 5.5) relative to the continued development and utilization of mission specialized spacecraft. Also to be considered is the annual cost of performing the mission model. Typical annual costs are indicated in Figure 6.1. The incremental cash flow (standardized vs. mission specialized spacecraft) is illustrated in Figure 6.2 and demonstrates that effectively little or no investment is required to achieve standardization and the large potential benefits** (i.e., cost savings) resulting from standardization. The relatively small investment results because of the investments in mission specialized

* No conclusions can be drawn relative to other forms of standardization (i.e., piece/part and subsystem) since this analysis has not addressed this situation.

** The reduction in benefits in the latter years is due to the finite planning horizon considered and the resulting elimination of flights which would normally be encountered beyond the planning horizon and would result in costs which would be spread backward in time and hence occur prior to the planning horizon.

Figure 6.1 Typical Annual Cost Patterns (Technology Base #7)

Figure 6.2 Incremental Cash Flow Pattern (Potential savings resulting from Standardization for Technology Base # 7)

spacecraft which are foregone when standardized spacecraft are developed. It should be noted that in order to achieve the indicated potential benefits it is necessary that the applicable missions utilize the standardized spacecraft. This introduces both an element of risk increase and risk reduction into the space program. The element of increased risk is associated with the probability that a standardized spacecraft will be used on any particular mission. The risk reduction comes about since once a standardized spacecraft is developed there is little or no uncertainty associated with the spacecraft cost (possibly only with modification and mission equipment integration) for each mission.

Spacecraft definition and cost estimates are not considered to be of sufficient accuracy to allow decisions regarding spacecraft mix and power levels to be made at this time. The estimates are deemed of sufficient accuracy so as to demonstrate the desirability of spacecraft standardization and the methodology which is necessary to decide upon the best mix of standardized spacecraft and their design power levels. It is shown that there is an important relationship between maximum design power capability and spacecraft assignment and cost. Changes in cost and/or performance result in spacecraft-mission assignment changes and changes in the power capability which should be achieved.

It is also demonstrated that there is a distinct possibility that, for a reasonably large set of missions, that the development and use of a single standardized spacecraft may minimize the present value of cost. This may occur even though the spacecraft is utilized very inefficiently (in terms of power capability and resulting mass) on several of the missions. This is illustrated in Figures 6.3 and 6.4 where spacecraft assignment and power capability are shown for technology bases #2 and #3, respectively. These technology bases, each consisting of a single standardized spacecraft (nuclear and solar powered, respectively) and a mission specialized spacecraft, each achieve approximately the same minimum present value of cost (see Table 5.5). This is accomplished in spite of apparent gross mismatch of capability and mission requirement (see, for example, missions 2 and 3). It should be noted that the spacecraft power requirements and capabilities differ for technology bases #2 and #3. This is the result of mission power requirements being a function of power subsystem technology (solar or nuclear).

Figure 6.3 Technology Base #2

Standardized spacecraft/mission power information

- spacecraft max power (watts) -
- power allocated for mission (watts) -
- mission power requirement (watts) -
- ratio of power modules used to number available -

spacecraft type	mission									
	1	2	3	4	5	6	7	8	9	10
2	0.0,	1364.0,	1364.0,	1364.0,	1364.0,	1364.0,	1364.0,	1364.0,	1364.0,	1364.0,
	0.0,	341.0,	682.0,	341.0,	341.0,	1364.0,	1364.0,	1364.0,	1023.0,	682.0,
	0.0,	100.0,	391.0,	273.0,	167.0,	1090.0,	1364.0,	1090.0,	818.0,	545.0,
	0/0,	1/4,	2/4,	1/4,	1/4,	4/4,	4/4,	4/4,	3/4,	2/4,

Figure 6.4 Technology Base #3

Standardized spacecraft/mission power information

- spacecraft max power (watts) -
- power allocated for mission (watts) -
- mission power requirement (watts) -
- ratio of power modules used to number available -

spacecraft type	mission									
	1	2	3	4	5	6	7	8	9	10
3	0.0,	1500.4,	1500.4,	1500.4,	1500.4,	1500.4,	1500.4,	1500.4,	1500.4,	1500.4,
	0.0,	250.1,	500.1,	500.1,	250.1,	1250.3,	1500.4,	1250.3,	1000.3,	750.2,
	0.0,	125.0,	430.1,	300.3,	200.4,	1199.0,	1500.4,	1199.0,	899.8,	599.5,
	0/0,	1/6,	2/6,	2/6,	1/6,	5/6,	6/6,	5/6,	4/6,	3/6,

As stated above, the minimization of the present value of cost is achieved, for a specified mission model, with gross mismatches between mission power requirements and spacecraft capability. This is the result of the mission model being formulated without prior knowledge of the standardized spacecraft capability. It appears that an iterative process should be carried out. The mission model should be reviewed, having a-posteriori knowledge of standardized spacecraft capability, in order to determine desirable modifications to the mission model. This may result in achieving the same capability (i.e., providing the same science and/or services) with fewer missions and/or flights causing a further decrease in the cost of performing the mission model. The previously described methodology can thence be repeated in terms of the modified mission model and a new mix of desirable standardized and mission specialized spacecraft and power levels determined. The mission model can thence be reviewed in terms of the spacecraft capabilities and the overall process continued until no further cost savings can be achieved. Caution must be exercised in this process to include (outside the previously described mathematical model) incremental payload integration costs which may result from the increased problems of mounting multiple payloads on a single spacecraft.

Also to be considered are incremental payload costs which are the direct result of the specific level of capability of the different standardized spacecraft configurations under consideration. For example, the illustrated (Figures 2.4, 2.4 and 2.5) solar and nuclear powered standardized spacecraft may affect mission payload equipment in different ways thereby resulting in different payload cost. The design of the standardized nuclear powered spacecraft assumes that thermal control will be provided by the spacecraft for the mission payload equipment whereas the design of the standardized solar powered spacecraft assumes that thermal control will be provided by the mission payload equipment. The difference in payload costs directly attributable to the alternative spacecraft concepts must ultimately be included in the analysis. The previously described analysis alludes to this fact but does not make specific provision for incorporating these incremental costs into the cash flow streams.

The comparison and ultimate decisions with regard to standardized spacecraft should be considered in light of the uncertainty associated with the basic cost and performance estimates and the resulting risk. An attempt has been made to illustrate a methodology for explicitly quantitatively considering uncertainty and risk. The uncertainties which should be considered are the various mass and cost estimates, sensitivity or scaling rules, missions and mission requirements, probability that if standardized spacecraft are developed they will be utilized as anticipated, etc. In order to make informed decisions these areas need to be quantified and brought into the analysis. It should be noted that lack of these considerations and resulting lack of quantification of uncertainty implies that there is no uncertainty.

The developed methodology and capability can be utilized to assist with the decision making process relative to standardized spacecraft. Various postulated spacecraft concepts with associated performance and cost characteristics can be easily evaluated in terms of different mission models. For example, the effect of increased spacecraft power capability (so as to achieve increased flexibility with respect to mission planning) can be evaluated by establishing the increase in the present value of costs which are the direct result of the increased spacecraft capability. This thence provides a measure of the cost of achieving increased capability and/or flexibility.

It is frequently stated that standardization will have a negative effect on the development of new technology. This, it is argued, will result both from the reduction in the number of different spacecraft procured each with its own specific advances in technology and from the reduction in competition amongst spacecraft designers. It should be noted, to the contrary, that if standardization is pursued correctly the development of new technology may actually be enhanced. The reason for this is it appears that standardization, which may be achieved with little or no increase in net investment, can generate large potential benefits in the form of net savings in providing a capability for performing a specified mission model. In a constrained or fixed budget situation these savings may be reinvested directly in new research and development programs which will provide advances in desired technology.

REFERENCES

1. Hunter, M. W., Miller, W. F., Gray, R. M., The Space Shuttle Will Cut Payload Costs, Astronautics & Aeronautics, June 1972.
2. Hunter, M. W., An Analysis of the Effects of the Space Shuttle on Payloads, presented at the 5th U.S./European Conference, San Francisco, May 1972.
3. Payload Effects Analysis Study, Lockheed Missiles and Space Company Final Report for NASA, Contract NASW-2156, June 30, 1971.
4. Tishler, A. O., Lower Space Costs Mean More Space Flight, Astronautics & Aeronautics, June 1974.
5. NASA Payload Data Book, Payload Analysis for Space Shuttle, Aerospace Report ATR-72-(7312)-1 Vol. II, 31 July 1972.
6. Standardization and Economics of Nuclear Spacecraft, Fairchild Industries, Inc., prepared for Space Nuclear Systems Division, AEC, Contract AT (49-15) - 3063, March 1973.
7. Dominguez, Capt. R., McDonald, Capt. F. L., Rohwer, Lt. C. J., Fong, F. K., et al, Space and Missile Systems Organization Unmanned Spacecraft Cost Model, SAMSO TR No. 73-247, Second Edition, July 1973.
8. Greenberg, J. S., Edelman, F., Venture Analysis: The Assessment of Uncertainty and Risk, Management: A Book of Readings, H. Koontz and C. O'Donnel, eds., McGraw-Hill, 1972.
9. Greenberg, J. S., Reliability, Uncertainty and Risk Analysis of Space Systems - A Methodology for Decision Making, Princeton University, AMS Report No. 1085, Dec. 1972.
10. Greenberg, J. S., Hazelrigg Jr., G. A., Methodology for Reliability - Cost - Risk Analysis of Satellite Networks, Journal of Spacecraft and Rockets, Sept. 1974.
11. Greenberg, J. S., Risk Analysis, Astronautics & Aeronautics, Nov. 1974.
12. Anchutin, A., Russell, S., Configuration Study of Standardized Solar-Powered Spacecraft, Princeton University ASAR Memo No. 143, 31 July 1974.

13. Integrated Operations/Payloads/Fleet Analysis Final Report, Aerospace Report ATR-72-(7231)-1 Vol. II, August 1971.
14. Organic Rankine Cycle Economic Radioisotope Thermodynamic Generator Study, Phase I Final Briefing, TRW, Dec. 13, 1973, prepared for Space Nuclear Systems Div. AEC, Contract AT(04-3)-941.
15. Economic Analysis of Advanced Propulsion Systems (Vol. II), prepared for NASA Space Nuclear Systems Office by Mathematica, Inc., 30 April 1973, Contract SNSO-2.
16. Cramér, H., The Elements of Probability Theory, John Wiley & Sons, 1955.

APPENDIX A

DEFINITION OF DATA REQUIREMENTS

APPENDIX A
DEFINITION OF DATA REQUIREMENTS

SECTION I - GENERAL INFORMATION

1. XA(K)	Cost spreading coefficients to be used for the K cost spreading function	
2. XB(K)	Cost spreading coefficients to be used for the K cost spreading function	
3. JMAX	Maximum number of missions to be considered	
4. IMAX	Maximum number of years to be considered	
5. IRMAX	Maximum number of discount rates to be considered	
6. XDR(IR)	Discount rates to be used in present value computations	(%)
7. LMAX	Maximum number of different types of standardized spacecraft	
8. NMAX	Maximum number of upper stages to be considered. An upper stage (tug, for example) is considered as n different stages if it is necessary to place payloads into n significantly different orbits.	

SECTION II - MISSION MODEL

9. NO_(I)	No. of satellites associated with mission_(J) launched in year I	
10. XPOW(J)	Required spacecraft power (not including thermal control, battery charging and power conditioning) at BOL	(watts)
11. XPOWP(J)	Percentage increase in power for thermal control, battery charging and power conditioning	(%)

12.	IAC(J)	Specification of attitude control system type: for 1-axis stabilization, IAC = 1 for 3-axis stabilization, IAC = 3 for either stabilization, IAC = 2	
13.	XPSP(J)	Percent spares required for the Jth mission	(%)
14.	XMPL(J)	Mass of mission equipment (payload)	(kg)
15.	LMISS(J)	Specification of the type (value of L) of standardized spacecraft to be used for mission J. When equal to zero the analysis will determine which spacecraft will be used.	
16.	XPLL(J)	Incremental mission equipment length when emplaced upon a standardized spacecraft.	(m)

SECTION III - TRANSPORTATION SYSTEM DATA

17.	XCS	Average cost of placing a unit mass (kg) into the Space Shuttle altitude low earth orbit	(K\$)
18.	XFS	Average Space Shuttle load factor (fraction of full payload capability which is utilized on the average)	
19.	XMPS	Maximum payload capability of the Space Shuttle to low earth orbit	(kg)
20.	XMLS	Maximum usable length of Space Shuttle payload bay	(m)
21.	XMTT(N)	Gross mass (including propellant) of the Nth upper stage	(kg)
22.	XCT(N)	Cost (including launch operations) of the Nth upper stage	(K\$)
23.	XLT(N)	Length (without payload) of the Nth upper stage	(m)
24.	XMPT(N)	Maximum payload capability of the Nth upper stage	(kg)

25. XFT(N) Average load factor (fraction of full payload capability which is utilized on average) associated with the Nth upper stage
26. NUPS(J) Name of the upper stage to be used for the Jth mission

SECTION IV - MISSION-SPECIALIZED SPACECRAFT DATA
(Solar Power)

27. XM1(J) Structure, thermal control & interstage subsystem mass (kg)
28. XM2(J) Electrical power supply subsystem mass (kg)
29. XM3(J) Telemetry, tracking & command subsystem mass (kg)
30. XM4(J) Communications subsystem mass (kg)
31. XM6(J) Attitude control subsystem mass (kg)
32. XM7(J) Dispenser subsystem mass of spacecraft designed for mission J (kg)
33. XIT(J) Apogee kick motor total impulse for spacecraft designed for mission J (kilonewton-sec)
34. NAKM(J) Number of apogee kick motors for spacecraft designed for mission J
35. IACN(J) Type of attitude control used by mission-specialized spacecraft:
 for 1-axis stabilization, IACN=1
 for 3-axis stabilization, IACN=3
36. XSOLA(J) Solar array area of spacecraft designed for mission J (m^2)
37. XMT(J) Total satellite mass (including experiments and other mission equip.) (kg)
38. KN(J) The name of the cost spreading function to be used for non-recurring costs
39. XYRSN(J) The number of years over which non-recurring costs are to be spread (years)

40.	CALR(J)	Cumulative average learning rate for spacecraft of mission J	(%)
41.	KR(J)	The name of the cost spreading function to be used for recurring costs	
42.	XYRSR(J)	The number of years over which recurring costs are to be spread	(years)
43.	XPL(J)	Payload length (including final orbit injection stages, spacecraft, mission equipment, etc.) for the Jth mission	(m)
44.	XUL(J)	Expected useful life of spacecraft design technology	(years)
45.	XDLR(J)	Spacecraft development cost learning rate	(%)

SECTION V - STANDARDIZED SPACECRAFT DATA

46.	XM1S(L)	Structure, thermal control & interstage subsystem mass of spacecraft at max. power	(kg)
47.	XM2S(L)	Electrical power supply subsystem mass at max. power	(kg)
48.	XM3S(L)	Telemetry, tracking & command subsystem mass of spacecraft at max. power	(kg)
49.	XM4S(L)	Communications subsystem mass of spacecraft at max. power	(kg)
50.	XM6S(L)	Attitude control subsystem mass of spacecraft at max. power	(kg)
51.	XM7S(L)	Dispenser subsystem mass of spacecraft at max. power	(kg)
52.	XM8S(L)	Attitude control and station keeping propellant mass of spacecraft at max. power	(kg)
53.	XITS(L)	Apogee kick motor total impulse of spacecraft at max. power	(kilonewton-sec)
54.	NAKMS(L)	Number of apogee kick motors of spacecraft at max. power	

55. IPTYP(L) Spacecraft power supply type:
 for nuclear, IPTYP=0
 for solar, IPTYP=1
56. IACS(L) Type of attitude control used by spacecraft:
 for 1-axis stabilization, IACS=1
 for 3-axis stabilization, IACS=3
57. XMAXP(L) Maximum permissible power subsystem capability of spacecraft (watts)
58. ~~X~~DESP(L) Design point or nominal power subsystem capability of spacecraft (watts)
59. MAXPS(L) Maximum number of power steps
60. XPWSS(L) Power step size as percent of max. power.
 If input as zero, then XPWSS is computed
 as $XPWSS = 100/MAXPS$. (%)
61. XDM1S(L) Change in structure, thermal control & interstage subsystem mass per unit mass change of other subsystems (kg/kg)
62. XDM6S(L) Change in attitude control subsystem mass per unit mass change of other subsystems (neglecting propellant) (kg/kg)
63. XDM7S(L) Change in dispenser subsystem mass per unit mass change of other subsystems (kg/kg)
64. XDPW(L) Change in power subsystem mass per watt change in electric power (kg/watt)*
65. XCSTPR(L) Unit recurring cost associated with the standardized power subsystem at the nominal power level (K\$)
66. XDCSTR(L) Change in power subsystem recurring cost per watt change in electric power (K\$/watt)
67. KRS(L) The name of the cost spreading function to be used for the recurring cost
68. XYRSRS(L) The number of years over which standardized spacecraft recurring costs are to be spread (years)
69. XSCL(L) Spacecraft length (without mission equipment) (m)
70. XCALRS(L) Cumulative average learning rate for recurring cost (%)

71.	KNS(L)	The name of the cost spreading function to be used for the non-recurring cost of the spacecraft (less power subsystem)	
72.	XYRSNS(L)	The number of years over which non-recurring spacecraft (less power subsystem) costs are spread	(years)
73.	XULSC(L)	Expected useful life of spacecraft design technology	(years)
74.	XULSCL(L)	Spacecraft development (non-recurring) cost learning rate	(%)
75.	KGROUP(L)	Specification of the group to which the power subsystem belongs (non-recurring cost only)	
76.	XCSTPN(KK)	Non-recurring cost of the KK family of standardized power subsystem	(K\$)
77.	XDCSTN(KK)	Change in non-recurring cost of the KK family of standardized power subsystem per watt change in electric power	(K\$/watt)
78.	KNSP(KK)	The name of the cost spreading function to be used for the non-recurring cost of the KK power subsystem	
79.	XYRSPN(KK)	The number of years over which non-recurring power subsystem costs are spread	(years)
80.	XULP(KK)	Expected useful life of power subsystem design technology	(years)
81.	XULPL(KK)	Power subsystem development cost learning rate	(%)

NOTE:

$\emptyset < K < 11$
 $\emptyset < IR < IRMAX+1$ and $IRMAX < 6$
 $\emptyset < I < IMAX+1$ and $IMAX < 31$
 $\emptyset < L < LMAX+1$ and $LMAX < 21$
 $\emptyset < J < JMAX+1$ and $JMAX < 51$
 $\emptyset < N < NMAX+1$ and $NMAX < 17$
 $\emptyset < KK < LMAX+1$ and $LMAX < 21$

APPENDIX B

DESCRIPTION OF MATHEMATICAL MODEL

APPENDIX B

DESCRIPTION OF MATHEMATICAL MODEL

The mathematical model^{*} is basically divided into two parts with, as will be seen, a great deal of commonality. The first part of the model is concerned with the computations associated with the economic evaluation of non-standardized spacecraft and the second part is concerned with the economic evaluation of standardized spacecraft. All input data definitions are given in Appendix A. All input data are in MKS units.

PART I: Non-Standardized Spacecraft (LMAX = 0)

The mathematical model makes use of the following CERS where XNR is the non-recurring cost and XUR is the unit recurring cost measured in thousands of 1970 dollars. The J subscript is the mission identifier or mission index.

a. Structure, Thermal Control and Interstage Subsystem:

$$XNR_{1,J} = 579.49 + 29.7 * (2.2046 * XM_{1,J})^{.63}$$

$$XUR_{1,J} = 42.61 + 1.32 * (2.2046 * XM_{1,J})^{.90}$$

and $XM_{1,J}$ must satisfy the following in order for the above relationship to be applicable.^{**}

$$6.8 \leq XM_{1,J} \leq 331.1$$

* The equations presented in this Appendix do not explicitly include the "mix-optimizer." The equations used in the mix-optimizer are basically the same but with a number of approximations to facilitate the computations (see Figure 4.4). The output of the mix-optimizer is the specification of which spacecraft will be used on which mission and the maximum spacecraft power capability. This information is thence available as input data for the equations which are described in the following pages.

** The implementation of the model is such that when the "conditions" are not satisfied the computations are performed and a warning message printed.

b. Telemetry, Tracking and Command (TT&C) Subsystem:

$$XNR_{3,J} = 335.1 * (2.2046 * XM_{3,J})^{.36}$$

$$XUR_{3,J} = -113.59 + 18.36 * XM_{3,J}$$

and $XM_{3,J}$ must satisfy the following in order for the above relationships to be applicable.

$$3.63 \leq XM_{3,J} \leq 71.67$$

c. Electrical Power Supply Subsystem:

$$XNR_{5,J} = 120.84 * (XMAO_J)^{.45}$$

$$XUR_{5,J} = 103.27 + 1.24 * (23.73 * XM_{2,J} * XSOLA_J)^{.55}$$

where $XMAO_J = XPOW_J + XPOW_J * XPOWP_J/100$ and $XMAO_J$ must satisfy the following in order for the above relationships to be applicable.

$$25.0 \leq XMAO_J \leq 1320.0$$

d. Attitude Control Subsystem (1 and 3 axis):

The input data will specify ISAC = 1 or 3 where the former value refers to single axis stabilization and the latter refers to three axis stabilization.

$$XNR_{6,J} = 28.88 + 39.97 * XM_{6,J} + 418.82 * ISAC$$

$$XUR_{6,J} = 72.78 + 5.40 * XM_{6,J} * ISAC$$

and ISAC = 1 or 3 and $XM_{6,J}$ must satisfy the following in order for the above relationship to be applicable.

$$1.36 \leq XM_{6,J} \leq 81.65$$

e. Communications Subsystem:

$$XNR_{4,J} = 332.0 * (2.2046 * XM_{4,J})^{.44}$$

$$XUR_{4,J} = 7.80 + 10.65 * XM_{4,J}$$

and $XM_{4,J}$ must satisfy the following in order for the above relationships to be applicable.

$$5.90 \leq XM_{4,J} \leq 104.33$$

f. Propulsion Subsystem (Apogee Kick Motor):

$$XNR_{2,J} = -2.07.16 + 48.93 * XIT_J$$

$$XUR_{2,J} = 33.4 * NAKM_J$$

and XIT_J must satisfy the following in order for the above relationships to be applicable.

$$11.69 \leq XIT_J \leq 47.88$$

g. Dispenser Subsystem:

$$XNR_{7,J} = -28.40 + 6.53 * XMT_J$$

$$XUR_{7,J} = 13.64 + .40 * XM_{7,J}$$

and $XM_{7,J}$ must satisfy the following in order for the above relationships to be applicable.

$$7.71 \leq XM_{7,J} \leq 14.1$$

The total first unit non-recurring cost ($XNRT_J$) and recurring cost ($XURT_J$) are given by

$$XNRT_J = 1.13 * 2.06 * 1.4 * \sum_{A=1}^7 XNR_{A,J}$$

$$XURT_J = 1.13 * 2.06 * 1.3 * \sum_{A=1}^7 XUR_{A,J}$$

where the 1.13 factor accounts for a 13% fee, the 2.06 factor accounts for Burden & G & A at 106%. The factors of 1.4 and 1.3 account for program level costs which are related to program management, reliability, planning, quality assurance, systems analysis, project control and other program level costs. Note that aerospace ground equipment (AGE) costs are not included.

In the following discussions, the I subscript is the time (years) index. Prior to computing mission costs it is necessary to determine the number of spacecraft spares which are required. The basic procedure, if the specified percentage of spares is greater than zero, i.e., $PSP_J > 0$, is to purchase a spare spacecraft the first time $NO_{I,J} > 0$. This spacecraft is placed in inventory and the cost associated with this spacecraft is eventually added to the annual cash flow, $XCFR_{I,J}$, in the appropriate year. When a spacecraft fails, the spacecraft is removed from inventory and flown and another spacecraft acquired and placed in inventory. The specifics of the algorithm used for increasing the number of mission flights to account for spares is as follows:

Initialize $NSP_{I,J} = 0$ for all I and J. Thence

$$ADD_J = \frac{PSP_J}{1.0} * \sum_{II=1}^I NO_{II,J} - \sum_{II=1}^I NSP_{II,J}$$

$$\underline{\text{If}} \quad ADD_J > 0.$$

Then

$$NSP_{I,J} = NSP_{I,J} + \text{Integer} [ADD_J + .9999]$$

$$\underline{\text{If}} \quad ADD_J \leq 0.$$

Then

$$NSP_{I,J} = NSP_{I,J}$$

$$NO_{I,J} = NO_{I,J} + NSP_{I,J}$$

Learning effects are applied to the total spacecraft recurring costs per mission as follows:

$$EXPO_J = \left[\log_{10} (CALR)_J - 1.699 \right] / 0.301$$

$$XURTL_{N,J} = XURT_J * (N)^{EXPO_J - 1.0}$$

$$\text{and } 0 \leq N \leq \sum_{I=1}^{IMAX} NO_{I,J} \quad \text{and the following terminology is utilized:}$$

EXPO = learning curve exponent

CALR = cumulative average learning rate (%)

N = number of satellites

$XURTL_{N,J}$ = spacecraft unit recurring cost associated with the N^{th} satellite of the J^{th} mission.

It should be noted in the above that it is assumed that there is no learning from mission to mission.

The annual cash flow, $XCFR_{I,J}$, associated with the J^{th} mission in the I^{th} year, taking into account the learning effects, but prior to the adjustment by cost spreading functions is given by

$$XCFR_{I,J} = \sum_{N=IA+1}^{IB} XURTL_{N,J}$$

$$\text{where } IA = \sum_{II=1}^I NO_{II-1,J}$$

$$\text{and } IB = \sum_{II=1}^I NO_{II,J}$$

The annual cash flow associated with the non-recurring costs prior to the adjustment by the cost spreading functions is given by

$$XCFNR_{I=INR_J,J} = XNRT_J$$

where INR_J is the year during which $\sum_{II=1}^I NO_{II,J} > 0$ for the first time.

The non-recurring costs are now adjusted to take into account the possibility of additional DDT&E costs (treated as non-recurring costs) that may be necessary for spacecraft redesign within the time period covered by the mission. This is accomplished in a gross manner by specifying the

expected useful life (years) of the spacecraft design, XUL_J , and the spacecraft development cost learning rate, $XDLR_J$. It is assumed that every XUL_J years a further investment is required. The specifics of this adjustment of non-recurring cost are as follows:

$$I = INR_J + XUL_J$$

$$IX_J = \text{Integer} \{ I + .9999 \}$$

The following computations are performed for all IX_J such that $IX_J \leq IMAX$.

If

$$NO_{IX_J, J} = \emptyset$$

Then

$$I = IX_J + 1$$

$$IX_J = I \text{ and } NO_{IX_J, J} \text{ is tested again!}$$

If

$$NO_{IX_J, J} > \emptyset$$

Then

$$XCFNR_{IX_J, J} = XNRT_J * (N)^{-1.0 + [\log_{10}(XDLR_J) - 1.699]/.301}$$

$$I = I + XUL_J$$

$$IX_J = \text{Integer} \{ I + .9999 \}$$

The recurring and non-recurring costs are maintained separately so that cost spreading can be accomplished. After cost spreading the annual costs are summed. Cost spreading is performed as follows. A table of XA_K and XB_K is maintained where SA_K and XB_K are coefficients which define the shape of the K^{th} cost spreading function. For each mission it is necessary to specify a value of KR_J and $XYRSR_J$ for the recurring cost spreading and KN_J and $KYRSN_J$ for the non-recurring cost spreading. KR_J and

KN_J define the value of K to be used for the J^{th} mission. The following rules are followed for the cost spreading.

- (a) Recurring costs are spread backward in time with the last year of recurring cost being the year during which the satellite launch is to take place.
- (b) Non-recurring costs are spread backward in time with the last year of non-recurring cost preceeding the year during which the launch is to take place.
- (c) The recurring and non-recurring cost spreading are assumed to be independent.

For the recurring costs:

$$IYRSR_J = \text{Integer} \left\{ XYRSR_J + .9999 \right\}$$

If $XCFR_{I,J} > \emptyset$. and $I - IYRSR_J < \emptyset$

Then

Print error message and halt!

If $XCFR_{I,J} \geq \emptyset$. and $I - IYRSR_J \geq \emptyset$

Then

for all IT such that $1 \leq IT \leq IYRSR_J$ and for all J such that $1 \leq J \leq JMAX$ (Note: before performing the following computations it is necessary to set all $XCF_I = \emptyset$.)

$$XCF_{I-IYRSR_J} + IT = XCF_{I-IYRSR_J} + IT + XFCR_{I,J} * XF_{IT,J}$$

$$XR_{IYRSR_J - IT + 1,J} = [IYRSR_J - IT + 1] / IYRSR_J$$

$$IZ = IYRSR_J - IT + 1$$

The general cost spreading function used for the recurring costs is given by

$$\begin{aligned} XFT_{IT,J} = & (10.0 * XBB_J - 4.0) * XR_{IZ,J}^5 + (10.0 * XAA_J \\ & - 20.0 * XBB_J + 5.0) * XR_{IZ,J}^4 + (10.0 * XBB_J \\ & - 20.0 * XAA_J) * XR_{IZ,J}^3 + 10.0 * XAA_J * XR_{IZ,J}^2 \end{aligned}$$

$$XF_{IT,J} = XFT_{IT,J} - XFT_{IT-1,J}$$

where $XF_{IT,J}$ is the fraction of the cost to be allocated to the IT^{th} year of the cost spreading interval, XAA_J and XBB_J are the values selected from the XA_K and XB_K table as per the input data (KR_J) and

$$XFT_{0,J} = 0.$$

$$XAA_J = XA_K = KR_J$$

$$XBB_J = XB_K = KR_J$$

Typical cost spreading data is summarized in Table B-1.

Table B-1 Typical Cost Spreading Data

K	Spread Distribution (cost of 50% time)	XA_K	XB_K
1	80%	.96	.04
2	60%	.32	.68
3	50%	.0	1.0
4	40%	.0	.68
5	20%	.0	.04
6	32%	1.01	-.30

For the non-recurring costs:

$$IYRSNR_J = \text{Integer} \left\{ XYRSN_J + .9999 \right\}$$

If $XCFNR_{I,J} > 0$. and $I - IYRSNR_J < 0$

Then

Print error message and halt!

If $XCFNR_{I,J} \geq 0$. and $I - IYRSNR_J \geq 0$

Then

for all IT such that $1 \leq IT \leq IYRSNR_J$ and for all J
such that $1 \leq J \leq JMAX$ (Note: do not zero out XCF_I
as was done previously.)

$$XCF_{I - IYRSNR_J + IT - 1} = XCF_{I - IYRSNR_J + IT - 1} + XCFNR_{I,J} * XF_{IT,J}$$

$$X_{IYRSNR_J - IT + 1, J} = [IYRSNR_J - IT + 1] / IYRSNR_J$$

$$IZ = IYRSNR_J - IT + 1$$

The cost spreading function, $XFT_{IT, J}$, is the same as described previously and

$$XAA_J = XA_K = KN_J$$

$$XBB_J = XB_K = KN_J$$

The last step prior to computing the present value is the determination of the transportation cost to be charged to each mission. The purpose of the transportation cost model is to establish an estimate of the transportation charges which might be incurred by each mission in terms of the particular spacecraft design. The major areas to be highlighted are the differences in transportation costs which might result from differences in the mass and configuration (length) of the alternative spacecraft design concepts. The transportation charge is the sum of the Space Shuttle charge (to low earth orbit) and the tug or other upper stage charge.

Transportation charges are assumed to be proportional to the ratio of payload mass to payload capability or payload length to payload length capability, whichever is larger. Therefore

$$XF1_J = XMT_J / X_{MPT_{LL}} = NUP_J$$

$$XF2_J = XPL_J / [X_{MLS} - X_{LT_{LL}} = NUP_J]$$

$$XF_J = \text{Max} \{ XF1_J, XF2_J \}$$

where the LL subscript identifies the upper stage which is to be used for the J^{th} mission. The transportation charge, XC_J , is given by

$$XC_J = \frac{XCS}{XFS} * \left[XMTT_{LL} = NUP_J * XF_J + XMT_J \right] * \left[1.0 + \frac{XDEL_J}{A} \right]$$

$$+ \frac{XCT_{LL} = NUP_J}{XFT_{LL} = NUP_J} * XF_J$$

It should be noted that if spares are allocated for a mission, then transportation charges are not to be charged for the first spare (it is placed in inventory).

$$\text{When } \frac{\left[XMTT_{LL} = NUP_J * XF_J + XMT_J \right]}{XMPS} \geq \frac{\left[XPL_J + XLT_{LL} = NUP_J * XF_J \right]}{XMLS}$$

Then

$$XDEL_J = 0$$

A = any finite value

Otherwise

$$XDEL_J = \frac{\left[XPL_J + XLT_{LL} = NUP_J * XF_J \right]}{XMLS} - \frac{\left[XMT_J + XMTT_{LL} = NUP_J * XF_J \right]}{XMPS}$$

$$A = \left[XMTT_{LL} = NUP_J * XF_J + XMT_J \right] / XMPS$$

The total cash flow (cost) is therefore given by

$$XCF_I = XCF_I + \sum_{J=1}^{JMAX} NO_{I,J} * XC_J$$

The final step is the computation of the present value of the cash flow stream at several different discount rates denoted by the IR subscript.

Therefore, for $1 \leq IR \leq IRMAX$

$$XPV_{IR} = \sum_{I=1}^{IMAX} \frac{XCF_I}{\left(1.0 + \frac{XDR_{IR}}{200.} \right) \left(1.0 + \frac{XDR_{IR}}{100.} \right)^{I-1}}$$

Part II: Standardized Spacecraft (LMAX > 0)

The standardized spacecraft analysis utilizes the same CER's as described previously, with one exception, to evaluate the spacecraft subsystem recurring and non-recurring costs. The one exception is the power subsystem where nominal unit recurring and non-recurring costs and cost differentials are used to establish the actual unit costs at the computed maximum power capability.

To use the CER's, the subsystem masses which are related to the spacecraft total mass or power must be calculated. Three of these subsystem masses are input as nominal mass parameters ($XM_{1,L}$, $XM_{6,L}$, $XM_{7,L}$) with derivative parameters ($XDM_{1,L}$, $XDM_{6,L}$, $XDM_{7,L}$) which specify how much the subsystem masses change from the nominal value per change in the total spacecraft mass from the nominal total mass (XMT_L). The nominal total mass is the sum of all the nominal subsystem masses.

The power subsystem mass is input as a nominal mass parameter ($XM_{2,L}$) with a derivative parameter ($XDPW_L$) which specifies the estimated subsystem mass change (from the nominal value) per watt change in the maximum power capability (from the nominal value).

The masses of the subsystems corresponding to $XM_{1,L}$, $XM_{6,L}$, $XM_{7,L}$, and $XM_{2,L}$ are then expressed as:

$$\text{Structure: } M_{1,L} = XM_{1,L} + \Delta M_{1,L}$$

$$\text{Attitude Control: } M_{6,L} = XM_{6,L} + \Delta M_{6,L}$$

$$\text{Dispenser: } M_{7,L} = XM_{7,L} + \Delta M_{7,L}$$

$$\text{Power Subsystem: } M_{2,L} = XM_{2,L} + \Delta M_{2,L}$$

The following relationships hold:

$$\Delta M_{1,L} = XDM_{1,L} * (\Delta XMT_L)$$

$$\Delta M_{6,L} = XDM_{6,L} * (\Delta XMT_L)$$

$$\Delta M_{7,L} = XDM_{7,L} * (\Delta XMT_L)$$

$$\Delta M_{2,L} = XDPW_L * (\Delta P_L)$$

where

$$\Delta P_L = \frac{1}{2} \frac{\text{designed maximum power capability} - \text{power subsystem maximum power capability}}{\text{power subsystem maximum power capability}}$$

Since these subsystems alone have variable masses, the change in the total mass from the nominal value is given by

$$\Delta XMT_L = \Delta M_{1,L} + \Delta M_{6,L} + \Delta M_{7,L} + \Delta M_{2,L}$$

$\Delta M_{1,L}$, $\Delta M_{6,L}$, $\Delta M_{7,L}$ are then solved for in terms of $XDM_{1,L}$, $XDM_{6,L}$, $XDM_{7,L}$, and $\Delta M_{2,L}$ by

$$\begin{pmatrix} \Delta M_{1,L} \\ \Delta M_{6,L} \\ \Delta M_{7,L} \end{pmatrix} = \begin{pmatrix} K_{1,L} & 1 & 1 \\ 1 & K_{2,L} & 1 \\ 1 & 1 & K_{7,L} \end{pmatrix}^{-1} \begin{pmatrix} -\Delta M_{2,L} \\ -\Delta M_{2,L} \\ -\Delta M_{2,L} \end{pmatrix}$$

where

$$K_{1,L} = \frac{XDM_{1,L} - 1}{XDM_{1,L}} \quad K_{6,L} = \frac{XDM_{6,L} - 1}{XDM_{6,L}} \quad K_{7,L} = \frac{XDM_{7,L} - 1}{XDM_{7,L}}$$

After the subsystem masses are established, the same CER's are used as in the non-standardized case with the exception of the power subsystem.

The unit recurring cost of the spacecraft varies over missions due to power subsystem modularity. The power subsystem first unit recurring cost, $PRCST_{L,J}$ is given by

$$PRCST_{L,J} = USEFRACTION_{L,J} * (XCSTPR_L + XDCSTR_L * \Delta P_L)$$

where

$USEFRACTION_{L,J}$ = Number of power modules used by mission J divided by the number available in spacecraft L

$XCSTPR_L$ = nominal cost of power subsystem at nominal max power capability

$XDCSTR_L$ = change in power subsystem cost from nominal cost per watt
change in maximum power capability from nominal maximum power
capability

The first unit recurring cost for the standardized spacecraft is
given by

$$XCST_L = PRCST_{L,J} + 1.13 * 2.06 * 1.3 * \sum \text{recurring costs of subsystems except power subsystem}$$

the non-recurring costs of the standardized spacecraft subsystems (not including the power subsystem) are computed from the same CER's as for the non-standardized case.

The first unit non-recurring cost, which is subject to learning effects when redevelopment is necessary, is given by:

$$XNRS_L = 1.13 * 2.06 * 1.4 * \sum \text{non-recurring costs of subsystems except power subsystem}$$

The 1.13 factor accounts for a 13% fee and the 2.06 factor accounts for Burden & G & A at 106%. The factors 1.4 and 1.3 account for program level costs which are related to program management, reliability, planning, quality assurance, systems analysis, project control and other program level costs. Note that aerospace ground equipment (AGE) costs are not included.

The power subsystem non-recurring cost is evaluated by using a nominal non-recurring cost parameter and a cost derivative. The power subsystem non-recurring cost is given by

$$PNR\bar{S}_L = XCSTPN_L + XDCSTN_L * \Delta P_L$$

where

$XCSTPN_L$ = nominal non-recurring cost at power subsystem nominal
maximum power capability

$XDCSTN_L$ = change in power subsystem non-recurring cost from nominal
cost per change in maximum power capability from nominal
capability

The next step is to establish the number of standardized spacecraft
of each type as a function of time. To accomplish this

Initialize $NSSC_{I,L} = \emptyset$ for all I and L .

The L subscript identifies the type of standardized spacecraft. The following
are calculated for all J such that $1 \leq J \leq JMAX$ and all I such that $1 \leq$
I $\leq$ IMAX.

Spares are calculated in a manner similar to the "spares" algorithm
described for the non-standardized spacecraft. The only exception to this is
the determination of the value of the spare placed in inventory. The time of
placing a spare into inventory is the first year that $NSS_{I,L} > \emptyset$ for each L.
As with the non-standardized spacecraft the spares algorithm is

$$ADDS_{L=LMISS_J} = \frac{PSP_J}{100} * \sum_{II=1}^I NO_{II,J} - \sum_{II=1}^I NSP_{II,J}$$

If $ADDS_{L=LMISS_J} > \emptyset$

Then $NSP_{I,J} = NSP_{I,J} + \text{Integer} \left\{ \begin{matrix} ADDS_{L=LMISS_J} + .9999 \end{matrix} \right\}$

$$\underline{\text{If}} \quad \text{ADDS}_{L=\text{LMISS}_J} \leq 0$$

$$\underline{\text{Then}} \quad \text{NSP}_{I,J} = \text{NSP}_{I,J}$$

and $\text{NO}_{I,J} = \text{NO}_{I,J} + \text{NSP}_{I,J}$

$$\text{NSSC}_{I,L=\text{LMISS}_J} = \text{NO}_{I,J} + \text{NSSC}_{I,L=\text{LMISS}_J}$$

,

$$\text{NSS}_{I,L} = \sum_{IA=1}^I \text{NSSC}_{IA,L}$$

Learning effects are applied to the first unit recurring spacecraft cost based upon the total number of spacecraft of type L which are utilized. Therefore the learning curve exponent is given by

$$\text{EXPOL}_L = [\log_{10}(\text{XCALRS})_L - 1.699]/.301$$

and the annual recurring cost associated with the standardized spacecraft is given by, for $1 \leq L \leq \text{LMAX}$,

$$\text{XCFRSL}_{I,L} = \text{XCST}_L * \sum_{NN=\text{NSS}_{I-1,L}}^{\text{NSS}_{I,L}} (\text{NN})^{\text{EXPOL}_L - 1.0} * 10^{-3}$$

The annual cash flow associated with the power subsystem non-recurring costs prior to the adjustment by the cost spreading functions is given by

$$\text{XCFNRS}_{I=\text{INRS}_L,L} = \text{XNRS}_L$$

where $INRS_L$ is the year during which $NSS_{I,L} > 0$ for the first time.

The annual cash flow associated with the power subsystem non-recurring costs prior to the adjustment by the cost spreading functions is given by

$$PCFNRS_{I=INRS_L,L} = PNRS_L$$

The spacecraft and power subsystem non-recurring costs are now adjusted, in the same manner as the non-standardized spacecraft, to take into account the possibility of additional DDT & E costs (treated as non-recurring costs) that may be necessary for spacecraft or power subsystem redesign within the time period covered by the mission model. This is accomplished in a gross manner by specifying the expected useful life (years) of the spacecraft and power subsystem design, $XULSC_L$ and $XULP_{KK}$ and the spacecraft and power subsystem development cost learning rates, $XULSCL_L$ and $XULPUL_{KK}$, respectively. The subscript KK refers to the type of power subsystem used in spacecraft L. It is assumed that every $XULSC_L$ and $XULP_{KK}$ years further investment is required. The specifics of this adjustment of non-recurring costs follow.

For the spacecraft non-recurring costs

$$I = \text{INR}_L + \text{XULSC}_L$$

$$\text{IX} = \text{Integer} \{ I + .9999 \}$$

The following computations are performed if $\text{IX} \leq \text{IMAX}$

If

$$\text{NSS}_{\text{IX},L} = \emptyset$$

Then

$$I = \text{IX} + 1$$

$$\text{IX} = I \quad \text{and} \quad \text{NSS}_{\text{IX},J} \text{ is tested again!}$$

If

$$\text{NSS}_{\text{IX},L} > \emptyset$$

Then

$$\text{XCFNRS}_{\text{IX},L} = \text{XNRS}_L * (N)^{-1.0 + [\log_{10} (\text{XULSCL}_L) - 1.699]/.301}$$

$$I = I + \text{XULSC}_L$$

$$\text{IX} = \text{Integer} \{ I + .9999 \}$$

For the power subsystem non-recurring costs,

where

KK = KGROUP(L) indicating the type of power subsystem used in spacecraft L

$$I = \text{INR}_L + \text{XULP}_{\text{KK}}$$

$$\text{IX} = \text{Integer} \{I + .9999\}$$

the following computations are performed if $\text{IX} \leq \text{IMAX}$

If

$$\text{NSS}_{\text{IX},L} = \emptyset$$

Then

$$I = \text{IX} + 1$$

$$\text{IX} = I \quad \text{and } \text{NSS}_{\text{IX},J} \text{ is tested again!}$$

If

$$\text{NSS}_{\text{IX},L} > \emptyset$$

Then

$$\text{PCFNRS}_{\text{IX},L} = \text{PNRS}_L * (N)^{-1.0} + [\log_{10}(\text{XULPL}_{\text{KK}}) - 1.699]/.301$$

$$I = I + \text{XULP}_{\text{KK}}$$

$$\text{IX} = \text{Integer} \{I + .9999\}$$

The recurring and non-recurring costs are maintained separately so that cost spreading can be accomplished. After cost spreading the annual costs are summed. Cost spreading is also similar to that presented for the non-standardized spacecraft - the same basic rules are followed.

For the recurring costs:

$$IYRSRS_L = \text{Integer} \left\{ XYRSRS_L + .9999 \right\}$$

If

$$XCFL_{I,L} > 0. \text{ and } I - IYRSRS_L < 0$$

Then

Print error message and halt!

$$\text{If } XCFL_{I,L} \geq 0. \text{ and } I - IYRSRS_L \geq 0$$

Then for all IT such that $1 \leq IT \leq IYRSRS_L$ and for all L such that $1 \leq L \leq LMAX$ (Note: before performing the following computations it is necessary to set all $XCFL_I = 0$.)

$$XCFL_I - IYRSRS_L + IT = XCFL_I - IYRSRS_L + IT + XCFL_{I,L} * XFF_{IT,L}$$

$$XRR_{IYRSRS_L - IT + 1, L} = [IYRSRS_L - IT + 1] / IYRSRS_L$$

$$IZ = IYRSRS_L - IT + 1$$

The general cost spreading function used for the recurring costs is of the same form as discussed previously and is given by

$$\begin{aligned} \text{XFFT}_{IT,L} = & (10.0 * \text{XBBB}_L - 4.0) * \text{XRR}_{IZ,L}^5 + (10.0 * \text{XAAA}_L \\ & - 20.0 * \text{XBBB}_L + 5.0) * \text{XRR}_{IZ,L}^4 + (10.0 * \text{XBBB}_L \\ & - 20.0 * \text{XAAA}_L) * \text{XRR}_{IZ,L}^3 + 10.0 * \text{XAAA}_L * \text{XRR}_{IZ,L}^2 \end{aligned}$$

$$\text{XFF}_{IT,L} = \text{XFFT}_{IT,L} - \text{XFFT}_{IT-1,L}$$

and $\text{XFFT}_{0,L} = 0.$

$$\text{XAAA}_L = \text{XA}_K = \text{KRS}_L$$

$$\text{XBBB}_L = \text{XB}_K = \text{KRS}_L$$

For the spacecraft non-recurring costs

$$\text{IYRSNS}_L = \text{Integer} \left\{ \text{XYRSNS}_L + .9999 \right\}$$

If

$$\text{XCFNRS}_{I,L} > 0 \text{ and } I - \text{IYRSNS}_L < 0$$

Then

Print error message and halt!

If

$$\text{XCFNRS}_{I,L} \geq 0 \text{ and } I - \text{IYRSNS}_L \geq 0$$

Then for all IT such that $1 \leq IT \leq \text{IYRSNS}_L$ and for all L

(Note: do not zero out XCFL_I as was done previously.)

$$\text{XCFL}_{I - \text{IYRSNS}_L + IT - 1} = \text{XCFL}_{I - \text{IYRSNS}_L + IT - 1} + \text{XCFNRS}_{I,L} * \text{XFF}_{IT,L}$$

$$XRR_{IYRSNS_L - IT + 1, KK} = [IYRSNS_L - IT + 1] / IYRSNS_L$$

The cost spreading function, $XFFT_{IT,L}$, is the same as described previously and

$$XAAA_L = XA_{K=KNS_L}$$

$$XBBB_{KK} = XB_{K=KNS_L}$$

For the power subsystem non-recurring costs where $KK = KGROUP(L)$

$$IYRSNS_L = \text{Integer} \left\{ XYRSPN_{KK} + .9999 \right\}$$

If

$$PCFNRS_{I,L} > 0. \text{ and } I - IYRSNS_L < 0$$

Then

Print error message and halt!

If

$$PCFNRS_{I,L} \geq 0 \text{ and } I - IYRSNS_L \geq 0$$

Then for all IT such that $1 \leq IT \leq IYRSNS_L$ and for all L

$$XCFL_{I - IYRSNS_L + IT - 1} = XCFL_{I - IYRSNS_L + IT - 1} + PCFNRS_{I,L} * XFF_{IT, KK}$$

$$XRR_{IT,L} = IT / XYRSPN_{KK}$$

$$XRR_{IYRSNS_L - IT + 1, L} = [IYRSNS_L - IT + 1] / IYRSNS_L$$

The cost spreading function*, $XFFT_{IT, KK}$, is the same as described previously and

$$XAAA_{KK} = XA_{K=KNSP(KK)}$$

$$XBBB_{KK} = XB_{K=KNSP(KK)}$$

The last step prior to computing the present value is the determination of the transportation cost to be charged to each mission. The purpose of the transportation cost model has been discussed previously. The equations are repeated here to indicate the minor variations in the names of the variables which are utilized. Therefore

$$XF1_J = XPMS_J / XMPT_{LL=NUPS_J}$$

$$XF2_J = XPLS_J / [XMLS - XLT_{LL=NUPS_J}]$$

$$XF_J = \text{Max} \left\{ XF1_J, XF2_J \right\}$$

where

$$XPMS_J = \sum \text{ subsystem masses of } SPACECRAFT_{L=LMISS_J} + XMPL_J$$

$$XPLS_J = XSCL_{L=LMISS_J} + XPLL_J$$

The LL subscript identifies the upper stage which is to be used for the J^{th} mission. The transportation charge, XC_J , is given by

* Note that the previously used subscript, L, has been replaced by KK. This is allowable since $KK \leq LMAX$.

$$XC_J = \frac{XCS}{XFS} * \left[XMTT_{LL} = NUPS_J * XF_J + XPMS_J \right] * \left[1. + \frac{XDEL_J}{A} \right]$$

$$+ \frac{XCT_{LL} = NUPS_J}{XFT_{LL} = NUPS_J} * XF_J$$

It should be noted that if spares are allocated for a spacecraft family, then transportation charges are not to be charged for the first spare per family (placed in inventory).

When
$$\frac{\left[XMTT_{LL} = NUPS_J * XF_J + XPMS_J \right]}{XMPS} \geq \frac{\left[XPLS_J + XLT_{LL} = NUPS_J * XF_J \right]}{XMLS}$$

Then

$$XDEL_J = \emptyset.$$

A = any finite value

Otherwise

$$XDEL_J = \frac{\left[XPLS_J + XLT_{LL} = NUPS_J * XF_J \right]}{XMLS} - \frac{\left[XPMS_J + XMTT_{LL} = NUPS_J * XF_J \right]}{XMPS}$$

$$A = \left[XMTT_{LL} = NUP_J * XF_J + XPMS_J \right] / XMPS$$

The total cash flow (cost) is therefore given by

$$XCFL_I = XCFL_I + \sum_{J=1}^{JMAX} NO_{I,J} * XC_J$$

The final step is the computation of the present value of the cash flow stream at several different discount rates denoted by the IR subscript. Therefore, for $1 \leq IR \leq IRMAX$

$$XPVS_{IR} = \sum_{I=1}^{IMAX} \frac{XCFL_I}{\left(1.0 + \frac{XDR_{IR}}{200.}\right) \left(1.0 + \frac{XDR_{IR}}{100.}\right)^{I-1}}$$

An annotated set of computer outputs follows.

APPENDIX C

TYPICAL MODEL OUTPUTS

Section I - general information

cost spreading function, %

	1	2	3	4	5	6	7	8	9	10
1. YA =	0.96,	0.32,	0.0 ,	0.0 ,	0.0 ,	1.01,	0.0 ,	0.0 ,	0.0 ,	0.0 ,
2. XP =	0.04,	0.68,	1.00,	0.68,	0.04,	-0.30,	1.00,	1.00,	1.00,	1.00,
3. JMAX =	10									
4. IMAX =	18									
5. IFMAX =	5									

discount rate, %

	1	2	3	4	5
6. XDR =	5.0,	8.0,	10.0,	12.0,	15.0,
7. IMAX =	2				
8. NMAX =	4				

SECTION II - MISSION MODFI

YEAR, Y

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
9.	NC1	0,	0,	0,	0,	0,	0,	1,	1,	1,	1,	1,	1,	1,	1,	1,	1,	1,	1,
	NC2	0,	0,	0,	0,	0,	0,	1,	0,	0,	0,	0,	0,	1,	0,	0,	0,	0,	0,
	NC3	0,	0,	0,	0,	0,	0,	0,	1,	1,	1,	1,	1,	1,	1,	1,	1,	1,	0,
	NC4	0,	0,	0,	0,	0,	0,	1,	1,	1,	2,	2,	1,	1,	1,	1,	1,	1,	1,
	NC5	0,	0,	0,	0,	0,	0,	0,	0,	1,	0,	0,	0,	1,	0,	0,	0,	0,	1,
	NC6	0,	0,	0,	0,	0,	0,	1,	0,	1,	0,	1,	0,	1,	0,	1,	1,	1,	1,
	NC7	0,	0,	0,	0,	0,	0,	0,	1,	0,	1,	0,	1,	0,	1,	0,	1,	0,	0,
	NC8	0,	0,	0,	0,	0,	0,	2,	2,	1,	1,	1,	1,	1,	1,	1,	1,	1,	1,
	NC9	0,	0,	0,	0,	0,	0,	1,	1,	0,	0,	1,	1,	0,	0,	1,	1,	0,	0,
	NC10	0,	0,	0,	0,	0,	0,	0,	2,	0,	1,	0,	2,	0,	1,	0,	1,	1,	0,

MISSION, J

		1	2	3	4	5	6	7	8	9	10
10.	XFOJ =	77.0,	100.0,	291.0,	273.0,	167.0,	1090.0,	1364.0,	1090.0,	818.0,	545.0,
	** WARNING ** XFOJ OUTSIDE RANGE OF CFF										
11.	YFOJF =	30.0,	25.0,	10.0,	10.0,	20.0,	10.0,	10.0,	10.0,	10.0,	10.0,
12.	IAC =	1,	2,	2,	3,	3,	3,	3,	2,	2,	3,
13.	YPSF =	20.0,	20.0,	20.0,	20.0,	20.0,	20.0,	20.0,	20.0,	20.0,	20.0,
14.	YMDL =	45.0,	57.0,	99.0,	113.4,	111.1,	412.8,	412.8,	408.2,	226.8,	142.9,
15.	IMISS =	0,	0,	0,	0,	0,	0,	0,	0,	0,	0,
16.	YELL =	1.0,	1.0,	1.0,	1.0,	1.0,	1.0,	1.0,	1.0,	1.0,	1.0,

SECTION III - transportation system data

launch system data

17. XCS = 0.340

18. XFS = 0.700

19. XMP5 = 29478.0

20. XPLS = 17.800

upper stage data

type, N

1 2 3 4

21. XMTT = 0.0, 27097.0, 27097.0, 27097.0,

22. XCT = 0.0, 1350.0, 1350.0, 1350.0,

23. XIT = 0.0, 10.7, 10.7, 10.7,

24. XMDT = 1.0, 4160.0, 10000.0, 5000.0,

25. XET = 1.0, 0.7, 0.7, 0.7,

MISSION, J

1 2 3 4 5 6 7 8 9 10

26. NIPS = 1 , 4 , 2 , 2 , 3 , 2 , 2 , 2 , 2 ,

Section IV - Mission Specialized Spacecraft Data

Mission, J

	1	2	3	4	5	6	7	8	9	10
27. XM1 =	122.5,	98.0,	72.0,	26.2,	39.8,	249.0,	168.0,	181.0,	131.0,	544.0
** WARNING ** - XM1 OUTSIDE RANGE OF CFP										
28. XM2 =	40.2,	90.7,	90.7,	113.4,	76.0,	317.5,	430.9,	430.2,	130.5,	22.0
** WARNING ** - XM2 OUTSIDE CFP RANGE										
29. XM3 =	45.4,	32.0,	0.0,	45.4,	40.3,	82.0,	43.0,	82.0,	54.0,	21.0,
30. XM4 =	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	0.0
31. XM6 =	272.2,	45.0,	535.0,	95.3,	79.4,	35.0,	94.0,	95.0,	135.0,	228.0
** WARNING ** - XM6 OUTSIDE RANGE OF CFP										
32. XM7 =	18.1,	18.0,	40.0,	15.9,	13.6,	54.0,	45.0,	41.0,	40.0,	65.0,
** WARNING ** - XM7 OUTSIDE RANGE OF CFP										
33. XIT =	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	0.0
34. NAKM =	0	0	0	0	0	0	0	0	0	0
35. IACM =	1	2	1	2	2	2	3	2	3	3
36. XSCLA =	3.5,	1.4,	15.0,	3.5,	2.3,	13.9,	17.4,	13.9,	10.4,	7.0
37. XMT =	544.3,	341.0,	838.0,	463.5,	467.2,	1143.0,	1179.0,	858.0,	838.0,	1362.0
38. KM =	4	4	4	4	4	4	4	4	4	4
39. XYFCM =	4.0,	3.0,	4.0,	4.0,	3.0,	4.0,	4.0,	4.0,	4.0,	4.0
40. CALD =	35.0,	90.0,	90.0,	90.0,	90.0,	90.0,	90.0,	90.0,	90.0,	90.0
41. K1 =	4	3	4	4	3	4	4	4	4	4
42. VYPSM =	2.5,	2.0,	2.5,	2.5,	2.0,	2.5,	2.5,	2.5,	2.5,	2.5
43. YFL =	2.2,	2.8,	5.2,	4.0,	5.0,	3.6,	3.6,	3.6,	5.2,	4.6
44. YBT =	4.0,	4.0,	4.0,	4.0,	4.0,	4.0,	4.0,	4.0,	4.0,	4.0
45. YS =	75.0,	75.0,	75.0,	75.0,	75.0,	75.0,	75.0,	75.0,	75.0,	75.0

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SECTION V - Standardized spacecraft data

Standardized spacecraft type, L

	1	2	3
46. XM1S =	133.0 ,	255.0 ,	189.0 ,
47. XM2S =	145.0 ,	320.0 ,	415.5 ,
48. XM3S =	51.5 ,	51.5 ,	51.5 ,
49. XM4S =	0.0 ,	0.0 ,	0.0 ,
50. XM6S =	78.9 ,	89.8 ,	129.3 ,
** WARNING ** - XM6S OUTSIDE CFR RANGE			
51. XM7S =	0.0 ,	0.0 ,	0.0 ,
52. XM8S =	168.7 ,	254.0 ,	342.0 ,
53. XI5S =	0.0 ,	0.0 ,	0.0 ,
54. NAKMS =	0 ,	0 ,	0 ,
55. IFMYP =	0 ,	0 ,	1 ,
56. TACS =	3 ,	3 ,	3 ,
57. XMAXP =	450.0 ,	2200.0 ,	1800.0 ,
58. XDISP =	450.0 ,	0.0 ,	0.0 ,
59. MAXPS =	3 ,	4 ,	6 ,
60. XFWSS =	0.0 ,	0.0 ,	0.0 ,
61. XDM1S =	0.30 ,	0.36 ,	0.31 ,
62. XDM6S =	0.16 ,	0.10 ,	0.19 ,
63. XDM7S =	0.0 ,	0.0 ,	0.0 ,
64. XDPW =	0.32 ,	0.15 ,	0.23 ,
65. XCSTPD =	1449.0 ,	4727.0 ,	1006.0 ,
66. XDCSTP =	3.22 ,	1.73 ,	1.06 ,
67. KFS =	6 ,	6 ,	6 ,

SECTION V - Standardized Spacecraft data

Standardized spacecraft type, L

	1	2	3
68. XYBSRS =	3.0 ,	3.0 ,	3.0 ,
69. YSCL =	1.0 ,	1.2 ,	1.3 ,
70. XCALRS =	95.0 ,	95.0 ,	95.0 ,
71. KMS =	3 ,	3 ,	3 ,
72. XYRSNS =	4.0 ,	4.0 ,	3.0 ,
73. XULSC =	5.0 ,	5.0 ,	5.0 ,
74. XULSCL =	50.0 ,	50.0 ,	50.0 ,
75. KGROUP =	1 ,	2 ,	3 ,

STANDARDIZED POWER SUBSYSTEM GROUP, KK

	1	2	3
76. XCSTPM =	22166.0,	43916.0,	1341.0,
77. XECSTPM =	20.0,	8.4,	0.2,
78. KNSP =	3 ,	3 ,	3 ,
79. XYRSPN =	2.5,	3.0,	2.0,
80. XULP =	5.0,	5.0,	5.0,
81. XULPI =	70.0,	70.0,	80.0,

Standardized power subsystem/spacecraft

unit cost information

- power subsystem first unit development cost (\$ millions) -
- power subsystem first unit recurring cost (\$ millions) -
- number of power supply modules available -
- power supply type -

			Spacecraft
1	2	3	
22.40,	36.91,	2.89,	
1.33,	3.24,	1.41,	
3 ,	4 ,	6 ,	
1 ,	2 ,	3 ,	

Standardized spacecraft/mission power information

- spacecraft max power (watts) -
- power allocated for mission (watts) -
- mission power requirement (watts) -
- ratio of power modules used to number available -

C- ∞	spacecraft type	mission									
		1	2	3	4	5	6	7	8	9	10
1		0.0,	411.9,	411.9,	411.9,	411.9,	0.0,	0.0,	0.0,	0.0,	0.0
		0.0,	137.3,	411.9,	274.6,	274.6,	0.0,	0.0,	0.0,	0.0,	0.0
		0.0,	100.0,	391.0,	273.0,	167.0,	0.0,	0.0,	0.0,	0.0,	0.0
		0/0,	1/3,	3/3,	2/3,	2/3,	0/0,	0/0,	0/0,	0/0,	0/0
2		0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	1364.0,	0.0,	0.0,	1364.0
		0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	1364.0,	0.0,	0.0,	682.0
		0.0,	0.0,	0.0,	0.0,	0.0,	0.0,	1364.0,	0.0,	0.0,	545.0
		0/0,	0/0,	0/0,	0/0,	0/0,	0/0,	4/4,	0/0,	0/0,	2/4
3		0.0,	0.0,	0.0,	0.0,	0.0,	1199.0,	0.0,	1199.0,	1199.0,	0.0
		0.0,	0.0,	0.0,	0.0,	0.0,	1199.0,	0.0,	1199.0,	999.2,	0.0
		0.0,	0.0,	0.0,	0.0,	0.0,	1199.0,	0.0,	1199.0,	899.8,	0.0
		0/0,	0/0,	0/0,	0/0,	0/0,	6/6,	0/0,	6/6,	5/6,	0/0

Standardized spacecraft unit costs
- first unit recurring cost/mission -
(\$ millions)

		mission									
spacecraft type		1	2	3	4	5	6	7	8	9	10
C-9	1	0.0	7.69	9.57	8.13	8.13	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	10.61	0.0	0.0	8.99
	3	0.0	0.0	0.0	0.0	0.0	9.49	0.0	9.49	9.26	0.0

- first unit development cost -
(\$ millions)

spacecraft		
1	2	3
37.18	42.42	46.68

Standardized spacecraft yearly costs

(prior to cost spreading)

- recurring cost -
- development cost -
- power subsystem development cost -

(\$ millions)

	spacecraft type	year									
		1	2	3	4	5	6	7	8	9	10
G-I-G	1	0.0	0.0	0.0	0.0	0.0	0.0	22.39	14.79	21.22	20.60
		0.0	0.0	0.0	0.0	0.0	0.0	37.18	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	22.40	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.91	0.0	17.09
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.42	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.91	0.0	0.0
	3	0.0	0.0	0.0	0.0	0.0	0.0	43.75	24.12	15.81	15.56
		0.0	0.0	0.0	0.0	0.0	0.0	46.68	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	2.89	0.0	0.0	0.0
	1	11	12	13	14	15	16	17	18		
		26.69	13.30	32.22	12.92	19.06	12.72	12.65	12.25		
		0.0	18.44	0.0	0.0	0.0	0.0	12.24	0.0		
		0.0	15.58	0.0	0.0	0.0	0.0	12.60	0.0		
	2	0.0	24.18	0.0	23.55	0.0	15.87	7.22	0.0		
		0.0	0.0	0.0	21.04	0.0	0.0	0.0	0.0		
		0.0	0.0	0.0	25.67	0.0	0.0	0.0	0.0		
	3	22.73	14.93	14.97	7.44	29.30	35.95	14.38	14.30		
		0.0	23.15	0.0	0.0	0.0	0.0	15.36	0.0		
		0.0	2.30	0.0	0.0	0.0	0.0	2.01	0.0		

Non-standardized spacecraft yearly costs
(prior to cost spreading)

- recurring cost -
- development cost -

(\$ millions)

(years)

mission	1	2	3	4	5	6	7	8	9	10
1	0.0	0.0	0.0	0.0	0.0	0.0	16.14	7.59	7.41	7.28
	0.0	0.0	0.0	0.0	0.0	0.0	62.45	0.0	0.0	0.0

Non-standardized spacecraft yearly costs
(prior to cost spreading)

- recurring cost -
- development cost -

(\$ millions)

(years)

mission	11	12	13	14	15	16	17	18
1	7.17 46.55	14.00 0.0	6.94 0.0	6.88 0.0	6.83 39.20	6.78 0.0	13.43 0.0	6.66 0.0

Standardized plus non-standardized spacecraft

total annual costs

(cost spreading included)

(\$ millions)

year	1	2	3	4	5	6	7	8	9	10
annual cost	0.0	0.0	8.56	50.50	140.95	142.78	115.65	118.28	115.79	138.91
year	11	12	13	14	15	16	17	18		
annual cost	126.88	132.29	114.68	111.11	115.07	103.69	53.59	29.04		

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Standardized plus non-standardized spacecraft

present value of costs

(\$ millions)

discount rate (%)	0.0	5.0	8.0	10.0	12.0
present value	1617.8	1015.3	787.9	671.8	576.9

APPENDIX D

PROGRAM LISTING

PROGRAM TO CHECK DATA

```

COMMON/BLOCK/XA(10),XB(10),JMAX,IMAX,IPMAX,XDR(5),LMAX,NMAX,
.XPOW(50),XPOWP(50),IAC(50),XPSP(50),XMP(50),IMISS(50),XPLL(50),
.XCS,XFS,XMPS,XMLS,XMTT(20),XCT(20),XLT(20),XMP(20),XFT(20),
.NUPS(50),XM1(50),XM2(50),XM3(50),XM4(50),XM6(50),XM7(50),XIT(50),
.NAKM(50),XSOLA(50),XMT(50),KN(50),XYPSN(50),CALR(50),KR(50),
.XYRST(50),XPL(50),XPI(50),XDLR(50),XM1S(20),XM2S(20),XM3S(20),
.XM4S(20),XM6S(20),XM7S(20),XM8S(20),XITS(20),NAKMS(20),IPTYP(20),
.IACS(20),XMAXP(20),MAXPS(20),XPOWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCCTPR(20),XCCTSR(20),KPS(20),XVRSPPS(20),
.XSCI(20),XCALRS(20),KGTOTD(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),XYFSPN(20),XYFMS(20),XULP(20),XULSC(20),XULPL(20),
.XUISCL(20),IUP,CDTL,TACN(50),XRES(20)
COMMON/MMODI/NO(30,50)
COMMON/PIOW/NPIOW(30),TR(10)
DIMENSION NO1(30),NO2(30),NO3(30),NO4(30),NO5(30),NO6(30),NO7(30),
.NO8(30),NO9(30),NO10(30),NO11(30),NO12(30),NO13(30),NO14(30),
.NO15(30),NO16(30),NO17(30),NO18(30),NO19(30),NO20(30),NO21(30),
.NO22(30),NO23(30),NO24(30),NO25(30),NO26(30),NO27(30),NO28(30),
.NO29(30),NO30(30),NO31(30),NO32(30),NO33(30),NO34(30),NO35(30),
.NO36(30),NO37(30),NO38(30),NO39(30),NO40(30),NO41(30),NO42(30),
.NO43(30),NO44(30),NO45(30),NO46(30),NO47(30),NO48(30),NO49(30),
.NO50(30)
DIMENSION SUMMAS(50),NPLGT(20),IIMX(20)
EQUIVALENCE (NO1(1),NO(1,1)),(NO2(1),NO(1,2)),(NO3(1),NO(1,3)),
.(NO4(1),NO(1,4)),(NO5(1),NO(1,5)),(NO6(1),NO(1,6)),
.(NO7(1),NO(1,7)),(NO8(1),NO(1,8)),(NO9(1),NO(1,9)),
.(NO10(1),NO(1,10)),(NO11(1),NO(1,11)),(NO12(1),NO(1,12)),
.(NO13(1),NO(1,13)),(NO14(1),NO(1,14)),(NO15(1),NO(1,15)),
.(NO16(1),NO(1,16)),(NO17(1),NO(1,17)),(NO18(1),NO(1,18)),
.(NO19(1),NO(1,19)),(NO20(1),NO(1,20)),(NO21(1),NO(1,21)),
.(NO22(1),NO(1,22)),(NO23(1),NO(1,23)),(NO24(1),NO(1,24)),
.(NO25(1),NO(1,25)),(NO26(1),NO(1,26)),(NO27(1),NO(1,27)),
.(NO28(1),NO(1,28)),(NO29(1),NO(1,29)),(NO30(1),NO(1,30)),
.(NO31(1),NO(1,31)),(NO32(1),NO(1,32)),(NO33(1),NO(1,33)),
.(NO34(1),NO(1,34)),(NO35(1),NO(1,35)),(NO36(1),NO(1,36)),
.(NO37(1),NO(1,37)),(NO38(1),NO(1,38)),(NO39(1),NO(1,39)),
.(NO40(1),NO(1,40)),(NO41(1),NO(1,41)),(NO42(1),NO(1,42)),
.(NO43(1),NO(1,43)),(NO44(1),NO(1,44)),(NO45(1),NO(1,45)),
.(NO46(1),NO(1,46)),(NO47(1),NO(1,47)),(NO48(1),NO(1,48)),
.(NO49(1),NO(1,49)),(NO50(1),NO(1,50))
NAMELIST/DATA/XA,XB,IMAX,IMAX,IPMAX,XDR,LMAX,NMAX,NO1,NO2,NO3,NO4,
.NO5,
.NO6,NO7,NO8,NO9,NO10,NO11,NO12,NO13,NO14,NO15,NO16,NO17,NO18,
.NO19,NO20,NO21,NO22,NO23,NO24,NO25,NO26,NO27,NO28,NO29,NO30,
.NO31,NO32,NO33,NO34,NO35,NO36,NO37,NO38,NO39,NO40,NO41,NO42,
.NO43,NO44,NO45,NO46,NO47,NO48,NO49,NO50,XPOW,XPOWP,IAC,XPSP,
.XMPI,IMISS,XPLL,XCS,XFS,XMPS,XMLS,XMTT,XCT,XLT,XMP,XFT,NUPS,
.IUP,CDTL,MMTSC
NAMELIST/CONST/XM1,XM2,XM3,XM4,XM6,XM7,XIT,NAKM,XSOLA,XMT,KN,
.XYRST,CALR,KP,XYRST,XPI,XUI,XDLR,TACN,IMISS,NUPS,XPOW,XPOWP,XPSP,
.XMPI,XPLL,TACN
NAMELIST/STP/XM1S,XM2S,XM3S,XM4S,XM6S,XM7S,XM8S,XITS,NAKMS,

```

```

      .TPTVP, IACS, XMAXP, MAXPS, XPMSS, XDM1S, XDM6S, XDM7S, XDPW, XCSTPR,
      .XDCSTP, KSS, XYBSPS, XSCI, XCALRS, KGROUP, XCSTPN, XDCSTN, KNSP, KNS,
      .XYBSPV, XYBSPS, XHIP, XULSC, XULPL, XULSCL, XDFSP
      NAMELIST/PATH/NFLOW, TR
      READ (5, PATH)
      READ (5, DATA)
      READ (5, NONSTD)
      ISTOP=0
      WRITE (6, 1001)
1001  FORMAT('1', ///)
      WRITE (6, 1000) XA
1000  FORMAT('1', T15, 'Section I - general information',
      %//, T34, 'cost spreading function, K',
      %//, T26, '1' 2 3 4 5 6 7 8 9 10',
      %//, T16, '1. XA = ', 10(F5.2, ', '))
20  WRITE (6, 1010) XR
1010  FORMAT('0', T16, '2. XB = ', 10(F5.2, ', '))
40  WRITE (6, 1020) JMAX
1020  FORMAT('0', T16, '3. JMAX = ', I2)
      IF (JMAX .GE. 1 .AND. JMAX .LE. 50) GO TO 50
      WRITE (6, 5010)
5010  FORMAT('1', T16, '** ERROR ** - JMAX out of range')
      JMAX=50
      ISTOP=1
50  WRITE (6, 1030) IMAX
1030  FORMAT('0', T16, '4. IMAX = ', I2)
      IF (IMAX .GE. 1 .AND. IMAX .LE. 30) GO TO 60
      WRITE (6, 5020)
5020  FORMAT('1', T16, '** ERROR ** - IMAX out of range')
      IMAX=30
      ISTOP=1
60  WRITE (6, 1040) IRMAX
1040  FORMAT('0', T16, '5. IRMAX = ', I2)
      IF (IRMAX .GE. 1 .AND. IRMAX .LE. 5) GO TO 70
      WRITE (6, 5030)
5030  FORMAT('1', T16, '** ERROR ** - IRMAX out of range')
      IRMAX=5
      ISTOP=1
70  WRITE (6, 1050) (I, I=1, IRMAX)
1050  FORMAT('0', T25, 'discount rate, IR',
      %//, T26, 5(T1, 5X))
      WRITE (6, 1055) (XDR(I), I=1, IRMAX)
1055  FORMAT('0', T16, '6. XDR = ', 5(F4.1, ', '))
      DO 80 I=1, IRMAX
      IF (XDR(I) .GE. 0.0 .AND. XDR(I) .LE. 100.) GO TO 80
      WRITE (6, 5040)
5040  FORMAT('1', T16, '** ERROR ** - improper discount rate')
      ISTOP=1
      GO TO 90
90  CONTINUE
90  WRITE (6, 1060) LMAX
1060  FORMAT('0', T16, '7. LMAX = ', I2)
      IF (LMAX .GE. 0 .AND. LMAX .LE. 10) GO TO 100
      WRITE (6, 5050)
5050  FORMAT('1', T16, '** ERROR ** - LMAX out of range')
      LMAX=10
      ISTOP=1

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100  WRITE(6,1061) NMAX
1061  FORMAT('0',T16,'8. NMAX = ',I2)
      IF (NMAX .GT. 0 .AND. NMAX .LT. 17) GO TO 101
      WRITE(6,5051)
5051  FORMAT(' ',T16,'** ERROR ** - NMAX OUT OF RANGE')
      ISTOP=1
      NMAX=16
101   I1=1
      I2=18
110   CONTINUE
      IF (I2 .GT. IMAX) I2=JMAX
      WRITE(6,1080) (I,I=1,IMAX)
1080  FORMAT('1',T16,'SECTION II - MISSION MODEL',
      .//,T37,'YEAR,I',//,(' ',T24,18(I2,2X)))
      WRITE(6,1085) (NO(I,1),I=I1,I2)
1085  FORMAT('0',T16,'9. NO1',(' ',T24,18(I2,' ', ')))
120   DO 130 I=I1,I2
      IF (NO(I,1) .GE. 0 .AND. NO(I,1) .LE. 20) GO TO 125
      WRITE(6,5060)
5060  FORMAT(' ',T16,'** ERROR ** - NO out of range')
      ISTOP=1
      GO TO 140
125   CONTINUE
130   CONTINUE
140   IF (JMAX .LT. 2) GO TO 190
      DO 180 J=2,JMAX
      IF (J .GE. 10) GO TO 150
      WRITE(6,1090) J, (NO(I,J),I=I1,I2)
1090  FORMAT(' ',T19,'NO',I1,(' ',T24,18(I2,' ', ')))
      GO TO 160
150   WRITE(6,1100) J, (NO(I,J),I=I1,I2)
1100  FORMAT(' ',T19,'NO',I2,(' ',T24,18(I2,' ', ')))
160   DO 170 I=I1,I2
      IF (NO(I,J) .GE. 0 .AND. NO(I,J) .LE. 20) GO TO 165
      WRITE(6,5060)
      ISTOP=1
      GO TO 180
165   CONTINUE
170   CONTINUE
180   CONTINUE
190   IF (I2 .EQ. IMAX) GO TO 7003
      I1=I1+18
      I2=I2+18
      IF (I2 .GT. IMAX) I2=IMAX
      GO TO 110
7003  CONTINUE
      WRITE(6,1114)
      WRITE(6,7004) (J,I=1,JMAX)
7004  FORMAT(' ',T53,'MISSION',J,//,(T31,10(I2,6X)))
      WRITE(6,7000) (XPOW(J),J=1,JMAX)
7000  FORMAT('0',T15,'10. XPOW =', (T28,10(F6.1,' ', ')))
      DO 365 J=1,JMAX
      IF (XPOW(J) .EQ. 0.) GO TO 365
      IF (XPOW(J) .GE. 25. .AND. XPOW(J) .LE. 1320.) GO TO 365
      WRITE(6,7002)
7002  FORMAT(' ',T16,'** WARNING ** XPOW OUTSIDE RANGE OF CUR')
      GO TO 366

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365  CONTINUE
366  CONTINUE
      WRITE(6,7010) (XPOWP(J),J=1,JMAX)
7010  FORMAT('0',T15,'11. XPOWP  =',(T28,10(F6.1,' ', ')))
      DO 7020 J=1,JMAX
      IF(XPOWP(J) .GE. 0. .AND. XPOWP(J) .LE. 1000.) GO TO 7020
      WRITE(6,7030)
7030  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC VALUES FOR XPOWP')
      GO TO 7021
7020  CONTINUE
7021  CONTINUE
      WRITE(6,7040) (IAC(J),J=1,JMAX)
7040  FORMAT('0',T15,'12. IAC    =',(T28,10(I4,2X,' ', ')))
      DO 7050 J=1,JMAX
      IF(IAC(J) .EQ. 1 .OR. IAC(J) .EQ. 2 .OR. IAC(J) .EQ. 3) GO TO 7050
      WRITE(6,7060)
7060  FORMAT(' ',T16,'** WARNING ** - INVALID IAC SPECIFICATION')
      GO TO 7070
7050  CONTINUE
7070  CONTINUE
      WRITE(6,7080) (XPSP(J),J=1,JMAX)
7080  FORMAT('0',T15,'13. XPSP   =',(T28,10(F6.1,' ', ')))
      DO 7090 J=1,JMAX
      IF(XPSP(J) .GE. 0. .AND. XPSP(J) .LE. 1000) GO TO 7090
      WRITE(6,7100)
7100  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XPSP SPECIFICATION')
      GO TO 7110
7090  CONTINUE
7110  CONTINUE
      WRITE(6,7120) (XMPL(J),J=1,JMAX)
7120  FORMAT('0',T15,'14. XMPL   =',(T28,10(F6.1,' ', ')))
      DO 7130 J=1,JMAX
      IF(XMPL(J) .GE. 0. .AND. XMPL(J) .LE. XMPS) GO TO 7130
      WRITE(6,7140)
7140  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC VALUE OF XMPL')
      GO TO 7150
7130  CONTINUE
7150  CONTINUE
      WRITE(6,7160) (LMISS(J),J=1,JMAX)
7160  FORMAT('0',T15,'15. LMISS  =',(T28,10(2X,I2,2X,' ', ')))
      DO 7170 J=1,JMAX
      IF(LMISS(J) .GE. 0 .AND. LMISS(J) .LE. LMAX) GO TO 7170
      WRITE(6,7180)
7180  FORMAT(' ',T16,'** WARNING ** - LMISS OUT OF RANGE')
7170  CONTINUE
7190  CONTINUE
      WRITE(6,7200) (XPLL(J),J=1,JMAX)
7200  FORMAT('0',T15,'16. XPLL   =',(T28,10(F6.1,' ', ')))
      DO 7210 J=1,JMAX
      IF(XPLL(J) .GE. 0. .AND. XPLL(J) .LE. XMLS) GO TO 7210
      WRITE(6,7220)
7220  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC VALUE OF XPLL')
      GO TO 7230
7210  CONTINUE
7230  CONTINUE
200  WRITE(6,1101)
1101  FORMAT('1',T16,'SECTION III - transportation system data',

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      '///,T15,'Launch system data')
      WRITE(6,1102) XCS
1102  FORMAT('0',T15,'17. XCS    = ',F7.3)
      IF (XCS .GT. 0.) GO TO 201
      ISTOP=1
      WRITE(6,5061)
5061  FORMAT(' ',T16,'** ERROR ** - XCS cannot be negative')
201  WRITE(6,1103) XFS
1103  FORMAT('0',T15,'18. XFS    = ',F7.3)
      IF (XFS .GT. 0. .AND. XFS .LE. 1.) GO TO 202
      ISTOP=1
      WRITE(6,5062)
5062  FORMAT(' ',T16,'** ERROR ** - XFS out of range')
202  WRITE(6,1104) XMPS
1104  FORMAT('0',T15,'19. XMPS   = ',F7.1)
      IF (XMPS .GT. 0.) GO TO 203
      ISTOP=1
      WRITE(6,5063)
5063  FORMAT(' ',T16,'** ERROR ** - XMPS cannot be negative')
203  XMPS=XMPS+2.2046
      WRITE(6,1105) XMLS
1105  FORMAT('0',T15,'20. XMLS   = ',F7.3)
      IF (XMLS .GT. 0.) GO TO 204
      ISTOP=1
      WRITE(6,5064)
5064  FORMAT(' ',T16,'** ERROR ** - XMLS cannot be negative')
204  WRITE(6,1106)
1106  FORMAT('0',//,T15,'upper stage data',//,T45,'+type, N')
      I1=1
      I2=10
      IF (I2 .GT. NMAX) I2=NMAX
199  WRITE(6,1107) (T,I=I1,I2)
1107  FORMAT('0',T30,10(T2,'X'))
      WRITE(6,1108) (XM(T),T=I1,I2)
1108  FORMAT('0',T15,'21. XM(T)  = ',10(F7.1,' ',))
      DO 206 I=I1,I2
      IF (XM(T) .GT. 0.) GO TO 206
      ISTOP=1
      WRITE(6,5065)
5065  FORMAT(' ',T15,'** ERROR ** - XM(T) cannot be negative')
      GO TO 207
206  CONTINUE
207  WRITE(6,1109) (XCM(T),I=I1,I2)
1109  FORMAT('0',T15,'22. XCM    = ',10(F6.1,' ',))
      DO 208 I=I1,I2
      IF (XCM(T) .GT. 0.) GO TO 208
      ISTOP=1
      WRITE(6,5066)
5066  FORMAT(' ',T15,'** ERROR ** - XCM cannot be negative')
      GO TO 209
208  CONTINUE
209  WRITE(6,1111) (XLT(T),I=I1,I2)
1111  FORMAT('0',T15,'23. XLT    = ',10(F6.1,' ',))
      DO 211 T=I1,I2
      IF (XLT(T) .LT. XMLS .AND. XLT(T) .GT. 0.) GO TO 211
      ISTOP=1
      WRITE(6,5067)

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5067  FORMAT(' ',T15,'** ERROR ** - XLT is out of range')
      GO TO 212
211   CONTINUE
212   WRITE(6,1112) (XMP(I),I=I1,I2)
1112  FORMAT('0',T15,'24. XMP = ',10(F7.1,' ','))
      DO 213 I=I1,I2
      IF (XMP(I) .GT. 0.) GO TO 213
      ISTOP=1
      WRITE(6,5068)
5068  FORMAT(' ',T15,'** ERROR ** - XMP must be positive')
      GO TO 214
213   CONTINUE
214   WRITE(6,1113) (XPT(I),I=I1,I2)
1113  FORMAT('0',T15,'25. XPT = ',10(F6.1,' ','))
      DO 215 I=I1,I2
      IF (XPT(I) .GT. 0. .AND. XPT(I) .LE. 1.) GO TO 215
      ISTOP=1
      WRITE(6,5069)
5069  FORMAT(' ',T15,'** ERROR ** - XPT is out of range')
      GO TO 216
215   CONTINUE
216   IF (I2 .EQ. NMAX) GO TO 217
      I2=NMAX
      I1=11
      WRITE(6,1114)
1114  FORMAT('0',/)
      GO TO 192
217   CONTINUE
      WRITE(6,1114)
      WRITE(6,7004) (I,J=1,JMAX)
      WRITE(6,8705) (NUPS(J),J=1,JMAX)
8705  FORMAT('0',T15,'26. NUPS = ',(T29,10(I4,2X,' ',)))
      DO 8710 J=1,JMAX
      IF (NUPS(J) .GT. 0. .AND. NUPS(J) .LE. NMAX) GO TO 8710
      WRITE(6,8715)
8715  FORMAT(' ',T15,'** WARNING ** - INVALID NUPS SPECIFICATION')
      GO TO 8720
8710  CONTINUE
8720  CONTINUE
      IF (XMTT(1) .EQ. 0. .AND. XCT(1) .EQ. 0. .AND. XLT(1) .EQ. 0.
& .AND. XMP(1) .EQ. 1. .AND. XPT(1) .EQ. 1.) GO TO 218
      WRITE(6,5071)
5071  FORMAT('0',T15,'** WARNING ** - default upper stage is incorrect')
      XMTT(1)=0.
      XCT(1)=0.
      XLT(1)=0.
      XMP(1)=1.
      XPT(1)=1.
218   CONTINUE
      WRITE(6,1110) (J,J=1,JMAX)
1110  FORMAT('1',T15,'Section IV - mission specialized spacecraft data',
& '//,T58,'mission, J',
& '//,(T31,10(I2,6X)))
      WRITE(6,1115) (XM1(J),J=1,JMAX)
1115  FORMAT('0',T15,'27. XM1 = ',(T28,10(F6.1,' ',)))
      ITEST=0
      DO 210 J=1,JMAX

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SUMMAS(J)=0
IF (XM1(J) .EQ. 0.) GO TO 210
SUMMAS(J)=SUMMAS(J)+XM1(J)
IF (XM1(J) .GE. 6.8 .AND. XM1(J) .LE. 331.1) GO TO 210
8115 IF (ITEST .EQ. 0) WRITE(6,5070)
5070 FORMAT(' ',T16,'** WARNING ** - XM1 OUTSIDE RANGE OF CER')
ITEST=1
210 CONTINUE
7240 CONTINUE
WRITE(6,7250) (XM2(J),J=1,JMAX)
7250 FORMAT('0',T15,'28. XM2      =', (T28,10(F6.1,' ', ')))
ITEST=0
DO 7260 J=1,JMAX
IF (XM2(J) .EQ. 0.) GO TO 7250
SUMMAS(J)=SUMMAS(J)+XM2(J)
IF (XM2(J) .GE. 5.49 .AND. XM2(J) .LE. 200.5) GO TO 7260
IF (ITEST .EQ. 0) WRITE(6,7270)
7270 FORMAT(' ',T16,'** WARNING ** - XM2 OUTSIDE CER RANGE')
ITEST=1
7260 CONTINUE
7280 CONTINUE
WRITE(6,1120) (XM3(J),J=1,JMAX)
1120 FORMAT('0',T15,'29. XM3      =', (T28,10(F6.1,' ', ')))
DO 230 J=1,JMAX
IF (XM3(J) .EQ. 0.) GO TO 230
SUMMAS(J)=SUMMAS(J)+XM3(J)
IF (XM3(J) .GE. 3.63 .AND. XM3(J) .LE. 71.67) GO TO 230
IF (ITEST .EQ. 0) WRITE(6,5080)
5080 FORMAT(' ',T16,'** WARNING ** - XM3 OUTSIDE OF CER BOUNDS')
ITEST=1
230 CONTINUE
WRITE(6,1130) (XM4(J),J=1,JMAX)
1130 FORMAT('0',T15,'30. XM4      =', (T28,10(F6.1,' ', ')))
ITEST=0
DO 250 J=1,JMAX
IF (XM4(J) .EQ. 0.) GO TO 250
SUMMAS(J)=SUMMAS(J)+XM4(J)
IF (XM4(J) .GE. 5.9 .AND. XM4(J) .LE. 104.33) GO TO 250
IF (ITEST .EQ. 0) WRITE(6,5090)
5090 FORMAT(' ',T16,'** WARNING ** - XM4 OUTSIDE RANGE OF CER')
ITEST=1
250 CONTINUE
WRITE(6,1140) (XM6(J),J=1,JMAX)
1140 FORMAT('0',T15,'31. XM6      =', (T28,10(F6.1,' ', ')))
ITEST=0
DO 290 J=1,JMAX
IF (XM6(J) .EQ. 0.) GO TO 290
SUMMAS(J)=SUMMAS(J)+XM6(J)
IF (XM6(J) .GE. 1.36 .AND. XM6(J) .LE. 31.65) GO TO 290
IF (ITEST .EQ. 0) WRITE(6,5110)
5110 FORMAT(' ',T16,'** WARNING ** - XM6 OUTSIDE RANGE OF CER')
ITEST=1
290 CONTINUE
WRITE(6,1150) (XM7(J),J=1,JMAX)
1150 FORMAT('0',T15,'32. XM7      =', (T28,10(F6.1,' ', ')))
ITEST=0
DO 310 J=1,JMAX
IF (XM7(J) .EQ. 0.) GO TO 310

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SUMMAS(J)=SUMMAS(J)+XM7(J)
IF(XM7(J) .GE. 7.71 .AND. XM7(J) .LE. 14.1) GO TO 310
IF(ITEST .EQ. 0) WRITE(6,5120)
5120 FORMAT(' ',T16,'** WARNING ** - XM7 OUTSIDE RANGE OF CER')
ITEST=1
310 CONTINUE
WRITE(6,1160) (XIT(J),J=1,JMAX)
1160 FORMAT('0',T15,'33. XIT      =',(T28,10(F6.1,' ', ')))
DO 330 J=1,JMAX
IF(XIT(J) .EQ. 0.) GO TO 330
IF(XIT(J) .GE. 231.31 .AND. XIT(J) .LE. 947.47) GO TO 330
WRITE(6,5130)
5130 FORMAT(' ',T16,'** WARNING ** - XIT OUTSIDE RANGE OF CER')
GO TO 340
330 CONTINUE
340 CONTINUE
WRITE(6,1170) (NAKM(J),J=1,JMAX)
1170 FORMAT('0',T15,'34. NAKM      =',(T28,10(2X,T2,2X,' ', ')))
DO 7290 J=1,JMAX
IF(NAKM(J) .GE. 0 .AND. NAKM(J) .LE. 10) GO TO 7290
WRITE(6,5140)
5140 FORMAT(' ',T16,'** WARNING ** - NAKM OUT OF RANGE')
GO TO 360
7290 CONTINUE
360 CONTINUE
WRITE(6,7300) (IACN(J),J=1,JMAX)
7300 FORMAT('0',T15,'35. IACN      =',(T28,10(2X,I2,2X,' ', ')))
DO 7310 J=1,JMAX
IF(IACN(J) .EQ. 1 .OR. IACN(J) .EQ. 3) GO TO 7310
WRITE(6,7320)
7320 FORMAT(' ',T16,'** WARNING ** - ILLEGAL SPECIFICATION OF IAC')
GO TO 7330
7310 CONTINUE
7330 CONTINUE
WRITE(6,1180) (XSOLA(J),J=1,JMAX)
1180 FORMAT('0',T15,'36. XSOLA     =',(T28,10(F6.1,' ', ')))
DO 360 J=1,JMAX
IF(XSOLA(J) .EQ. 0.) GO TO 360
IF(XSOLA(J) .GE. 1.208 .AND. XSOLA(J) .LE. 40.69) GO TO 360
WRITE(6,5150)
5150 FORMAT(' ',T16,'** WARNING ** - XSOLA OUTSIDE RANGE OF CER')
GO TO 370
360 CONTINUE
370 CONTINUE
WRITE(6,1190) (XMT(J),J=1,JMAX)
1190 FORMAT('0',T15,'37. XMT       =',(T28,10(F6.1,' ', ')))
ITEST=0
DO 380 I=1,JMAX
IF(XMT(I) .GT. SUMMAS(I)) GO TO 380
XMT(I)=1.2*SUMMAS(I)
IF(ITEST .EQ. 0) WRITE(6,5160)
5160 FORMAT(' ',T16,'** WARNING ** - XMT IS INCONSISTANT, FIXUP TAKEN')
380 CONTINUE
WRITE(6,1200) (KN(J),J=1,JMAX)
1200 FORMAT('0',T15,'38. KN        =',(T28,10(2X,I2,2X,' ', ')))
DO 390 I=1,JMAX
IF(KN(I) .GE. 1 .AND. KN(I) .LE. 10) GO TO 390

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WRITE(6,517))
5170 FORMAT(' ',T16,'** WARNING ** - KN OUT OF RANGE')
GO TO 400
390 CONTINUE
400 CONTINUE
WRITE(6,1210) (XYPSN(J),J=1,JMAX)
1210 FORMAT('0',T15,'40. XYPSN   =',(T28,10(F6.1,' ', ')))
DO 410 J=1,JMAX
IF(XYPSN(J) .GT. 0. .AND. XYPSN(J) .LE. 10.) GO TO 410
WRITE(6,5180)
5180 FORMAT(' ',T16,'** WARNING ** - XYPSN OUT OF RANGE')
GO TO 420
410 CONTINUE
420 CONTINUE
WRITE(6,1220) (CALR(J),J=1,JMAX)
1220 FORMAT('0',T15,'40. CALR    =',(T28,10(F6.1,' ', ')))
DO 430 J=1,JMAX
IF(CALR(J) .GT. 0. .AND. CALR(J) .LE. 100.) GO TO 430
WRITE(6,5190)
5190 FORMAT(' ',T16,'** WARNING ** - CALR OUT OF RANGE')
GO TO 440
430 CONTINUE
440 CONTINUE
WRITE(6,1230) (KR(J),J=1,JMAX)
1230 FORMAT('0',T15,'41. KR      =',(T28,10(2X,I2,2X,' ', ')))
DO 450 J=1,JMAX
IF(KR(J) .GT. 1 .AND. KR(J) .LE. 10) GO TO 450
WRITE(6,5200)
5200 FORMAT(' ',T16,'** WARNING ** - KR OUT OF RANGE')
GO TO 460
450 CONTINUE
460 CONTINUE
WRITE(6,1240) (XYPSR(J),J=1,JMAX)
1240 FORMAT('0',T15,'42. XYPSR   =',(T28,10(F6.1,' ', ')))
DO 470 J=1,JMAX
IF(XYPSR(J) .GT. 0. .AND. XYPSR(J) .LE. 10.) GO TO 470
WRITE(6,5121)
5121 FORMAT(' ',T16,'** WARNING ** - XYPSR OUT OF RANGE')
GO TO 480
470 CONTINUE
480 CONTINUE
WRITE(6,1241) (XPL(J),J=1,JMAX)
1241 FORMAT('0',T15,'43. XPL     =',(T28,10(F6.1,' ', ')))
DO 481 J=1,JMAX
IF(XPL(J) .GT. 0. .AND. XPL(J) .LE. XMPD) GO TO 481
WRITE(6,5211)
5211 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XPL SPECIFICATION')
GO TO 482
481 CONTINUE
482 CONTINUE
WRITE(6,6010) (XUL(J),J=1,JMAX)
6010 FORMAT('0',T15,'44. XUL     =',(T28,10(F6.1,' ', ')))
DO 6130 J=1,JMAX
IF(XUL(J) .GT. 0. .AND. XUL(J) .LE. 30.) GO TO 6130
WRITE(6,6020)
6020 FORMAT(' ',T16,'** WARNING ** - XUL OUT OF RANGE')
GO TO 6000
6130 CONTINUE
6000 CONTINUE
WRITE(6,6030) (XDLP(J),J=1,JMAX)
6030 FORMAT('0',T15,'45. XDLP    =',(T28,10(F6.1,' ', ')))
DO 6040 J=1,JMAX

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IF(XPLR(J) .GT. 0. .AND. YDLR(J) .LE. 100.) GO TO 6040
WRITE(5,6050)
6050 FORMAT(' ',T16,'** WARNING ** - XDIR IS OUT OF RANGE')
GO TO 6200
6040 CONTINUE
6200 CONTINUE
IF(MFLOW(1) .GT. 0 .AND. MFLOW(1) .LT. 4) GO TO 8505
IF(LMAX .LE. 0) GO TO 8900
8505 CONTINUE
IF(MFLOW(1) .EQ. 1) GO TO 8300
READ(5,STD)
WRITE(6,1250)
1250 FORMAT('1',T16,'SECTION V - Standardized spacecraft data')
WRITE(6,1270) (L,L=1,LMAX)
1270 FORMAT('0',T35,'Standardized spacecraft type, I',
//,(T30,10(I2,7X)))
WRITE(6,7400) (XM1S(L),L=1,LMAX)
7400 DO XM1T('0',T15,'46. XM1S =',(T28,10(F6.1,' ', ')))
GO 7410 L=1,LMAX
IF(XM1S(I) .EQ. 0) GO TO 7410
IF(XM1S(I) .GT. 6.8 .AND. XM1S(L) .LE. 331.1) GO TO 7410
WRITE(6,7415)
7415 FORMAT(' ',T16,'** WARNING ** - XM1S OUTSIDE RANGE OF CER')
GO TO 7420
7410 CONTINUE
7420 CONTINUE
WRITE(6,7425) (XM2S(L),L=1,LMAX)
7425 FORMAT('0',T15,'47. XM2S =',(T28,10(F6.1,' ', ')))
DO 7430 I=1,LMAX
IF(XM2S(I) .GT. 0. .AND. XM2S(L) .LT. XMPS) GO TO 7430
WRITE(6,7435)
7435 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XM2S SPECIFICATION')
GO TO 7440
7430 CONTINUE
7440 CONTINUE
WRITE(6,7445) (XM3S(L),L=1,LMAX)
7445 FORMAT('0',T15,'48. XM3S =',(T28,10(F6.1,' ', ')))
DO 7450 L=1,LMAX
IF(XM3S(I) .EQ. 0.) GO TO 7450
IF (XM3S(I) .GT. 3.63 .AND. XM3S(L) .LE. 71.67) GO TO 7450
WRITE(6,7455)
7455 FORMAT(' ',T15,'** WARNING ** - XM3S OUTSIDE RANGE OF CER')
GO TO 7460
7450 CONTINUE
7460 CONTINUE
WRITE(6,7465) (XM4S(L),L=1,LMAX)
7465 FORMAT('0',T15,'49. XM4S =',(T28,10(F6.1,' ', ')))
DO 7470 I=1,LMAX
IF(XM4S(I) .EQ. 0.) GO TO 7470
IF(XM4S(I) .GT. 5.9 .AND. XM4S(L) .LE. 104.33) GO TO 7470
WRITE(6,7475)
7475 FORMAT(' ',T16,'** WARNING ** - XM4S OUTSIDE RANGE OF CER')
GO TO 7480
7470 CONTINUE
7480 CONTINUE
WRITE(6,7485) (XM6S(L),L=1,LMAX)
7485 FORMAT('0',T15,'50. XM6S =',(T28,10(F6.1,' ', ')))

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DO 7400 I=1,LMAX
IF(XM6S(I) .EQ. 0.) GO TO 7490
IF(XM6S(L) .GE. 1.36 .AND. XM6S(L) .LE. 81.65) GO TO 7490
WRITE(6,7495)
7495 FORMAT(' ',T16,'** WARNING ** - XM6S OUTSIDE CER RANGE')
GO TO 7500
7490 CONTINUE
7500 CONTINUE
WRITE(6,7505) (XM7S(L),L=1,LMAX)
7505 FORMAT('0',T15,'51. XM7S  =',(T28,10(F6.1,' ', ')))
DO 7510 I=1,LMAX
IF(XM7S(L) .EQ. 0.) GO TO 7510
IF(XM7S(L) .GE. 7.71 .AND. XM7S(L) .LE. 14.1) GO TO 7510
WRITE(6,7515)
7515 FORMAT(' ',T16,'** WARNING ** - XM7S OUTSIDE RANGE OF CER')
GO TO 7520
7510 CONTINUE
7520 CONTINUE
WRITE(6,7525) (XM8S(L),L=1,LMAX)
7525 FORMAT('0',T15,'52. XM8S  =',(T28,10(F6.1,' ', ')))
DO 7530 I=1,LMAX
IF(XM8S(I) .GE. 0. .AND. XM8S(L) .LE. XMPS) GO TO 7530
WRITE(6,7535)
7535 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XM8S SPECIFICATION')
GO TO 7540
7530 CONTINUE
7540 CONTINUE
WRITE(6,7545) (XITS(L),L=1,LMAX)
7545 FORMAT('0',T15,'53. XITS  =',(T28,10(F6.1,' ', ')))
DO 7550 I=1,20
IF(XITS(L) .EQ. 0.) GO TO 7550
IF(XITS(L) .GE. 231.31 .AND. XITS(L) .LE. 347.47) GO TO 7550
WRITE(6,7555)
7555 FORMAT(' ',T16,'** WARNING ** - XITS OUTSIDE RANGE OF CER')
GO TO 7560
7550 CONTINUE
7560 CONTINUE
WRITE(6,7565) (NAKMS(I),L=1,LMAX)
7565 FORMAT('0',T15,'54. NAKMS  =',(T28,10(2X,T2,2X,' ', ')))
DO 7570 L=1,LMAX
IF(NAKMS(L) .GE. 0 .AND. NAKMS(L) .LE. 10) GO TO 7570
WRITE(6,7575)
7575 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC NAKMS SPECIFICATION')
GO TO 7580
7570 CONTINUE
7580 CONTINUE
WRITE(6,7585) (IPTYP(L),L=1,LMAX)
7585 FORMAT('0',T15,'55. IPTYP  =',(T28,10(2X,I2,2X,' ', ')))
DO 7590 I=1,LMAX
IF(IPTYP(L) .EQ. 0 .OR. IPTYP(L) .EQ. 1) GO TO 7590
WRITE(6,7595)
7595 FORMAT(' ',T16,'** WARNING ** - ILLEGAL IPTYP SPECIFICATION')
GO TO 7600
7590 CONTINUE
7600 CONTINUE
WRITE(6,7605) (IACS(L),L=1,LMAX)
7605 FORMAT('0',T15,'56. IACS  =',(T28,10(2X,I2,2X,' ', ')))
DO 7610 I=1,LMAX

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      IF(IACS(L) .EQ. 1 .OR. IACS(L) .EQ. 3) GO TO 7610
      WRITE(6,7615)
7615  FORMAT(' ',T15,'** WARNING ** - ILLEGAL IACS SPECIFICATION')
      GO TO 7620
7610  CONTINUE
7620  CONTINUE
      WRITE(6,7625) (XMAXP(L),L=1,LMAX)
7625  FORMAT('0',T15,'57. XMAXP  =',(T28,10(F6.1,' ', ')))
      DO 7630 L=1,LMAX
      IF(XMAXP(L) .GE. 50. .AND. XMAXP(L) .LE. 100000.) GO TO 7630
      WRITE(6,7635)
7635  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XMAXP SPECIFICATION')
      GO TO 7640
7630  CONTINUE
7640  CONTINUE
      WRITE(6,8150) (XDESP(L),L=1,LMAX)
8150  FORMAT('0',T15,'58. XDESP  =',(T28,10(F6.1,' ', ')))
      DO 8155 I=1,LMAX
      IF(XDESP(I) .EQ. 0.) GO TO 8155
      IF(XDESP(I) .GE. 50. .AND. XDESP(L) .LE. 100000.) GO TO 8155
      WRITE(6,8160)
8160  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XDESP SPECIFICATION')
      GO TO 8165
8155  CONTINUE
8165  CONTINUE
      WRITE(6,7645) (MAXPS(L),L=1,LMAX)
7645  FORMAT('0',T15,'59. MAXPS  =',(T28,10(T4,2X,' ', ')))
      DO 7650 I=1,LMAX
      IF(MAXPS(L) .GE. 0 .AND. MAXPS(L) .LE. 20) GO TO 7650
      WRITE(6,7655)
7655  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC MAXPS SPECIFICATION')
      GO TO 7660
7650  CONTINUE
7660  CONTINUE
      WRITE(6,7665) (XPWSS(L),L=1,LMAX)
7665  FORMAT('0',T15,'60. XPWSS  =',(T28,10(F6.1,' ', ')))
      DO 7670 I=1,LMAX
      IF(XPWSS(L) .GE. 0. .AND. XPWSS(L) .LE. 100.) GO TO 7670
      WRITE(6,7675)
7675  FORMAT(' ',T16,'** WARNING ** - INVALID XPWSS SPECIFICATION')
      GO TO 7680
7670  CONTINUE
7680  CONTINUE
      WRITE(6,7685) (XDM1S(L),L=1,LMAX)
7685  FORMAT('0',T15,'61. XDM1S  =',(T28,10(F7.2,' ', ')))
      DO 7690 I=1,LMAX
      IF(XDM1S(L) .GE. 0. .AND. XDM1S(L) .LE. 1.) GO TO 7690
      WRITE(6,7695)
7695  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XDM1S SPECIFICATION')
      GO TO 7700
7690  CONTINUE
7700  CONTINUE
      WRITE(6,7705) (XDM6S(L),L=1,LMAX)
7705  FORMAT('0',T15,'62. XDM6S  =',(T28,10(F7.2,' ', ')))
      DO 7710 I=1,LMAX
      IF(XDM6S(L) .GE. 0. .AND. XDM6S(L) .LT. 1.) GO TO 7710
      WRITE(6,7715)

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7715  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XDM6S SPECIFICATION')
      GO TO 7720
7710  CONTINUE
7720  CONTINUE
      WRITE(6,7725) (XDM7S(L),L=1,LMAX)
7725  FORMAT('0',T15,'63. XDM7S  =',(T28,10(F7.2,' , ')))
      DO 7730 L=1,LMAX
      IF(XDM7S(L) .GE. 0. .AND. XDM7S(L) .LT. 1.) GO TO 7730
      WRITE(6,7735)
7735  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XDM7S SPECIFICATION')
      GO TO 7740
7730  CONTINUE
7740  CONTINUE
      WRITE(6,7745) (XDPW(L),L=1,LMAX)
7745  FORMAT('0',T15,'64. XDPW   =',(T28,10(F7.2,' , ')))
      DO 7750 L=1,LMAX
      IF(XDESP(L) .EQ. 0) GO TO 7750
      IF(XDPW(L) .GE. 0. .AND. XDPW(L) .LE. XM2S(L)/XDESP(L)) GO TO 7750
      WRITE(6,7755)
7755  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XDPW SPECIFICATION')
      GO TO 7760
7750  CONTINUE
7760  CONTINUE
      WRITE(6,7765) (XCSTPR(L),L=1,LMAX)
7765  FORMAT('0',T15,'65. XCSTPR =',(T28,10(F6.1,' , ')))
      DO 7770 L=1,LMAX
      IF(XCSTPR(L) .GT. 0.) GO TO 7770
      WRITE(6,7775)
7775  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XCSTPR SPECIFICATION')
      GO TO 7780
7770  CONTINUE
7780  CONTINUE
      WRITE(6,7785) (XDCSTR(L),L=1,LMAX)
7785  FORMAT('0',T15,'66. XDCSTR =',(T28,10(F7.2,' , ')))
      DO 7790 L=1,LMAX
      IF(XDESP(L) .EQ. 0.) GO TO 7790
      IF(XDCSTR(L) .GE. 0. .AND. XDCSTR(L) .LE. XCSTPR(L)/XDESP(L))
      GO TO 7790
      WRITE(6,7795)
7795  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XDCSTR SPECIFICATION')
      GO TO 7800
7790  CONTINUE
7800  CONTINUE
      WRITE(6,7805) (KRS(L),L=1,LMAX)
7805  FORMAT('0',T15,'67. KRS    =',(T28,10(I4,2X,' , ')))
      DO 7810 L=1,LMAX
      IF(KRS(L) .GE. 1 .AND. KRS(L) .LE. 10) GO TO 7810
      WRITE(6,7815)
7815  FORMAT(' ',T16,'** WARNING ** - INVALID KRS SPECIFICATION')
      GO TO 7820
7810  CONTINUE
7820  CONTINUE
      WRITE(6,1250)
      WRITE(6,1270) (L,I=1,LMAX)
      WRITE(6,7825) (XYRSRS(L),L=1,LMAX)
7825  FORMAT('0',T15,'68. XYRSRS =',(T28,10(F6.1,' , ')))
      DO 7830 L=1,LMAX

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```

IF(XYPSNS(L) .GT. 0. .AND. XYPSNS(L) .LE. 10.) GO TO 7830
WRITE(6,7835)
7835 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XYPSNS SPECIFICATION')
GO TO 7840
7830 CONTINUE
7840 CONTINUE
WRITE(6,7845) (XSCL(L),L=1,LMAX)
7845 FORMAT('0',T15,'69. XSCL   =',(T28,10(F6.1,' ', ')))
DO 7850 I=1,LMAX
IF(XSCL(I) .GT. 0. .AND. XSCL(I) .LE. XMLS) GO TO 7850
WRITE(6,7855)
7855 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XSCL SPECIFICATION')
GO TO 7860
7850 CONTINUE
7860 CONTINUE
WRITE(6,7865) (XCALPS(L),L=1,LMAX)
7865 FORMAT('0',T15,'70. XCALPS =',(T28,10(F6.1,' ', ')))
DO 7870 I=1,LMAX
IF(XCALPS(L) .GT. 0. .AND. XCALPS(L) .LE. 100.) GO TO 7870
WRITE(6,7875)
7875 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XCALPS SPECIFICATION')
GO TO 7880
7870 CONTINUE
7880 CONTINUE
WRITE(6,7905) (KNS(L),L=1,LMAX)
7905 FORMAT('0',T15,'71. KNS    =',(T28,10(I4,2X,' ', ')))
DO 7910 I=1,LMAX
IF(KNS(L) .GT. 1 .AND. KNS(L) .LE. 10) GO TO 7910
WRITE(6,7915)
7915 FORMAT(' ',T16,'** WARNING * - INVALID KNS SPECIFICATION')
GO TO 7920
7910 CONTINUE
7920 CONTINUE
WRITE(6,7925) (XYPSNS(I),L=1,LMAX)
7925 FORMAT('0',T15,'72. XYPSNS =',(T28,10(F6.1,' ', ')))
DO 7930 I=1,LMAX
IF(XYPSNS(I) .GT. 0. .AND. XYPSNS(I) .LE. 10.) GO TO 7930
WRITE(6,7935)
7935 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XYPSNS SPECIFICATION')
GO TO 7940
7930 CONTINUE
7940 CONTINUE
WRITE(6,7950) (XULSC(I),L=1,LMAX)
7950 FORMAT('0',T15,'73. XULSC  =',(T28,10(F6.1,' ', ')))
DO 7960 I=1,LMAX
IF(XULSC(L) .GT. 0.) GO TO 7960
WRITE(6,7965)
7965 FORMAT(' ',T15,'** WARNING ** - UNREALISTIC XULSC SPECIFICATION')
GO TO 7970
7960 CONTINUE
7970 CONTINUE
WRITE(6,7975) (XULSCL(I),L=1,LMAX)
7975 FORMAT('0',T15,'74. XULSCL =',(T28,10(F6.1,' ', ')))
DO 7980 I=1,LMAX
IF(XULSCL(I) .GT. 0. .AND. XULSCL(L) .LE. 100.) GO TO 7980
WRITE(6,7985)
7985 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XULSCL SPECIFICATION')

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GO TO 7990
7980 CONTINUE
7990 CONTINUE
WRITE(6,7885) (KGROUP(L),I=1,LMAX)
7885 FORMAT('0',T15,'75. KGROUP =',(T28,10(I4,2X,' ', ')))
DO 7890 I=1,LMAX
IF(KGROUP(I) .GE. 1 .AND. KGROUP(I) .LE. LMAX) GO TO 7890
WRITE(6,7895)
7895 FORMAT(' ',T16,'** WARNING ** - INVALID KGROUP SPECIFICATION')
GO TO 7990
7890 CONTINUE
7900 CONTINUE
C **** LIMX AND NPLGT ARE USED AS WORK VARIABLES FOR KK CHECKS ****
DO 7995 I=1,LMAX
LJMX(L)=0
NPLGT(L)=0
7995 CONTINUE
DO 8005 I=1,LMAX
KK=KGROUP(I)
IF(KK .LT. 1 .OR. KK .GT. LMAX) GO TO 8005
NPLGT(KK)=1
8005 CONTINUE
KKMAX=0
DO 8010 KK=1,LMAX
IF(NPLGT(KK) .EQ. 0) GO TO 8010
KKMAX=KKMAX+1
LJMX(KKMAX)=KK
8010 CONTINUE
WRITE(6,8015) (LJMX(KK),KK=1,KKMAX)
8015 FORMAT('0',///,T31,'STANDARDIZED POWER SUBSYSTEM GROUP, KK',
.//,(T32,10(I2,7X)))
WRITE(6,8020) (XCSTPN(LJMX(KK)),KK=1,KKMAX)
8020 FORMAT('0',T15,'76. XCSTPN =',(T28,10(F7.1,' ', ')))
DO 8025 KK1=1,KKMAX
KK=LJMX(KK1)
IF(XCSTPN(KK) .GE. 0. .AND. XCSTPN(KK) .LT. 9999999.) GO TO 8025
WRITE(6,8030)
8030 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XCSTPN SPECIFICATION')
GO TO 8035
8035 CONTINUE
8035 CONTINUE
WRITE(6,8040) (XDCSTN(LJMX(KK)),KK=1,KKMAX)
8040 FORMAT('0',T15,'77. XDCSTN =',(T28,10(F7.1,' ', ')))
DO 8045 KK1=1,KKMAX
KK=LJMX(KK1)
IF(XDCSTN(KK) .GE. 0. .AND. XDCSTN(KK) .LE. XCSTPN(KK)) GO TO 8045
WRITE(6,8050)
8050 FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XDCSTN SPECIFICATION')
GO TO 8055
8055 CONTINUE
8055 CONTINUE
WRITE(6,8060) (KNSP(LJMX(KK)),KK=1,KKMAX)
8060 FORMAT('0',T15,'78. KNSP =',(T28,10(I5,2X,' ', ')))
DO 8065 KK1=1,KKMAX
KK=LJMX(KK1)
IF(KNSP(KK) .GE. 1 .AND. KNSP(KK) .LE. 10.) GO TO 8065
WRITE(6,8070)

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8070  FORMAT(' ',T16,'** WARNING ** - INVALID XNSP SPECIFICATION')
      GO TO 8075
8065  CONTINUE
8075  CONTINUE
      WRITE(6,8080) (XYRSPN(LJMX(KK)),KK=1,KKMAX)
8080  FORMAT('0',T15,'79. XYRSPN =',(T28,10(F7.1,' ', ')))
      DO 8085 KK1=1,KKMAX
      KK=LJMX(KK1)
      IF(XYRSPN(KK) .GT. 0 .AND. XYRSPN(KK) .LE. 10.) GO TO 8085
      WRITE(6,8090)
8090  FORMAT(' ',T15,'** WARNING ** - UNREALISTIC XYRSPN SPECIFICATION')
      GO TO 8095
8085  CONTINUE
8095  CONTINUE
      WRITE(6,8100) (XULP(LJMX(KK)),KK=1,KKMAX)
8100  FORMAT('0',T15,'80. XULP =',(T28,10(F7.1,' ', ')))
      DO 8105 KK1=1,KKMAX
      KK=LJMX(KK1)
      IF(XULP(KK) .GE. 0.) GO TO 8105
      WRITE(6,8110)
8110  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XULP SPECIFICATION')
      GO TO 8116
8105  CONTINUE
8116  CONTINUE
      WRITE(6,8120) (XULPL(LJMX(KK)),KK=1,KKMAX)
8120  FORMAT('0',T15,'81. XULPL =',(T28,10(F7.1,' ', ')))
      DO 8125 KK1=1,KKMAX
      KK=LJMX(KK1)
      IF(XULPL(KK) .GT. 0. .AND. XULPL(KK) .LE. 100.) GO TO 8125
      WRITE(6,8130)
8130  FORMAT(' ',T16,'** WARNING ** - UNREALISTIC XULPL SPECIFICATION')
      GO TO 8135
8125  CONTINUE
8135  CONTINUE
8900  CONTINUE
      WRITE(6,8903)
8903  FORMAT('1')
      STOP
      END

```

MAIN PROGRAM

```

COMMON/PILOCK/XA(10),YB(10),JMAX,IMAX,IRMAX,XDR(5),LMAX,NMAX,
.XPOW(50),XPCWP(50),IAC(50),XPSP(50),XMPL(50),LMISS(50),XPLL(50),
.XCS,XFS,XMPS,XMLS,XMTT(20),XCT(20),XLT(20),XMPT(20),XPT(20),
.NUPS(50),XM1(50),XM2(50),XM3(50),XM4(50),YM6(50),XM7(50),XIT(50),
.NAKM(50),XSOLA(50),XMT(50),KN(50),YVRSN(50),CALP(50),KR(50),
.XYBSP(50),YPI(50),XUL(50),XDIR(50),XM1S(20),XM2S(20),XM3S(20),
.XM4S(20),XM6S(20),YM7S(20),XM8S(20),XITS(20),NAKMS(20),IPTYP(20),
.IACS(20),YMAXP(20),MAXPS(20),XPWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCSTP(20),XDCSTR(20),KRS(20),XYRSPS(20),
.XSCL(20),XCALPS(20),KGROTP(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),XYRSPN(20),XYRSNS(20),XULP(20),XULSC(20),XULPL(20),
.XULSCL(20),IUP,CDEL,IACN(50),XXMP(20)
COMMON/MMODL/NO(30,50)
COMMON/FLOW/NFV1,NFV2,NFV3,NFV4,NFV5,NFV6,NFV7,NFV8,NFV9,NFV10,
.NFV11,NFV12,NFV13,NFV14,NFV15,NFV16,NFV17,NFV18,NFV19,NFV20,
.NFV21,NFV22,NFV23,NFV24,NFV25,NFV26,NFV27,NFV28,NFV29,NFV30,
.TP1,TP2,TP3,TR4,TR5,TP6,TR7,TR8,TP9,TR10
COMMON/LOCAL/LJMX(20),NPLIGT(50),JPMX(50,2),IUP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVMAX(20),MMISS(50)
COMMON/CHARAC/CHAR(130)
COMMON/ROUTNS/ROU(50)
REAL*8 ROU
REAL*8 CHAR
INTEGER TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10
99992 FORMAT(1Y,10A8)
C
C
WRITE(6,99992) ROU(1)
CALL INIT
CALL INPATH
CALL INDATA
GO TO (70),NFV2
CALL DATCHK
70 CONTINUE
CALL GPRCAL
GO TO (10,40,40),NFV1
IF (JMAX .EQ. 0) GO TO 10
40 CALL INSTD
CALL INNOX
IF (NF4 .EQ. 1) CALL NONCHK
CALL NDRCAL
GO TO (20),NFV3
CALL STDCHK
20 CALL SPRCAL
CALL ASSIGN
CALL OPTMTX
CALL STDGST
CALL SDSPLY
10 GO TO (30,50,30),NFV1
IF (LMAX .NE. 0) GO TO 50
30 CALL INNOX
GO TO (60),NFV4
CALL NONCHK
60 CALL NDRCAL
CALL NONGST
CALL NDSPLY
50 CONTINUE
WRITE(6,99994)
99994 FORMAT('1')
WRITE(6,99992) ROU(1),ROU(42)
STOP
END

```

```

SUBROUTINE INTT
COMMON/BLOCK/YA(10),XR(10),JMAX,IMAX,IMAX,XDR(5),IMAX,NMAX,
.XPDW(50),XPDWP(50),IAC(50),XFSP(50),YMPL(50),LMISS(50),XPLL(50),
.YCS,XFS,XMPS,YMLS,XMTT(20),XCT(20),XLT(20),XMTT(20),XFT(20),
.YMPS(50),YM1(50),YM2(50),YM3(50),YM4(50),YM6(50),YM7(50),XIT(50),
.NAKM(50),XSOLA(50),XMT(50),KN(50),YFRSN(50),CALR(50),KR(50),
.XYPSR(50),YPL(50),XUL(50),XDIH(50),XM1S(20),XM2S(20),XM3S(20),
.XY4S(20),XM6S(20),XM7S(20),XM8S(20),XITS(20),NAKMS(20),IPTYP(20),
.IACS(20),XMAXP(20),MAXPS(20),XPWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCSTR(20),XDCSTR(20),KRS(20),YFRSRS(20),
.XSCI(20),XCALPS(20),KGFOWP(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),XYPSPN(20),XYPSNS(20),XULP(20),XULSC(20),XULPL(20),
.XULSCL(20),IUP,CDEL,IACN(50),XXMP(20)
COMMON/MMODL/MO(30,50)
COMMON/FLOW/NFLOW(30),TR(10)
COMMON/LOCAL/LJMX(20),NFLIGHT(50),JPMX(50,2),IUP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVMAX(20),MMISS(50)
COMMON/CHAFAC/CHAP(130)
COMMON/ROUTNS/ROU(50)
PARAMETER ROU
PARAMETER CHAP
INTEGER TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10
INTEGER TP
EQUIVALENCE (TP(1),TR1),(TP(2),TR2),(TP(3),TR3),(TP(4),TR4),
.(TP(5),TR5),(TP(6),TR6),(TP(7),TR7),(TP(8),TR8),(TP(9),TR9),
.(TP(10),TR10)
WRITE(6,99992) ROU(2)
99992 FORMAT(1X,10A3)
STOP
END

```



```

ENTRY INDATA
IF (TR1 .EQ. 1) WRITE(6,99992) ROW(5 )
60 READ(5,DATA,END=70)
GO TO 60
70 REWIND 5
IF (NFLOW(19) .EQ. 1) RETURN
WRITE(6,DATA)
RETURN

```

```

ENTRY INSTD
IF (TR1 .EQ. 1) WRITE(6,99992) ROW(4 )
50 READ(5,STD,END=40)
GO TO 50
40 REWIND 5
WRITE(6,STD)
RETURN

```

```

ENTRY INNON
IF (TR1 .EQ. 1) WRITE(6,99992) ROW(6 )
80 READ(5,NONSTD,END=10)
GO TO 80
90 REWIND 5
IF (NFLOW(19) .EQ. 1) RETURN
WRITE(6,NONSTD)
RETURN
END

```

```

SUBROUTINE CHECK
COMMON/BLOCK/XA(10),XB(10),JMAX,IMAX,IPMAX,XDR(5),LMAX,NMAX,
.XPOW(50),XPOWP(50),IAC(50),XPSD(50),XMPL(50),LMISS(50),XPLL(50),
.XCS,XFS,XMPS,XMIS,XMTT(20),XCT(20),XIT(20),XMDT(20),XFT(20),
.NJPS(50),XM1(50),XM2(50),XM3(50),XM4(50),XM6(50),XM7(50),XIT(50),
.NAKM(50),XSOLA(50),XMT(50),KN(50),XYPSN(50),CALR(50),KR(50),
.XYPSR(50),XPL(50),XUL(50),XDLR(50),XM1S(20),XM2S(20),XM3S(20),
.XM4S(20),XM6S(20),XM7S(20),XM8S(20),VITS(20),NAKMS(20),IPTYP(20),
.IACS(20),XMAXP(20),MAXPS(20),XPWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCSTPR(20),XDCSTR(20),KPS(20),XYPSRS(20),
.XSCL(20),XCALPS(20),KGEQUP(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),XYPSPN(20),XYPSNS(20),XULP(20),XULSC(20),XULPL(20),
.XUISCL(20),IUP,CDEL,IACN(50),YXMP(20)
COMMON/MMODI/NO(30,50)
COMMON/FLOW/NFLOW(30),TP(10)
COMMON/LOCAL/LJMX(20),NPLGT(50),JPMX(50,2),IUP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVMAX(20),MMISS(50)
COMMON/CHAEAC/CHAP(130)
COMMON/ROUTNS/ROU(50)
REAL*8 ROU
INTEGER TP
INTEGER TP1,TP2,TP3,TP4,TP5,TP6,TP7,TP8,TP9,TP10
REAL*8 CHAP
EQUIVALENCE (TP(1),TP1),(TP(2),TP2),(TP(3),TP3),(TP(4),TP4),
.(TP(5),TP5),(TP(6),TP6),(TP(7),TP7),(TP(8),TP8),(TP(9),TP9),
.(TP(10),TP10)
99992 FORMAT(1X,10A8)
C
ENTRY PTHCHK
IF(TP1.EQ.1) WRITE(6,99992) ROU(7)
RETURN
C
ENTRY DATCHK
IF(TP1.EQ.1) WRITE(6,99992) ROU(8)
RETURN
C
ENTRY STDCHK
IF(TP1.EQ.1) WRITE(6,99992) ROU(9)
RETURN
C
ENTRY NONCHK
IF(TP1.EQ.1) WRITE(6,99992) ROU(10)
RETURN
C
ENTRY RSCHK(I,PVXP)
IF(TP1.EQ.1) WRITE(6,99992) ROU(11)
IF(NFLOW(3).EQ.0) RETURN
I=0
500 DM2=XPOW(I)*(PVMX-VMAXP(L))
DM1=SK1(L)+DM2
DM6=SK6(L)+DM2
DM7=SK7(L)+DM2
IF(I.EQ.0) A=RCRPS1(DM1,DM2,DM6,DM7,PVXP,L)
IF(I.EQ.1) A=RCRPS1(DM1,DM2,DM6,DM7,PVXP,L)
RETURN
C
ENTRY RSCHK(L,PVXP)

```

IF (TF1 .EQ. 1) WRITE (6,99992) POU(12)
IF (NFLOW(9) .EQ. 0) RETURN
I=1
GO TO 500

ENTRY RNCHK(J)
IF (TF1 .EQ. 1) WRITE (6,99992) POU(13)
IF (NFLOW(9) .EQ. 0) RETURN
A=PCFKN1(J)
RETURN

ENTRY DNCHK(J)
IF (TF1 .EQ. 1) WRITE (6,99992) POU(14)
IF (NFLOW(9) .EQ. 0) RETURN
A=DCFRN1(J)
RETURN
END

```

SUBROUTINE DRCAL
COMMON/BLOCK/XA(10),XB(10),JMAX,IMAX,IRMAX,XDR(5),LMAX,NMAX,
.XPOW(50),XPCWP(50),IAC(50),XPSD(50),XMP(50),LMISS(50),XPLL(50),
.XCS,XFS,XVPS,XMLS,XMTT(20),XCT(20),XLT(20),XMPT(20),XFT(20),
.NJPS(50),XM1(50),XM2(50),XM3(50),XM4(50),XM6(50),XM7(50),XIT(50),
.NAKM(50),XSOLA(50),XMP(50),KN(50),XYRSN(50),CALR(50),KR(50),
.XYRSP(50),XPI(50),XUI(50),XDLR(50),XM1S(20),XM2S(20),XM3S(20),
.XM4S(20),XM6S(20),XM7S(20),XM8S(20),XIIS(20),NAKMS(20),IPTYP(20),
.IACS(20),XMAXP(20),MAYPS(20),XPWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCSTPR(20),XDCSTR(20),KRS(20),XYRSPS(20),
.XSCL(20),XCALRS(20),KGROUP(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),XYRSPN(20),XYRSNS(20),XULP(20),XULSC(20),XUIPI(20),
.XULSCL(20),IUP,CDFL,IACN(50),XXMP(20)
COMMON/MMOIL/VO(30,50)
COMMON/PIOW/NFV1,NFV2,NFV3,NFV4,NFV5,NFV6,NFV7,NFV8,NFV9,NFV10,
.NFV11,NFV12,NFV13,NFV14,NFV15,NFV16,NFV17,NFV18,NFV19,NFV20,
.NFV21,NFV22,NFV23,NFV24,NFV25,NFV26,NFV27,NFV28,NFV29,NFV30,
.TP1,TP2,TP3,TP4,TP5,TP6,TP7,TP8,TP9,TP10
COMMON/LOCAL/LJMY(20),NPLGT(50),JPMX(50,2),IUP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVMAX(20),MMISS(50)
COMMON/CFAPAC/CHAR(130)
COMMON/ROUTNS/ROU(50)
REAL*8 ROU
REAL*8 CHAR
INTEGER TP1,TP2,TP3,TP4,TP5,TP6,TP7,TP8,TP9,TP10
DIMENSION LVEC(20)
DET(A,B,C)=-A*(B+1.)*(C+1.)/(2*A*B*C+A*B+A*C+3*C-1.)
99992 FORMAT(1X,10A8)
99990 FORMAT((1X,6(A6,'=' ,G12.7)))
99991 FORMAT(1X,A6,'=' , (1X,8G14.7))
ENTRY DRCAL
IF(TP1.EQ.1) WRITE(3,99992) ROU(15)
DO 200 I=1,11
LVEC(I)=0
200 CONTINUE
DO 110 L=1,LMAX
IF(XYRSPS(L).LT..001) XYRSPS(L)=.001
IF(XYRSNS(L).LT..001) XYRSNS(L)=.001
IF(XCALRS(L).LT.0.) GO TO 400
XCALRS(L)=(ALOG(XCALRS(L))-4.61)/.63
GO TO 410
400 CONTINUE
WRITE(3,420) L
420 FORMAT('0','** WARNING ** - XCALRS',I2,
,' < 0. -- DEFAULTED TO 7-60')
XCALRS(L)=1E-60
410 CONTINUE
IF(XULSC(L).LT.0..001) XULSC(L)=.001 GO TO 525
WRITE(3,530) L
530 FORMAT('0','** WARNING ** - 0. < XULSC',I2,' < 1. -- ',
,' XULSC DEFAULTED TO 1.')
XULSC(L)=1.
525 CONTINUE
IF(XULSC(L).GT.0.) GO TO 540
WRITE(3,535) L
535 FORMAT('0','** WARNING ** - XULSC',I2,' > 0. -- ',
,' DEFAULTED TO IMAX + 2')

```



```

      XULSC(L)=TMAX+2.
540  CONTINUE
      IF(XULSCL(I) .LT. 0.) GO TO 430
      XULSCL(L)=(ALOG(XULSCL(L))-4.61)/.69
      GO TO 440
430  CONTINUE
      WRITE(3,450) L
450  FORMAT('0','** WARNING ** - XULSCL',I2,
. ' < 0. -- DEFAULTED TO E-60')
      XULSCL(L)=1E-60
440  CONTINUE
      XPDWSS(I)=XPDWSS(L)/100.
      IF(XPDWSS(L) .LT. 0.) XPDWSS(L) = 1./MAXPS(L)
      IF(LVEC(KGROUP(I)) .EQ. 1) GO TO 110
      IF(XULPL(KGROUP(L)) .LT. 0.) GO TO 460
      XULPL(KGROUP(L))=(ALOG(XULPL(KGROUP(I)))-4.61)/.69
      GO TO 470
460  CONTINUE
      WRITE(3,480) KGROUP(L)
480  FORMAT('0','** WARNING ** - XULPL',I2,
. ' < 0. -- DEFAULTED TO E-60')
      XULPL(KGROUP(L))=1E-60
470  CONTINUE
      IF(XULP(KGROUP(I)) .LT. 0. .OR. XULP(KGROUP(L)) .GE. 1.)
. GO TO 505
      WRITE(3,510) KGROUP(L)
510  FORMAT('0','** WARNING ** - 0. < XULP(',I2,') < 1. -- '
. ' XULP DEFAULTED TO 1.')
      XULP(KGROUP(L))=1.
505  CONTINUE
      IF(XULP(KGROUP(L)) .GT. 0.) GO TO 515
      WRITE(3,520) KGROUP(L)
520  FORMAT('0','** WARNING ** - XULP(',I2,') < 0. -- '
. ' DEFAULTED TO TMAX + 2')
      XULP(KGROUP(I))=TMAX+2
515  CONTINUE
      LVEC(KGROUP(L))=1
110  CONTINUE
      IUP1=IUP+1
      DO 1 J=1,JMAX
      JPMX(J,1)=J
1  CONTINUE
      CALL SORT(JPMX,XPDW,JMAX)
      WRITE(3,90091) CHAR(86), (JPMX(I,1),I=1,JMAX)
      WRITE(3,90091) CHAR(10), (XPDW(I),I=1,JMAX)
      WRITE(3,90091) CHAR(11), (XPDW(I),I=1,JMAX)
      JPMX(1,2)=JPMX(1,1)
      IF(JMAX .EQ. 1) GO TO 210
      J1=1
      DO 10 J=2,JMAX
      JJ=JPMX(J,1)
      JJ1=JPMX(J1,1)
      WRITE(3,90091) CHAR(110),J1,JJ1
      WRITE(3,90091) CHAR(10),XPDW(JJ),CHAR(11),XPDW(JJ),
. CHAR(10),XPDW(JJ1),CHAR(11),XPDW(JJ1)
      IF(XPDW(JJ)*(1.+XPDW(JJ)) .LT. XPDW(JJ1)*(1.+XPDW(JJ1)))
. GO TO 20

```

```

J1=J
JPMX(J,2)=JJ
GO TO 10
20 JPMX(J,2)=JJ1
10 CONTINUE
210 CONTINUE
WRITE(3,99991) CHAR(86), (JPMX(J,2), J=1, JMAX)
DO 30 J=1, JMAX
MMISS(J)=LMISS(J)
NPLGT(J)=0
DO 40 I=1, IMAX
NPLGT(J)=NPLGT(J)+NO(I,J)
40 CONTINUE
30 CONTINUE
DO 50 L=1, LMAX
SK1(L)=DET(XDM1S(L), XDM6S(L), XDM7S(L))
SK6(L)=DET(XDM6S(L), XDM1S(L), XDM7S(L))
SK7(L)=DET(XDM7S(L), XDM1S(L), XDM6S(L))
IF (SK1(L) .LT. 0. .OR. SK6(L) .LT. 0. .OR. SK7(L) .LT. 0.)
. WRITE(3,55) SK1(L), SK6(L), SK7(L)
55 FORMAT(5X, '** ERROR ** -- ILLFGL SCALE FACTORS, L=', I2, 'SK1=', E15
. , 7, 'SK6=', E15, 7, 'SK7=', E15, 7)
50 CONTINUE
IF (TF3 .NE. 1) GO TO 300
WRITE(3,99991) CHAR(101), (SK1(L), L=1, LMAX)
WRITE(3,99991) CHAR(102), (SK6(L), L=1, LMAX)
WRITE(3,99991) CHAR(103), (SK7(L), L=1, LMAX)
300 CONTINUE
RETURN
ENTRY NPFCL
IF (TF1 .EQ. 1) WRITE(3,99992) ROW(16)
DO 100 J=1, JMAX
IF (CALP(J) .LT. 0.) GO TO 475
CALP(J)=(ALOG(CALP(J))-4.61)/.69
GO TO 431
475 CONTINUE
WRITE(3,485) J
485 FORMAT(10I, '** WARNING ** - CALP', I2,
. ' < OR = 0. -- DEFAULTTED TO E-60')
CALP(J)=1E-60
481 CONTINUE
IF (XDLP(J) .LT. 0.) GO TO 490
XDLP(J)=(ALOG(XDLP(J))-4.61)/.69
GO TO 485
490 CONTINUE
WRITE(3,500) J
500 FORMAT(10I, '** WARNING ** - XDLP', I2,
. ' < OR = 0. -- DEFAULTTED TO E-60')
XDLP(J)=1E-60
495 CONTINUE
IF (XYPSN(J) .LT. .001) XYPSN(J)=.001
IF (XYPSR(J) .LT. .001) XYPSR(J)=.001
IF (XHL(J) .LT. 0. .OR. XHL(J) .GE. 1.) GO TO 545
WRITE(3,550) J
550 FORMAT(10I, '** WARNING ** - 0. < XHL(', I2, ') < 1. -- ',
. ' XHL DEFAULTTED TO 1.')
XHL(J)=1.

```

```

545  CONTINUE
      IF (XUL(J) .GT. 0.) GO TO 555
      WRITE(3,560) J
560  FORMAT('0', '** WARNING ** - XUL(' ,I2,') < 0R = 0.  -- ',
. ' DEFAULTED TO IMAX + 2')
      XUL(J) = IMAX+2.
555  CONTINUE
100  CONTINUE
      RETURN
      ENTRY GPRCAL
      DO 207 J=1,JMAX
      XPOWP(J) = XPOWP(J) / 100
      XPSP(J) = XPSP(J) / 100
207  CONTINUE
      RETURN
      END

```

```

SUBROUTINE SORT(LIST,XPMR,LNG)
COMMON/FLOW/NFV1,NFV2,NFV3,NFV4,NFV5,NFV6,NFV7,NFV8,NFV9,NFV10,
.NFV11,NFV12,NFV13,NFV14,NFV15,NFV16,NFV17,NFV18,NFV19,NFV20,
.NFV21,NFV22,NFV23,NFV24,NFV25,NFV26,NFV27,NFV28,NFV29,NFV30,
.TF1,TF2,TF3,TF4,TF5,TF6,TF7,TF8,TF9,TF10
COMMON/ROUTNS/POU(50)
COMMON/CHARAC/CHAR(130)
INTEGER TF1,TF2,TF3,TF4,TF5,TF6,TF7,TF8,TF9,TF10
REAL*8 POU
REAL*8 CHAR
DIMENSION LIST(50),XPMR(50)

```

00

```

IF(TF1.EQ. 1) WRITE(6,99992) POU(17)
99992 FORMAT(1X,10A8)
IF(LNG.LT. 2) RETURN
IPT = 2
4  I1=IPT
   WRITE (6,7) IPT
7  FORMAT(1X,I3)
   I2=IPT-1
   M1=LIST(IPT)
3  IF(XPMR(LIST(IPT)).GE. XPMR(LIST(I2))) GO TO 6
   IF(I2.LE. 1) GO TO 5
   I2=I2-1
   GO TO 3
6  I2=I2+1
1  IF(I1.LE. I2) GO TO 2
5  LIST(I1)=LIST(I1-1)
   I1=I1-1
   GO TO 1
2  LIST(I2)=M1
   IF(IPT.GE. LNG) RETURN
   IPT=IPT+1
   GO TO 4
END

```

SUBROUTINE ASSIGN

```

COMMON/BLOCK/XA(10),XR(1),JMAX,IMAX,IRMAX,XDR(5),LMAY,NMAX,
.XPOW(50),XPOWP(50),IAC(50),XPSP(50),XMPL(50),LMISS(50),XPLI(50),
.XCS,XFS,XMPS,XMLS,XMTT(20),XCT(20),XLT(20),XMPT(20),XPT(20),
.NUPS(50),XM1(50),XM2(50),XM3(50),XM4(50),XM6(50),XM7(50),XIT(50),
.NAKM(50),XSOLA(50),XMT(50),KN(50),YVPSN(50),CALR(50),KR(50),
.XYRSF(50),XPI(50),XUL(50),XDLR(50),XM1S(20),XM2S(20),XM3S(20),
.XM4S(20),XM6S(20),XM7S(20),XM8S(20),XITS(20),NAKMS(20),IPTVP(20),
.IACS(20),XMAXP(20),MAXPS(20),XPWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCSTPP(20),XDCSTR(20),KRS(20),XYRSRS(20),
.XSCL(20),XCALES(20),XGPOUP(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),YVPSPN(20),YVPSNS(20),XULP(20),XULSC(20),XULPL(20),
.XULSCL(20),THP,CDFL,IACN(50),XXMP(20)

```

COMMON/MODL/NO(30,50)

```

COMMON/FLOW/NFV1,NFV2,NFV3,NFV4,NFV5,NFV6,NFV7,NFV8,NFV9,NFV10,
.NFV11,NFV12,NFV13,NFV14,NFV15,NFV16,NFV17,NFV18,NFV19,NFV20,
.NFV21,NFV22,NFV23,NFV24,NFV25,NFV26,NFV27,NFV28,NFV29,NFV30,
.TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10

```

```

COMMON/LOCAL/LJMX(20),NPLGT(50),JPMX(50,2),THP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVMAX(20),MMISS(50)

```

COMMON/CHAPAC/CHAP(130)

COMMON/ROUTNS/POU(50)

REAL*8 POU

REAL*8 CHAR

INTEGER TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10

DIMENSION LFLAG(20)

IF (TR1 .EQ. 1) WRITE(3,99992) POU(18)

99992 FORMAT(1X,10A8)

99997 FORMAT((1X,6(A6,'=' ,G14.7,1X)))

99991 FORMAT(1X,A6,'=' , (1X,8G14.7))

JX=JMAX

DO 61 L=1,LMAX

PVMAX(L)=0.

LFLAG(I)=0

61 CONTINUE

DO 30 L=1,LMAX

```

IF (TR2 .EQ. 1) WRITE(3,62) LFLAG(I),IAC(JPMX(JX,1)),IACS(L),
.XMAXP(L),LMISS(JPMX(JX,1)),L,JX,JPMX(JX,1)

```

62 FORMAT(' ASGN,LOOP TO FIND OPTIMUM MAX POWER TO FLY REMAINING MISS

```

IONS'/' LFLAG=' ,G12.6,' IAC=' ,G12.6,' IACS=' ,G12.6,' XMAXP=' ,
.G12.6,' LMISS=' ,I3,' L=' ,I3,' JX=' ,I3,' JPMX(JX,1)=' ,I3)

```

CLMN(L)=1775

IF (LFLAG(L) .EQ. 1) GO TO 30

IF (IAC(JPMX(JX,1))*IACS(L) .EQ. 3) GO TO 30

IF (XMAXP(L) .LE. 0.) GO TO 30

IF (LMISS(JPMX(JX,1)) .NE. L .AND. LMISS(JPMX(JX,1)) .NE. 0)

GO TO 30

IP=JFYP(L)

IO=IP+1

PX1=XPOW(JPMX(JX,IO))*(1.+TR*XPOWP(JPMX(JX,IO)))

IF (PX1 .LT. 50.) PX1 = 50.

IF (PX1 .GT. XXMP(L)) GO TO 30

PVC=0.

```

      TP(TUP .NF. 0) PNC=(XEMP(I)-PX1)/TUP
      TP(T2 .FO. 1) WRITE(3,4000) PX1,PNC
4000  FORMAT(' STARTING POWER PX1=',G12.6,' POWER INCREMENT PNC=',
      .G12.6)
      IF(PNC .GT. 0.) GO TO 40
      TP(TR1 .FO. 0) GO TO 30
      WRITE(3,41) PNC,JX,L
41    FORMAT(5X,'**WARNING **-- INVALID MAX POWER INCREMENT -- PNC =',
      .G15.7,' JX=',G15.7,' I=',G15.7)
      GO TO 30
C
40    DO 20 T=1,TUP1
      WRITE(3,3388)
8888  FORMAT('I',I)
      PMXP=PX1+(I-1)*PNC
      CIPF=0
      IF(T2 .FO. 1) WRITE(3,4001) PMXP,T
4001  FORMAT(' ASSIGN POWER OPT LOAD,PMXP=',G12.6,' I=',G12.6)
C
      DO 10 JY1=1,JX
      J=JPMX(JX1,1)
      IF(T2 .FO. 1) WRITE(3,4002) J,MMISS(J),IAC(J),IACS(L)
4002  FORMAT(' LOOP SUMMING COSTS OVER REMAINING MISSIONS,J=',
      .G12.6,' MMISS(J)=' ,G12.6,' IAC=' ,I3,' IACS' ,I3)
      IF(MMISS(J) .NF. 1 .AND. MMISS(J) .NF. 0) GO TO 10
      IF(IAC(J)*IACS(L) .FO. 3) GO TO 15
      NFIT=NFLIGHT(J)*(XPSP(J)+1.)+.9999
      IF(NFV7 .FO. 1) CALL RSCHK(L,PMXP)
      C=HTRCT1(L,J,PMXP)
      CIRT=CIPF+C*NFLT
      IF(T2 .FO. 1)
      .WRITE(3,99990) CHAR(116),C,CHAR(88),CIRT,CHAR(84),L,CHAR(85),J
      .,CHAR(111),NFIT
      GO TO 10
15    CONTINUE
      NUMSTM=15
      IF(MMISS(J) .FO. 1) WRITE(3,16) J,L,NUMSTM
16    FORMAT(1X,'** ERROR ** -- MISSION',I3,' DEDICATED TO S/C',I3,' IS
      .UNASSIGNABLE DUE TO STALL REQ INCOMPAT, NUMSTM=',I5)
10    CONTINUE
C
      IF (TR3 .FO. 1)
      .WRITE(3,99940) CHAR(88),CLRT,CHAR(83),CLMN(I),CHAR(84),L
      IF(CIRT .GT. CLMN(L)) GO TO 20
      CLMN(L)=CIRT
      PVMAX(L)=PMXP
      IF(TR3 .FO. 1) WRITE(3,99930) CHAR(91),PVMAX(L)
20    CONTINUE
C
30    CONTINUE
C
      IFLG2=0
      JX1=JPMX(JX,1)
      NFIT=NFLIGHT(JX1)*(XPSP(JX1)+1.)+.9999
      D=DCTN(JX1)
      R=RCTN(JX1)
      T=TCTN(JX1)

```

```

CR1=D/NFLT+R+T
IF (TP2 .EQ. 1) WRITE(3,25) D,R,T
25  FORMAT(' DCTN(JX1)=' ,G12.6,' RCTN(JX1)=' ,G12.6,' TCTN(JX1)=' ,
.G12.6)
IF (TP2 .EQ. 1) WRITE(3,31) JX1,NFLT,CR1
31  FORMAT(1X,' JX1=' ,G12.6,' NFLT=' ,G12.6,' CR1=' ,G12.6,' ASGN ASGN
.S/C NEXT')
C
DO 50 L=1,IMAX
IF (TR2 .EQ. 1) WRITE(3,32) L,MMISS(L),IAC(JX1),IACS(L)
32  FORMAT(1X,' ASGN ASGN LOOP L=' ,G12.6,' MMISS=' ,G12.6,
.' IAC=' ,G12.6,' IACS=' ,G12.6)
IF (MMISS(JX1) .NE. L .AND. MMISS(JX1) .NE. 0) GO TO 50
IF (IAC(JX1)*IACS(L) .EQ. 3) GO TO 35
IF (XMAXP(L) .LE. 0.) GO TO 35
IF (XPOW(JX1)*(1.+IPTYP(L)*XPOW(JX1)) .GT. PVMAX(L)) GO TO 35
C1=RT+CT2(I,JX1,PVMAX(L))
WRITE(3,99990) CHAR(92),CR1,CHAR(93),C1,CHAR(84),L,CHAR(110),JX1
IF (C1 .GE. CR1) GO TO 50
LMISS (JX1)=L
CR1=C1
IFLG2=1
GO TO 50
35  CONTINUE
NUMSTM=35
IF (MMISS(JX1) .EQ. L) WRITE(3,16) JX1,L,NUMSTM
50  CONTINUE
C
IF (IFLG2 .EQ. 0) WRITE (3,51) JX1,JX
IF (IFLG2 .EQ. 0) LMISS(JX1)=0
51  FORMAT(5X,'** NOTE ** -- MISSION',I3,' WITH POWER RANK',I3,' IS UN
.ASSIGNABLE')
IF (IFLG2 .NE. 0) LFLAG(LMISS(JX1))=1
WRITE(3,99990) CHAR(87),LFLAG(LMISS(JX1)),CHAR(84),I
WRITE(3,99990) CHAR(15),LMISS(JX1),CHAR(35),JX1
IF (JX .IF. 1) GO TO 55
JX=JX-1
GO TO 60
55  CONTINUE
NUMSTM=55
WRITE(3,99991) CHAR(15), (LMISS(J),J=1,IMAX)
C
DO 57 J=1,JMAX
IF (LMISS(J) .EQ. 0) WRITE(3,56) J,NUMSTM
56  FORMAT(1X,'** NOTE ** -- MISSION',I3,' UNASSIGNED, STMT NO=',I5)
57  CONTINUE
C
DO 58 L=1,LMAX
IF (LFLAG(L) .NE. 1) WRITE (3,121) L,LFLAG(L)
121  FORMAT(1X,'** NOTE ** -- SPACECRAFT',I3,' HAS NO ASSIGNMENTS -- LFL
.AG=',I5)
58  CONTINUE
C
WRITE(3,99991) CHAR(91), (PVMAX(L),L=1,LMAX)
RTUUFM
END

```

```

SUBROUTINE OPTMIX
COMMON/BLOCK/XA(10),XP(10),JMAX,IMAX,TPMAX,XDR(5),LMAX,NMAX,
.XPOW(50),XPOWP(50),IAC(50),XPSD(50),XMPL(50),LMISS(50),XPDL(50),
.XCS,XPS,XMPS,XMLS,XMTT(20),XCT(20),XLT(20),XMPD(20),XPT(20),
.NUPS(50),XM1(50),XM2(50),XM3(50),XM4(50),XM6(50),XM7(50),XIT(50),
.NAKM(50),XSOLA(50),XMT(50),KN(50),XVRSN(50),CALP(50),KR(50),
.XYRSR(50),XPI(50),XUL(50),XDLP(50),XM1S(20),XM2S(20),XM3S(20),
.XM4S(20),XM6S(20),XM7S(20),XM8S(20),XITS(20),NAKMS(20),IDTYP(20),
.IACS(20),XMAXP(20),MAXPS(20),XPWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCSTPR(20),XDCSTP(20),KPS(20),XYRSPS(20),
.XSCL(20),XCAIRS(20),KGPOHP(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),XYRSPM(20),XYRSNS(20),XULP(20),XULSC(20),XULPL(20),
.XULSCL(20),IUP,CDPL,IACN(50),XXMP(20)
COMMON/MMODL/NO(30,50)
COMMON/FLOW/NFV1,NFV2,NFV3,NFV4,NFV5,NFV6,NFV7,NFV8,NFV9,NFV10,
.NFV11,NFV12,NFV13,NFV14,NFV15,NFV16,NFV17,NFV18,NFV19,NFV20,
.NFV21,NFV22,NFV23,NFV24,NFV25,NFV26,NFV27,NFV28,NFV29,NFV30,
.TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10
COMMON/LOCAL/LJMX(20),NPLGT(50),JPMX(50,2),IUP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVMAX(20),MMISS(50)
COMMON/CHAPAC/CHAP(130)
COMMON/ROUTNS/ROU(50)
REAL*8 ROU
REAL*8 CHAP
INTEGER TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10

C
C
IF(TR1.EQ.1) WRITE(3,99992) ROU(12)
99992 FORMAT(1X,10A8)
99990 FORMAT((1X,6(A6,'=' ,G12.7,1X)))
99991 FORMAT(1X,A6,'=' , (1X,8G14.7))
TFLG1=1
NCT1=1
CMDL=1E75
300 CONTINUE
IF(TR5.EQ.1) WRITE(3,301) NCT1,CMDI
301 FORMAT(1X,' ITERATION NUMBER, NCT1=',G12.6,' MISSION MODEL COST,
.CMDI=',G12.6)
C
DO 70 I=1,LMAX
LJMX(I)=0
70 CONTINUE

DO 80 J=1,JMAX
L=LMISS(J)
IF(L.LE.0 .OR. L.GT.LMAX) GO TO 79
IP=IDTYP(I)
IF(LJMX(L).EQ.0) LJMX(L)=J
PX2=XPOW(I)*(1.+IP*XPOWP(J))
PX3=XPOW(LJMX(L))*(1.+IP*XPOWP(LJMX(L)))
IF(PX2.LE.PX3) GO TO 80
LJMX(L)=J
GO TO 80
79 WRITE(3,71) J,L,J
71 FORMAT(1X,'** NOTE ** -- LMISS',I3,' = ',I3,' -- MISSION',I3,' IS
.UNASSIGNABLE AND IGNORED')
80 CONTINUE

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C
71 IF (T15 .EQ. 1) WRITE (3,73) (LMTSS(J),J=1,JMAX)
73 FORMAT(1X,' MISSION ASSIGNMENT STATUS, LMISS=',10(1X,I3))
72 IF (T15 .EQ. 1) WRITE (3,72) (LJMX(L),L=1,LMAX)
72 FORMAT(1X,' SPACECRAFT ASSIGNMENT STATUS, LJMX=',5(1X,I3))
230 C41=0.
IF (T15 .EQ. 1) WRITE (3,231) IFLG1
231 FORMAT(1X,' CONVERGENCE CRITERION IFLG1=',G12.6)
IF (IFLG1 .EQ. 0) GO TO 240

DO 100 L=1,LMAX
IF (T15 .EQ. 1) WRITE (3,232) L,LJMX(L),XMAXP(L)
232 FORMAT(1X,' START OPT--SELECT SPACECRAFT TO OPTIMIZE CONDITIONALLY
.'/ L=',G12.6,' LJMX=',G12.6,' XMAXP=',G12.6)
IF (LJMX(L) .EQ. 0) GO TO 100
IF (XMAXP(L) .LE. 0.) GO TO 100
IP=IPTYP(L)
PY1=XPOW(LJMX(L))*(1.+IP*XPOWD(LJMX(L)))
IT(PX1 .IT. 50.) PX1=50.
PNC=0.
IF (TUP .NE. 0) PNC=(XMP(L)-PY1)/IUP
IT(PNC .IT. 0.) WRITE (3,81) PNC,XMP(L),PX1
81 FORMAT(5X,'** WARNING ** -- INVALID MAX POWER INCREMENT -- PNC=',
P15.7,' L=',I3,' XMP=',P15.7,' PX1=',P15.7)
C41N(L)=1.275
CLPT=0
PMXP=PVMAX(L)
IF (T15 .EQ. 1) WRITE (3,82) PMXP
82 FORMAT(1X,' SET CURRENT MAX PWR PMXP=PVMAX=',G12.6)
IF (PMXP .LE. XMP(L) .AND. PMXP .GT. PX1 .AND. PMXP .GT. 50.) GO
TO 115
WRITE (3,116) PMXP,L
116 FORMAT(5X,'** WARNING ** -- PMXP OUT OF RANGE -- PMXP=',P15.7,' L=
',I3,' PMXP=',P15.7,' XMAXP=',P15.7)
GO TO 100

C
115 DO 120 J=1,JMAX
IF (T15 .EQ. 1) WRITE (3,117) L,J,LMTSS(J)
117 FORMAT(' OPT INIT SUMMING COSTS FOR MISSIONS ASSIGNED TO S/C',I3,
' AT CURRENT MAX PWR-- LMTSS',I3,' =',I4)
IF (LMTSS(J) .NE. L) GO TO 120
P=XPOW(J)*(1.+IP*XPOWD(J))
IF (P .GT. PMXP) WRITE (3,123) J,L,P,XPOW(J),XPOWD(J),IP
XPLT=XPLTIG(J)*(XPOW(J)+1.)+.99999
Z=RTCT1(I,J,PMXP)
CLPT=CLPT+Z*P*P*P
IF (T15 .EQ. 1) WRITE (3,9993) CHAR(116),P,CHAR(88),CLPT,CHAR(84),L
,CHAR(85),J,CHAR(111),XPLT
120 CONTINUE

C41N(L)=CLPT
IF (T15 .EQ. 1) WRITE (3,124) CLPT,PMXP,L
124 FORMAT(1X,' INITIAL COST AT CURRENT MAX PWR TO FIX ALL ASSIGNMENTS
, L=',G12.6,' CURRENT PWR, PMXP=',G12.6,' L=',G12.6/
' PROCEED TO OPTIMIZE COST OVER MAX POWER RANGE')

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DO 130 I=1,IUP1
CLRT=0
PMXP=PX1+(I-1)*PNC
IF (TR3 .EQ. 1) WRITE(3,121) PMXP,PX1,PNC,I
121 FORMAT(' OPT OPTIMIZING LOOP OVER MAX PWR PMXP=',G12.6,' PX1=',
.G12.6,' PNC=',G12.6,' I=',I5)
C
DO 140 J=1,JMAX
IF (LMISS(J) .NE. 1) GO TO 140
NFLT=NFLIGHT(J)*(XPSP(J)+1.)+.99999
P=XPWP(J)*(1+IP*XPWP(J))
IF (P .GT. PMXP) WRITE(3,123) J,L,P,XPWP(J),XPWP(J),IP
123 FORMAT(1X,'** ERROR ** -- MISSION',I3,' ASSIGNED TO SPACECRAFT',I3
.,' REQUIRING',G12.6,' WATTS HAS POWER REQUIREMENT CONFLICTS' /
.1X,' XPWP=',G12.6,' XPWP=',G12.6,' IP*YP=',G12.6)
R=RTCT1(L,J,PMXP)
CLRT=CLRT+P*NFLT
IF (TR3 .EQ. 1) WRITE(3,99990) CHAR(116),R,CHAR(88),CLRT,CHAR(84),L
.,CHAR(85),J,CHAR(111),NFLT
140 CONTINUE
C
IF (TR3 .EQ. 1) WRITE(3,145) L,CLRT,PVMAX(L)
145 FORMAT(1X,' MAX PWR OPT LOOP FINISHED FOR S/C',I3,' ASGNMNTS COST,
.CLRT=',G12.6/' MXPWP PVMAX SET AT',G12.6)
IF (CLRT .GE. CLMN(L)) GO TO 130
CLMN(L)=CLRT
PVMAX(L)=PMXP
IF (PVMAX(L) .GT. 50) GO TO 142
WRITE(3,141) L,PVMAX(L)
141 FORMAT(1X,'PVMAX',I3,' = ',G12.7,' IS ILLEGAL -- DEFAULT TO 50.0 P
.ERFORMED')
PVMAX(I)=50.
142 CONTINUE
WRITE(3,99990) CHAR(91),PVMAX(L)
130 CONTINUE
C
CM1=CM1+CLMN(L)
100 CONTINUE
C
DO 305 J=1,JMAX
IF (LMISS(J) .NE. 0) GO TO 305
NFLT=NFLIGHT(J)*(XPSP(J)+1.)+.9999
CM1=CM1+DCCN(J)+(PCTN(J)+TCN(J))*NFLT
305 CONTINUE
IF (TF5 .EQ. 1) WRITE(3,144) CM1,CMDL,L
144 FORMAT(' MAX PWR OPT LOOP FINISHED FOR ALL S/C, NEW MODEL CST,CM1
.= ',G12.6,' OLD MODEL CST,CMDL=',G12.6)
IF (TF5 .EQ. 1) WRITE(3,102) CMDL,CM1,CDEL
102 FORMAT(' CONVERGENCE CRITERION CMDL-CM1 < CDEL,CMDL=',G12.6,
.' CM1=',G12.6,' CDEL=',G12.6/' OPT ASGN NEXT')
IF (CMDL-CM1 .LT. CDEL) GO TO 240
CMDL=CM1
NCT1=NCT1+1
IFIG1=0
IF (TF5 .EQ. 1) WRITE(3,103) CMDL
103 FORMAT(' NEW MODEL COST,CMDL=',G12.6,' PROCEEDING TO RE-ASSIGN MI
.SSIGNS TO SPACECRAFT')

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C
DO 200 J=1,JMAX
L=IMISS(J)
NFLT=NFLTGT(J)*(XP5D(J)+1.) + .9999
CLM1=DCRN(J)/NFLT + RCTN(J) + TCTN(J)
IFLG2=0
IF (TR3 .EQ. 1) WRITE(3,201) CLM1,NFLT,J
201  FORMAT(' OPT ASGN -- SET MISSION NSTD COST CLM1=',G12.6,' NFLT=',
.G12.6,' J=',G12.6)
C
DO 210 L=1,LMAX
IF (TR3 .EQ. 1) WRITE(3,202) LJMX(I),MMISS(J),IAC(J),IACS(L),
.XMAXP(L)
202  FORMAT(' FIND CHEAPEST SPACECRAFT FOR MISSION OR NSTD'/
.' LJMX=',G12.6,' MMISS=',G12.6,' IAC=',G12.6,' IACS=',G12.6,
.' YMAXP=',G12.6)
IF (LJMX(I) .EQ. 0) GO TO 210
IF (MMISS(J) .NE. I .AND. MMISS(J) .NE. 0) GO TO 210
IF (IAC(J)*IACS(L) .EQ. 3) GO TO 215
IF (XMAXP(L) .LE. 0.) GO TO 215
IF (XP5D(J)*(1.+IPTYP(L)*XP5D(J)) .GT. PVMAX(L)) GO TO 215
CLRT=RTDCT2(L,I,PVMAX(L))
IF (TR3 .EQ. 1) WRITE(3,203) L,CLRT,CLM1
203  FORMAT(' CHOOSE CHEAPEST S/C,COST OF S/C',I3,' =CLRT=',G12.6,
.' PREVIOUS LOWEST COST=CLM1=',G12.6)
IF (CLRT .GE. CLM1) GO TO 210
CLM1=CLRT
IF (LMISS(J) .NE. L) IFLG1=1
LMISS(J)=L
IFLG2=1
GO TO 210
215  CONTINUE
NUMSTM=215
IF (MMISS(J) .EQ. 1) WRITE(3,216) J,L,NUMSTM
216  FORMAT(1X,'** ERROR ** -- MISSION',I3,' DEDICATED TO S/C',I3,' IS
.UNASSIGNABLE DUE TO MISSION/SPACECRAFT PFO INCOMPAT, STMT',I5)
210  CONTINUE
C
IF (IFLG2 .EQ. 0) WRITE(3,220) J
IF (IFLG2 .EQ. 0) MMISS(J)=0
220  FORMAT(5X,'** NOTE ** -- MISSION',I3,' CAN NOT BE ASSIGNED TO AN
.Y SPACECRAFT')
200  CONTINUE
C
GO TO 230
240  CONTINUE
C
DO 260 L=1,LMAX
LJMX(L)=0
260  CONTINUE
C
DO 250 J=1,JMAX
I=IMISS(J)
IF (I .EQ. 0) WRITE(3,251) J
251  FORMAT(' ** NOTE ** -- MISSION',I3,' WAS NOT ASSIGNED IN OPTMIX A
.VD WILL BE FOUND NON-STANDARDIZED')
IF (I .NE. 0) LJMX(L)=1

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```

250  CONTINUE
C
DO 270 L=1,IMAX
IF (LJMY(L) .NE. 1) WRITE(3,271) L
271  FORMAT(' ** NOTE ** -- SPACECRAFT',I3,' WAS NOT ASSIGNED ANY MISS
.IONS IN OPTMIX')
270  CONTINUE
C
WRITE(3,99990) CHAR(95),CMDL,CHAR(92),CM1,CHAR(108),IFLG1,
.CHAR(107),NCT1
WRITE(3,99991) CHAR(91), (PVMAX(L), L=1, LMAX)
RETURN
END

```

```

FUNCTION COST(L,J,PMXP)
COMMON/BLOCK/XA(10),XB(10),JMAX,IMAX,IPMAX,XDR(5),LMAX,NMAX,
.XPDW(50),XPDWP(50),IAC(50),XPSD(50),XMPD(50),LMISS(50),XPDL(50),
.XCS,XFS,XMPS,XMLS,XMTT(20),XCT(20),XLT(20),XMT(20),XPT(20),
.NMPS(50),XM1(50),XM2(50),XM3(50),XM4(50),XM6(50),XM7(50),XIT(50),
.NAKM(50),XSOLA(50),YMT(50),KN(50),XYRSN(50),CALR(50),KR(50),
.XYRSP(50),YPL(50),XUL(50),XDLF(50),XM1S(20),XM2S(20),XM3S(20),
.XM4S(20),XM6S(20),XM7S(20),XM8S(20),YITS(20),NAKMS(20),IPTYP(20),
.TACS(20),XMAXP(20),MAYPS(20),XPDWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCSTPR(20),XDCSTP(20),KPS(20),XYRSRS(20),
.XSCL(20),XCALRS(20),KGROU(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),XYDPSN(20),XYPSNS(20),XULP(20),XULSC(20),XULPL(20),
.XHISCL(20),IUP,CDFL,IACN(50),XXMP(20)
COMMON/MMODL/MO(30,50)
COMMON/FLOW/NFV1,NFV2,NFV3,NFV4,NFV5,NFV6,NFV7,NFV8,NFV9,NFV10,
.NFV11,NFV12,NFV13,NFV14,NFV15,NFV16,NFV17,NFV18,NFV19,NFV20,
.NFV21,NFV22,NFV23,NFV24,NFV25,NFV26,NFV27,NFV28,NFV29,NFV30,
.TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10
COMMON/LOCAL/LJMX(20),NFLJGT(50),JPMX(50,2),IUP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVMAX(20),MMISS(50)
COMMON/CHAPAC/CHAP(130)
COMMON/ROUTNS/ROU(50)
REAL*8 ROU
REAL*8 CHAR
INTEGER TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10
99990 FORMAT((1X,6(A6,'=' ,G12.6,1X)))
99991 FORMAT(1X,A6,'=' ,1X,8G14.7))
99992 FORMAT('?',10A8)
COST=).
C
C
ENTRY PTCM1(L,J,PMXP)
IF(TR1 .EQ. 1) WRITE(6,99992) ROU(20)
IFNT=1
GO TO 100
120 PTCM1=PCST+TPNCST
RETURN
C
ENTRY PTCM2(L,J,PMXP)
IF(TR1 .EQ. 1) WRITE(6,99992) ROU(21)
IFNT=2
GO TO 100
200 PTCM2=PCST+TPNCST
RETURN
C
ENTRY PCTS(L,J,PMXP)
IF(TR1 .EQ. 1) WRITE(6,99992) ROU(22)
IFNT=3
GO TO 100
300 PCPS=PCST
RETURN
C
ENTRY DCIS(I,PMXP)
IF(TR1 .EQ. 1) WRITE(6,99992) ROU(43)
DM2=XDPW(L)*(PMXP-XMAXP(L))
IF(PMXP .GT. XYMP(L)) WRITE(6,510) DM2,XDPW(L),PMXP,XMAXP(L),L
510 FORMAT(1Y,'** REFOR ** -- INVALID MASS DIFFERENTIAL DUE TO POWER P

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.APARATEMP INCONGRUITIES --'/T16,' DM2='G12.6,' YDPW='G12.6,
.' PMXP='G12.6,' XMAXP='G12.6,' L='I3)
DM1=SK1(I)*DM2
DM6=SK6(L)*DM2
DM7=SK7(L)*DM2
DCTS=DCPS(DM1,DM2,D40,DM7,L)
DCTS=1.13*2.06*1.4*DCTS
IF(TP2 .EQ. 2) WRITE(6,515) DCTS,PMXP,L
515 FORMAT(1X,'DCTS='G12.6,' PMXP='G12.6,' L='I3)
RETURN
C
ENTRY TCTS(L,J,PMXP)
IF(TP1 .EQ. 1) WRITE(6,9992) ROU(23)
IFMT=4
GO TO 100
400 TCTS=TFNCST
RETURN
C
ENTRY FCTN(J)
IF(TP1 .EQ. 1) WRITE(6,9992) ROU(24)
RCTN=RCFEN(J)
RCTN=1.13*2.06*1.3*RCTN
IF(TP2 .EQ. 2) WRITE(6,472) J,RCTN
472 FORMAT(1X,'RCTN',I3,' ='G12.6)
RETURN
C
ENTRY DCTN(J)
IF(TP1 .EQ. 1) WRITE(6,9992) ROU(25)
DCTN=DCFEN(J)
DCTN=1.13*2.06*1.4*DCTN
IF(TP2 .EQ. 2) WRITE(6,473) J,DCTN
473 FORMAT(1X,'DCTN',I3,' ='G12.6)
RETURN
C
ENTRY TCTN(J)
IF(TP1 .EQ. 1) WRITE(6,9992) ROU(26)
XF1=XMT(J)/XMP(T(NIPS(J)))
XF=XPL(J)/(XMLS-YLF(NIPS(J)))
IF(XF1 .GT. XF) XF=XF1
SF=(YMTT(NIPS(J))*XF+XMT(J))/XMP
SF1=(YLT(NIPS(J))*XF+XPL(J))/XMLS
IF(SF1 .GT. SF) SF=SF1
TCFN=SF*XCS*XMP/YFS+YF*XCT(NIPS(J))/XFT(NIPS(J))
IF(TP2 .EQ. 2) WRITE(6,474) J,TCFN
474 FORMAT(1X,'TCFN',I3,' ='G12.6)
RETURN
C
100 IF(IACS(L)*IAC(J) .NE. 3) GO TO 1
WRITE(6,2) I,J
2 FORMAT(5X,'** ERROR ** -- SPACECRAFT TYPE ('I2,') AND MISSION ('
.,I3,') HAVE INCOMPATIBLE STABILIZATION REQUIREMENTS'/26X,'FIXUP PP
.OCEDURE TAKEN'/)
10 CONTINUE
NUMSTM=10
IF(MISS(J) .EQ. 1) WRITE(6,21) J,I,NUMSTM
21 FORMAT(1X,'MISSION',I3,' DEDICATED TO',I3,' HAS CONFLICTS,NUMSTM='
.,I5)

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```

IF (IENT .NE. 1) GO TO 16
RCST=0.
TRNCST=0.
GO TO 120
16 IF (IENT .NE. 2) GO TO 17
RCST=1E7F
TRNCST=0.
GO TO 200
17 IF (IENT .NE. 3) GO TO 18
RCST=0.
WRITE (6,10) I,J
19 FORMAT (5X,'** ERROR ** -- RECURRING COST DEFAULTED TO ZERO -- IENT
.=',I14,' SPACECRAFT',I3,' AND MISSION',I3,' INVOLVED')
GO TO 300
18 WRITE (6,11) IENT,PMXP
11 FORMAT (5X,'** ERROR ** -- FIXUP NOT POSSIBLE -- IENT=',I2,' PMXP'
.,F8.3,' I=',I2,' J=',I3)
RCST=0.
TRNCST=0.
GO TO (120,200,300),IENT
WRITE (6,710) IENT,I,J
710 FORMAT (1X,'** SEVERE ERROR ** -- INVALID IENT=',I10,' L=',I3,' J=
.,I3)
RETURN
C
1 DMIS=XPOW (J)*(1+IPTYP (L)*XPOW (J))
RCST=0.
IF (TR4 .EQ. 1.) WRITE (6,99990) CHAR (99),PMIS,CHAR (90),PMXP,
.CHAR (91),PVMAX (L),CHAR (56),XMAXP (L)
IF (PMIS .GT. PMXP) GO TO 10
IF (PMXP .LT. 50.) GO TO 18
IF (PMXP .GT. XMAXP (L)) WRITE (6,3) PMXP,XXMP (I),L
3 FORMAT ('** ERROR ** - COST ROUTE, PMXP>MAX PERMISS PWR,',
.'PMXP=',G12.5,' XXMP=',G12.5,' L=',I4)
DM2=XPOW (L)*(PMXP-XMAXP (L))
DM1=SK1 (I)*DM2
DM6=SK6 (L)*DM2
DM7=SK7 (I)*DM2
GO TO (12,13),NEVS
12 CONTINUE
R=RPWR1 (PMIS,PMXP,L,LVLIP)
RCST=RCST+R
IF (TR4 .EQ. 1) WRITE (6,99990) CHAR (125),R
GO TO 14
13 CONTINUE
R=RPWR2 (PMIS,PMXP,L,LVLIP)
RCST=RCST+R
IF (TR4 .EQ. 1) WRITE (6,99990) CHAR (126),R
14 CONTINUE
GO TO (160,160,160,110),IENT
C
160 CONTINUE
R=RCFRS (DM1,DM6,DM7,L)
RCST=RCST+1.13*2.06*1.3*R
IF (TR4 .EQ. 1) WRITE (6,99990) CHAR (112),DM1,CHAR (113),DM2,
.CHAR (114),DM6,CHAR (115),DM7,CHAR (116),RCST
GO TO (110,110,300,150),IENT

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```

110  CONTINUE
      MXPS=MAXPS(L)
      IF(MXPS .EQ. 0) MXPS=1VLP
      YDMS=DM6+DM7+DM1+XM1S(L)+XM3S(L)+XM4S(I)+XM6S(L)+XM7S(L)+
      . XM8S(L)+XMPL(J)+((Y2S(L)+DM2)*LVL2)/MXPS
      XF1=YDMS/XMPT(NUPS(J))
      XF=(XPLL(J)+XSCL(L))/(XMLS-XLT(NUPS(J)))
      IF(XF1 .GT. XF) XF=XF1
      SF=(XMTT(NUPS(J))*XF+YDMS)/XMP5
      SF1=(XIT(NUPS(J))*XF+XPLL(J)+XSCL(L))/XMLS
      IF(SF1 .GT. SF) SF=SF1
      TRNCST=SF*YCS*YMP5/YFS+XF*YCT(NUPS(J))/XFT(NUPS(J))
      IF(TP4 .EQ. 1) WRITE(6,99990) CHAF(123),TRNCST
      GO TO (120,20),300,400),TENT
      WRITE(6,130) TENT
150  WRITE(6,130) TENT
130  FORMAT(5X,'INVALID PROGRAM FLOW -- ILLEGAL VALUE OF TENT AT BRANCH
      . POINT -- TENT-',T15)
      RETURN
      END

```



```

FUNCTION CFP (DM1,DM6,DM7,L)
COMMON/BLOCK/XA(10),XR(10),JMAX,IMAX,IRMAX,XDP(5),LMAX,NMAX,
.XPOW(50),XPOWD(50),JAC(50),XPSP(50),XMPL(50),LMISS(50),XPLL(50),
.XCS,XPS,YXPS,XMLS,XMTT(20),XCT(20),XLT(20),XMPT(20),XPT(20),
.NUPS(50),XM1(50),XM2(50),XM3(50),XM4(50),XM6(50),XM7(50),XTT(50),
.NAKM(50),XSCLA(50),XMT(50),KN(50),XYRSV(50),CALR(50),KR(50),
.XYRSP(50),XPL(50),XUL(50),XDLP(50),XM1S(20),XM2S(20),XM3S(20),
.XM4S(20),XM6S(20),XM7S(20),XM8S(20),XITS(20),NAKMS(20),IPTYP(20),
.IACS(20),XMAXP(20),MAXPS(20),XPWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCSTPP(20),XDCSTR(20),KRS(20),XYRSRS(20),
.XSCL(20),XCALRS(20),KGROUP(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),XYISPN(20),XYRSNS(20),XULP(20),XULSC(20),XULPL(20),
.XULSCL(20),IUP,CDFL,IACN(50),XXMP(20)
COMMON/MMODL/NO(30,50)
COMMON/FLOW/NFV1,NFV2,NFV3,NFV4,NFV5,NFV6,NFV7,NFV8,NFV9,NFV10,
.NFV11,NFV12,NFV13,NFV14,NFV15,NFV16,NFV17,NFV18,NFV19,NFV20,
.NFV21,NFV22,NFV23,NFV24,NFV25,NFV26,NFV27,NFV28,NFV29,NFV30,
.TF1,TF2,TR3,TR4,TF5,TR6,TR7,TR8,TF9,TR10
COMMON/LOCAL/LJMX(20),NFLGT(50),JPMX(50,2),IUP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVWAY(20),MMISS(50)
COMMON/CHARAC/CHAR(130)
COMMON/ROUTNS/ROU(50)
RFAL*8 ROU
RFAL*8 CHAR
INTEGDE TR1,TF2,TF3,TF4,TR5,TR6,TR7,TR8,TF9,TR10
99992 FORMAT(1Y,10A8)
99990 FORMAT((1X,6(A6,'=' ,G12.6,1X)))
C
CFR=0
C
ENTRY PCFRS(DM1,DM6,DM7,L)
IF(TF1.EQ.1) WRITE(6,99992) ROU(27)

```

```

RCER=0.
IF (XM1S(I) .LE. 0.) GO TO 10
RCER=42.61+1.32*((2.2046*(XM1S(L)+DM1))**.9)
10 IF (XM3S(L) .LE. 0.) GO TO 20
RCER=RCER-113.59+13.36*XM3S(L)
20 IF (XM4S(L) .LE. 0.) GO TO 30
RCER=RCER+7.8+10.65*XM4S(L)
30 IF (XM6S(L) .LE. 0.) GO TO 40
RCER=72.78+5.4*IACS(L)*(XM6S(L)+DM6)+RCER
40 IF (XM7S(L) .LE. 0.) GO TO 50
RCER=13.64+.4*(XM7S(L)+DM7)+RCER
50 IF (XAKMS(I) .LE. 0) GO TO 60
RCER=33.4*XAKMS(L)+RCER
60 CONTINUE
RCERS=RCER
RETURN

C
ENTRY DCERS(DM1,DM2,DM6,DM7,L)
IF (TF1 .EQ. 1) WRITE(6,99992) POU(28)
IF (TF2 .EQ. 2) WRITE(6,99990) CHAR(112),DM1,CHAR(113),DM2,
CHAR(114),DM6,CHAR(115),DM7,CHAR(84),L
DCERS=0.
IF (XM1S(L) .LE. 0.) GO TO 110
DCERS=579.49+29.7*(2.2046*(XM1S(L)+DM1))**.63
110 IF (TF2 .EQ. 2) WRITE(6,119) DCERS
FORMAT(1X,'DCERS=',G14.7)
110 IF (XM3S(L) .LE. 0.) GO TO 120
DCERS=DCERS+335.1*(2.2046*XM3S(L))**.36
120 IF (TF2 .EQ. 2) WRITE(6,119) DCERS
IF (XM4S(L) .LE. 0.) GO TO 130
DCERS=DCERS+332.0*(2.2046*XM4S(L))**.44
130 IF (TF2 .EQ. 2) WRITE(6,119) DCERS
IF (XM6S(L) .LE. 0.) GO TO 140
DCERS=DCERS+28.88+33.97*(XM6S(L)+DM6)+418.32*IACS(L)
140 IF (TF2 .EQ. 2) WRITE(6,119) DCERS
CONTINUE
XPMS=DM1+DM2+DM6+DM7+XM1S(L)+XM2S(L)+XM3S(L)+XM4S(L)+XM6S(L)+
XM7S(L)+XM8S(L)
DCERS=DCERS-28.4+6.53*XPMS
150 IF (TF2 .EQ. 2) WRITE(6,119) DCERS
IF (XITS(L) .LE. 0.) GO TO 160
DCERS=DCERS-207.16+2.473*XITS(L)
160 IF (TF2 .EQ. 2) WRITE(6,119) DCERS
CONTINUE
RETURN

C
ENTRY RCERN(J)
IF (TF1 .EQ. 1) WRITE(6,99992) POU(29)
RCERN=0.
IF (XM1(J) .LE. 0.) GO TO 210
RCERN=42.61+1.32*(2.2046*XM1(J))**.9
210 IF (XM3(J) .LE. 0.) GO TO 220
RCERN=RCERN-113.59+13.36*XM3(J)
220 IF (XM4(J) .LE. 0.) GO TO 230
RCERN=RCERN+7.8+10.65*XM4(J)
230 IF (XM6(J) .LE. 0.) GO TO 240
ISAC=IACN(J)
IF (ISAC .EQ. 2) ISAC=1

```

```

      RCFERN=RCFERN+72.78+5.4*XM6(J)*TSAC
240  IF(XM7(J) .LE. 0.) GO TO 250
      RCFERN=RCFERN+13.64+.4*XM7(J)
250  IF(NAKM(J) .LE. 0.) GO TO 260
      RCFERN=RCFERN+33.4*NAKM(J)
260  CONTINUE
      IF(XM2(J) .LE. 0. .OR. XSOLA(J) .LE. 0.) GO TO 270
      RCFERN=RCFERN+103.27+1.24*(23.73*XM2(J)*XSOLA(J))**.55
270  CONTINUE
      RETURN
C
      ENTRY DCFERN(J)
      IF(TF1 .EQ. 1) WRITE(6,99992) ROU(30)
      DCFERN=0.
      IF(XM1(J) .LE. 0.) GO TO 310
      DCFERN=579.49+29.7*(2.2046*XM1(J))**.63
310  IF(XM3(J) .LE. 0.) GO TO 320
      DCFERN=DCFERN+335.1*(2.2046*XM3(J))**.36
320  IF(XM4(J) .LE. 0.) GO TO 330
      DCFERN=DCFERN+332.*(2.2046*XM4(J))**.44
330  IF(XM6(J) .LE. 0.) GO TO 340
      TSAC=IACN(J)
      IF(TSAC .EQ. 2) TSAC=1
      DCFERN=DCFERN+28.88+39.97*XM6(J)+412.92*TSAC
340  IF(XMT(J) .LE. 0.) GO TO 350
      DCFERN=DCFERN-28.4+6.53*XMT(J)
350  IF(XIT(J) .LE. 0.) GO TO 360
      DCFERN=DCFERN-207.16+48.93*XIT(J)
360  CONTINUE
      PMXP=XPOW(J)*(1.+XPOW(J))
      DCFERN=DCFERN+120.84*PMXP**.45
      RETURN
C
      ENTRY RCFERS1(DM1,DM2,DM6,DM7,PMXP,L)
      IF(TF1 .EQ. 1) WRITE(6,99992) ROU(31)
      IF(NAKMS(L) .LT. 0 .OR. NAKMS(L) .GT. 100) WRITE(6,70)
      .CHAR(53),I,NAKMS(L)
      GO TO 80
C
      ENTRY DCFERS1(DM1,DM2,DM6,DM7,PMXP,L)
      IF(TF1 .EQ. 1) WRITE(6,99992) ROU(32)
      IF(XITS(I) .LT. 11.69 .OR. XITS(L) .GT. 47.88) WRITE(6,70)
      .CHAR(52),L,XITS(L)
      GO TO 30
C
      ENTRY RCFERN1(J)
      IF(TF1 .EQ. 1) WRITE(6,99992) ROU(33)
      IF(NAKM(J) .LT. 0 .OR. NAKM(J) .GT. 100) WRITE(6,70)
      .CHAR(34),J,NAKM(J)
      IF(XM2(J) .LT. 0.) WRITE(6,70) CHAR(28),J,XM2(J)
      IF(XSOLA(J) .LT. 1.208 .OR. XSOLA(J) .GT. 40.69) WRITE(6,70)
      .CHAR(35),J,XSOLA(J)
      GO TO 30
C
      ENTRY DCFERN1(J)
      IF(TF1 .EQ. 1) WRITE(6,99992) ROU(34)
      IF(XIT(J) .LT. 231.31 .OR. XIT(J) .GT. 947.47) WRITE(6,70)
      .CHAR(33),J,XIT(J)

```

```

GO TO 90
CONTINUE
IF (XM1S(I)+DM1 .LT. 6.8 .OR. XM1S(L)+DM1 .GT. 331.1) WRITE(6,70)
.CHAP(45),L,XM1S(I)
IF (XM3S(I) .LT. 3.63 .OR. XM3S(L) .GT. 71.67) WRITE(6,70)
.CHAP(47),L,XM3S(L)
IF (XM4S(I) .LT. 5.90 .OR. XM4S(L) .GT. 104.33) WRITE(6,70)
.CHAP(48),L,XM4S(L)
IF (XM6S(I)+DM6 .LT. 1.36 .OR. XM6S(L)+DM6 .GT. 81.65) WRITE(6,70)
.CHAP(49),L,XM6S(L)
IF (XM7S(L)+DM7 .LT. 7.71 .OR. XM7S(L)+DM7 .GT. 14.1) WRITE(6,70)
.CHAP(50),L,XM7S(L)
DCFRS1=1
RCFRS1=1
70  FORMAT(1X,'CRR BOUNDRY VIOLATED ',A6,1X,I3,1X,'= ',G15.7,
.A6,' = ',G15.7)
RETURN

```

```

C
90  CONTINUE
IF (XM1(J) .LT. 6.8 .OR. XM1(J) .GT. 331.1) WRITE(6,70)
.CHAP(27),J,XM1(J)
IF (XM3(J) .LT. 3.63 .OR. XM3(J) .GT. 71.67) WRITE(6,70)
.CHAP(29),J,XM3(J)
IF (XM4(J) .LT. 5.90 .OR. XM4(J) .GT. 104.33) WRITE(6,70)
.CHAP(30),J,XM4(J)
IF (XM6(J) .LT. 1.36 .OR. XM6(J) .GT. 31.65) WRITE(6,70)
.CHAP(31),J,XM6(J)
IF (XM7(J) .LT. 7.71 .OR. XM7(J) .GT. 14.1) WRITE(6,70)
.CHAP(32),J,XM7(J)
RCFRN1=2
DCFRN1=3
RETURN

```

```

C
ENTRY RPWR1(PMIS,PMXP,L,LVLP)
IF (TR1 .EQ. 1) WRITE(6,99992) ROW(35)
LVLP=PMIS*MAXPS(L)/PMXP+.99999
IF (LVLP .LT. 1) WRITE(6,400) LVLP,PMIS,MAXPS(L),PMXP,L
400  FORMAT(' ** POWER ** -- ILLEGAL POWER LEVEL'/' LVLP=',
.G12.5,' PMIS=',G12.5,' MAXPS=',G12.5,' PMXP=',G12.5,
.' L=',G12.5)
MAXPS=MAXPS(L)
IF (MAXPS .LE. 0) MAXPS=LVLP
RPWR1=(LVLP*(XCSTR(L)+XDCSTR(L)*(PMXP-XMAXP(L))))/MAXPS
IF (TR4 .EQ. 1) WRITE(6,99990) CHAP(100),LVLP,CHAP(90),PMXP,
.CHAP(125),RPWR1,CHAP(56),XMAXP(L),CHAP(57),MAXPS(L),CHAP(63),
XCSTR(L),CHAP(64),XDCSTR(L),CHAP(99),PMIS
RETURN

```

```

C
ENTRY RPWR2(PMIS,PMXP,L,LVLP)
IF (TR1 .EQ. 1) WRITE(6,99992) ROW(36)
LVLP=(PMXP-PMIS)/(XPWSS(L)*PMXP)
DP=LVLP*XPWSS(L)*PMXP
RPWR2=XCSTR(L)+XDCSTR(L)*(PMXP-XMAXP(L))-DP
RETURN

```

```

C
ENTRY SPREAD(B,A,S)
SPREAD=((((10.0*B-4.0)*S+(10.0*A-20.0*B+5.0))*S+(10.0*B-20.0*A))*
*S+(10.0*A))*S*S
RETURN
END

```

```

SUBROUTINE PVCOST
COMMON/BLOCK/YA(10),XB(10),JMAX,IMAX,TPMAX,XDR(5),LMAX,NMAX,
.XPDW(50),YPDW(50),IAC(50),XPSP(50),XMPL(50),LMTSS(50),XPLL(50),
.XCS,XPS,XMPS,XMLS,XMTT(20),YCT(20),XLT(20),XMP(20),XFT(20),
.VUES(50),YM1(50),YM2(50),YM3(50),YM4(50),YM6(50),YM7(50),XIT(50),
.NAKM(50),XSOLA(50),XMT(50),KN(50),YRSN(50),CALR(50),KR(50),
.XYRSR(50),YPI(50),YUL(50),XDLP(50),XM1S(20),XM2S(20),YM3S(20),
.XM4S(20),XM6S(20),XM7S(20),XM8S(20),XITS(20),NAKMS(20),IPTYP(20),
.IACS(20),XMAXP(20),MAYPS(20),XPWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCSTPR(20),XDCSTR(20),KRS(20),XYRSPS(20),
.XSCL(20),XCALPS(20),KGROUP(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),YYFSDN(20),YYRSNS(20),XULP(20),XULSC(20),XULPL(20),
.XULSCI(20),IUP,CDFL,IACN(50),XXMP(20)
COMMON/MMODL/NO(30,50)
COMMON/FLOW/NFV1,NFV2,NFV3,NFV4,NFV5,NFV6,NFV7,NFV8,NFV9,NFV10,
.NFV11,NFV12,NFV13,NFV14,NFV15,NFV16,NFV17,NFV18,NFV19,NFV20,
.NFV21,NFV22,NFV23,NFV24,NFV25,NFV26,NFV27,NFV28,NFV29,NFV30,
.TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10
COMMON/LOCAL/LJMX(20),NFLIGT(50),JPMX(50,2),IUP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVMAX(20),PMISS(50)
COMMON/CHARAC/CHAR(130)
COMMON/ROUTNS/ROU(50)
REAL*8 ROU
REAL*8 CHAR
INTEGER TP1,TP2,TP3,TP4,TP5,TP6,TP7,TR8,TR9,TR10
COMMON/LOC2/XORT(30,70),XCFR(30,70),XCF(30),XPV(5),INDX(50),
.XCFPS(30,20),NNCN
DIMENSION ZCT(20),YCT(20),LKNT(20),LFLAG(20),IULSCT(20),
.IULPCT(20),XCFDS(30,50)
DIMENSION XNRT(50),XURT(50),XNPS(20)
EQUIVALENCE (XCFDS(1,1),XORT(1,1))

```

```

END SUBROUTINE PVCOST

```

```

IF (TP1 .EQ. 1) WRITE(6,99992) ROU(37)

```

```

99992 FORMAT(1X,10A3)

```

```

99991 FORMAT(1X,A6,' = ',(1X,8G12.7))

```

```

LJ=LMAX+JMAX

```

```

DO 530 J=1,LJ

```

```

DO 531 I=1,IMAX

```

```

XCFR(I,J)=0.

```

```

XCFDS(I,J)=0.

```

```

531 CONTINUE

```

```

530 CONTINUE

```

```

DO 30 M=1,IMAX

```

```

XNPS(M)=DCFS(M,PVMAX(M))

```

```

IF (NFV9 .EQ. 1) CALL DSCHK(M,PVMAX(M))

```

```

ZCT(M)=XULSC(M)

```

```

YCT(M)=XULP(M)

```

```

LKNT(M)=1

```

```

IULSCT(M)=1

```

```

IULPCT(M)=1

```

```

LFLAG(M)=1

```

```

DO 9 I=1,IMAX
XCFDS(I,M)=0.
CONTINUE

30 CONTINUE

DO 11 I=1,IMAX
XCF(I)=0.
CONTINUE

11 C
DO 12 IF=1,IFMAX
XDV(IF)=0.
CONTINUE

12 C
IF(TEMP .EQ. 1) WRITE(6,41) (XNRS(M),M=1,LMAX)
41 FORMAT(1X,'XNRS=',(1X,BG14.7))

DO 10 J=1,JMAX
IF(XFSP(J) .EQ. 0.) GO TO 10
NTOT=0
NSPT=0

C
DO 20 I=1,IMAX
NTOT=NTOT+NO(I,J)
IF(XFSP(J)*NTOT .LE. NSPT) GO TO 20
IADD=INT(YFSP(J)*NTOT+.9999)-NSPT
IF(NSPT .EQ. 0) IADD=IADD-1
NO(I,J)=NO(I,J)+IADD
NSPT=YFSP(J)+IADD
IF(NSPT .EQ. IADD) NSPT=NSPT+1
20 CONTINUE

10 CONTINUE

DO 40 I=1,IMAX

C
DO 50 J=1,JMAX
IF(TEMP .EQ. 1) WRITE(6,58) I,J,LMISS(J),NO(I,J)
58 FORMAT(1X,'I=',I3,' J=',I3,' LMISS=',I3,' NO(I,J)=',I6)
L=LMISS(J)
IF(L .EQ. 0) GO TO 50
IF(NO(I,J) .EQ. 0) GO TO 50
IF(ZCT(L) .LT. XHLSCL(L)) GO TO 52
ZCT(L)=ZCT(L)-XHLSCL(L)
IF(ZCT(L) .GE. 1.) ZCT(L)=0.
ITNSTP=YFSPNS(L)+.9999
XTNSTP=ITNSTP-XFSPNS(L)
KNI=KNS(L)
SPRID1=0.
CST=XFDS(L)*XHLSCL(L)*XHLSCL(L)
XCFDS(I,L)=XCFDS(I,L)+CST
IF(TEMP .EQ. 1) WRITE(6,59) CST,XCFDS(I,L),I,J,L
59 FORMAT(1X,'CST=',G12.6,' XCFDS=',G12.6,' I=',I3,' J=',I3,' L=',I3)

C
DO 60 IT=1,ITNSTP
XR=(IT-XTNSTP)/XFSPNS(L)
IF(XR .GT. 1.) XR=1.

```

```

ITLP=1-ITNSTP+IT-1
IF (ITLP .LT. 1 .OR. ITIP .GT. IMAX) GO TO 5050
SPRED2=SPRED(XB(KNL),XA(KNL),XP)
XCF(ITIP)=XCF(ITIP)+(SPRED2-SPRED1)*CST
SPRED1=SPRED2
50 CONTINUE

IULSCP(L)=IULSCP(L)+1
IF (IFLAG(L) .EQ. 0) GO TO 52
XCF(I,I)=XCF(I,I)+BCTS(L,J,PVMAX(L))
LKNT(L)=LKNT(L)+1
LFLAG(L)=0
52 CONTINUE
IF (YCT(L) .LT. YULP(L)) GO TO 70
LL=KGPOUP(L)
YCT(L)=YCT(L)-XULP(L)
IF (YCT(L) .GE. 1.) YCT(L)=0.
POWCST=(YCSTN(I)+YDCSTN(LL)*(PVMAX(L)-XMAXP(L)))
CST=POWCST*IULPCT(L)**YULPL(LL)
XCFPS(I,L)=CST
IF (TF7 .EQ. 1) WRITE(6,53) POWCST,CST,XCFPS(I,L),I,J,L
53 FORMAT(1X,'POWCST=',G12.6,' CST=',G12.6,' XCFPS=',G12.6,' I=',I3,
. ' J=',I3,' L=',I3)
ITNSTP=XYRSPN(LL)+.9999
XTNSTP=ITNSTP-XYRSPN(LL)
KNL=KNSP(LL)
SPRED1=0.

C
DO 80 IT=1,ITNSTP
XP=(IT-XTNSTP)/XYRSPN(LL)
IF (XP .GT. 1.) XR=1.
ITLP=1-ITNSTP+IT-1
IF (ITLP .LT. 1 .OR. ITIP .GT. IMAX) GO TO 5060
SPRED2=SPRED(XB(KNL),XA(KNL),XP)
XCF(ITIP)=XCF(ITIP)+(SPRED2-SPRED1)*CST
SPRED1=SPRED2
80 CONTINUE

IULPCT(L)=IULPCT(L)+1
70 CONTINUE
XCST=BCTS(L,J,PVMAX(L))
IF (TF8 .EQ. 1) WRITE(6,73) XCST,PVMAX(L),XCALRS(L),I,J,L
73 FORMAT(1X,'XCST=',G12.6,' PVMAX=',G12.6,' XCALRS=',G12.6,' I=',I3,
. ' J=',I3,' L=',I3)
NOFND=NO(I,J)

C
DO 90 K=1,NOFND
XCTP(I,L)=XCF(I,I)+XCST*LKNT(L)**XCALRS(L)
LKNT(L)=LKNT(L)+1
90 CONTINUE

IF (TF7 .EQ. 1) WRITE(6,93) XCF(I,I),XCST,L
93 FORMAT(1X,'XCF=',G12.6,' XCST=',G12.6,' L=',I3)
TRNCST=BCTS(L,J,PVMAX(I))
IF (TF7 .EQ. 1) WRITE(6,92) TRNCST,L,J,PVMAX(L),NO(I,J)
92 FORMAT(1X,'TRNCST=',G12.6,' L=',I3,' I=',I3,' PVMAX(L)=',G12.6,
. ' NO(I,J)=',G12.6)

```

```

      XCF(I)=XCF(I)+TPNCS*NO(I,J)
50  CONTINUE
C
      DO 100 M=1,LMAY
      ZCT(M)=ZCT(M)+1.
      YCT(M)=YCT(M)+1.
100  CONTINUE
C
      DO 110 I=1,LMAX
      IF(XCF(I,L).EQ.0.) GO TO 110
      ITFSTP=XYSRS(L)+.9999
      XTRSTP=ITRSTP-XYSRS(I)
      KRL=KRS(I)
      SPRED1=0.
C
      DO 121 IT=1,ITRSTP
      XR=(IT-XFSTP)/XYSRS(L)
      IF(XR.GT.1.) XR=1.
      ITLP=I-ITRSTP+IT
      IF(ITLP.LT.1.OR.ITLP.GT.30) GO TO 5070
      SPRED2=SPRED(XR(KRL),XA(KRL),XR)
      S=SPRED2-SPRED1
      XCF(ITLP)=XCF(ITLP)+XCF(I,L)*(SPRED2-SPRED1)
      IF(TR9.EQ.1) WRITE(6,105) XCF(ITLP),XCF(I,L),S,ITLP,I,L
105  FORMAT(1X,'XCF=',G12.6,' XCF=',G12.6,' S=',G12.6,'ITLP=',
      .I3,' I=',I3,' L=',I3)
      SPRED1=SPRED2
121  CONTINUE
C
110  CONTINUE
C
40  CONTINUE
C
      DO 43 J=1,JMAX
      IF(LMISS(J).EQ.0) GO TO 125
43  CONTINUE
C
540  CONTINUE
C
      DO 131 IP=1,IRMAX
      XDV(IP)=0.
C
      DO 141 I=1,IMAX
      XDV(IP)=XDV(IP)+XCF(I)/((1.0+.005*XDR(IP))*((1.0+.01*XDR(IP))
      .*(I-1)))
      IF(TR10.EQ.1) WRITE(6,143) XDV(IP),XCF(I),XDR(IP),IP,I
143  FORMAT(1X,'XDV=',G12.6,' XCF=',G12.6,' XDR=',G12.6,' IP=',I3,' I='
      .,I3)
C
141  CONTINUE
C
131  CONTINUE
      RETURN
C
      ENTRY NONCST
      IF(TR1.EQ.1) WRITE(6,99992) POU(38)

```



```

DO 37 J=1,JMAX
IF (XPSD(J) .NE. 0.) GO TO 37
NTOT=0
NSPT=0
C
DO 33 I=1,IMAX
NTOT=NTOT+NO(I,J)
IF (XISD(J)*NTOT .NE. NSPT) GO TO 33
IADD=INT(XPSD(J)*NTOT+.9999)-NSPT
IF (NSPT .EQ. 0) IADD=IADD-1
NO(I,J)=NO(I,J)+IADD
NSPT=NSPT+IADD
IF (NSPT .EQ. IADD) NSPT=NSPT+1
33 CONTINUE
C
37 CONTINUE
C
IF (LMAX .NE. 0) GO TO 125
C
DO 38 I=1,IMAX
YCF(I)=0.
DO 39 J=1,JMAX
XOIT(I,J)=0.
YCFR(I,J)=0.
39 CONTINUE
38 CONTINUE
C
125 CONTINUE
IF (TR1 .EQ. 1) WRITE(6,126)
126 FORMAT(' NON-STANDARDIZED PRESENT VALUE COST ALGORITHM')
NNON=0
C
DO 170 J=1,JMAX
JS=J
IF (TR6 .EQ. 1) WRITE(6,1261) JS,LMAX,LMISS(J)
1261 FORMAT(' NONST CALC MISSION COSTS LOOP,J=',I3,' LMAX=',I3,
. ' LMISS=',I3)
IF (LMAX .NE. 0 .AND. LMISS(J) .NE. 0) GO TO 170
IF (LMAX .EQ. 0) GO TO 119
NNON=NNON+1
JS=NNON+LMAX
INDX(NNON)=J
119 CONTINUE
IF (TR6 .EQ. 1) WRITE(6,127) JS,NNON
127 FORMAT(' JS=',G12.6,' NNON=',G12.6)
ITRSTP=YYPSS(J)+.9999
XTRSTP=ITRSTP-YYPSS(J)
ITNSTP=YVPSN(J)+.9999
XTNSTP=ITNSTP-YVPSN(J)
KRJ=KP(J)
KNJ=KN(J)
NOSUM=0
ZCT(1)=XUL(J)
N=1
TRNCSN=TCN(J)
CALL RICPK(J)
YHPT(J)=FCTN(J)

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CALL DNGCHK(J)
XNRT(J)=DCTN(J)
IF (TR6 .EQ. 1) WRITE(6,128) TRNCST,XURT(J),XNRT(J)
128  FORMAT(' MISSION UNIT COSTS  TRNCST=',G12.6,' XURT=',G12.6,
. ' XNRT=',G12.6)
C
DO 160 I=1,IMAX
XORT(I,JS)=0
IF (TR6 .EQ. 1) WRITE(6,129) NO(I,J),NOSUM,I,J
129  FORMAT(' YEARLY COSTS LOOP,NO(I,J)=',G12.6,' NOSUM=',G12.6,
. ' I=',G12.6,' J=',I4)
IF (NO(I,J) .EQ. 0) GO TO 160
XCF(I)=XCF(I)+NO(I,J)*TPNCST
IF (NOSUM .EQ. 0 .AND. XPSP(J) .NE. 0.) NO(I,J)=NO(I,J)+1
NOEND=NOSUM+NO(I,J)
NOSUM=NOSUM+1
C
DO 120 K=NOSUM,NOEND
XCFR(I,JS)=XCFR(I,JS)+XURT(J)*V**CALR(J)
120  CONTINUE
C
IF (TR6 .EQ. 1) WRITE(6,132) XCFR(I,JS),XURT(J),CALR(J),I,JS
132  FORMAT(' AFTER SUMMING RECUR COSTS WITH LEAPNING,XCFR(I,JS)=',
. G12.6,' XURT=',G12.6,' CALR=',G12.6,' I=',I3,' JS=',I3)
SPRED1=0.
C
DO 130 IT=1,ITRSTP
XR=(IT-ITRSTP)/YRSP(J)
IF (XR .GT. 1.) XR=1.
ITLP=I-ITRSTP+IT
IF (ITLP .LT. 1 .OR. ITLP .GT. 30) GO TO 5030
SPRED2=SPREFAD(XR(KRJ),XA(KRJ),XR)
XCF(ITLP)=XCF(ITLP)+XCFR(I,JS)*(SPRED2-SPRED1)
IF (TI10 .EQ. 2) WRITE(6,133) XCF(ITLP),ITLP
133  FORMAT(' RECUR CST SPREAD LOOP XCF=',G12.6,' ITLP=',G12.6)
SPRED1=SPRED2
130  CONTINUE
C
IF (TR6 .EQ. 1) WRITE(6,134) ZCT(1),XUL(J)
134  FORMAT(' REDEV CST IF ZCT(1) >=XUL(J) -- ZCT(1)=',G12.6,
. ' XUL(J)=',G12.6)
IF (ZCT(1) .LT. XUL(J)) GO TO 150
ZCT(1)=ZCT(1)-XUL(J)
IF (ZCT(1) .GT. 1.) ZCT(1)=0.
SPRED1=0.
XQRT(I,JS)=XNRT(J)*N**XDLR(J)
IF (TR6 .EQ. 1) WRITE(6,135) XORT(I,JS),I,JS,XNRT(J),N,XDLR(J)
135  FORMAT(' REDEV OCCURRED XORT(I,JS)=',G12.6,' I=',I3,' JS=',I3,
. ' XNRT=',G12.6,' N=',G12.6,' XDLR=',G12.6)
C
DO 140 IT=1,ITNSTP
XR=(IT-ITNSTP)/YRSP(J)
IF (XR .GT. 1.) XR=1.
ITLP=I-ITNSTP+IT-1
IF (ITLP .LT. 1 .OR. ITLP .GT. 30) GO TO 5040
SPRED2=SPREAD(XR(KNJ),XA(KNJ),XR)
XCF(ITLP)=XCF(ITLP)+XQRT(I,JS)*(SPRED2-SPRED1)

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      IF (TPI0 .EQ. 2) WRITE(6,136) XCF(ITLP),ITLP
136   FORMAT(' DFV CST SPREADING XCF=',G12.6,' ITLP=',G12.6)
      SPRFD1=SPRFD2
140   CONTINUE
C
      N=N+1
150   NOSUM=N)END
160   ZCT(1)=ZCT(1) + 1
C
170   CONTINUE
C
      GO TO 540
5040  WRITE(6,5041) ITIP,J
5041  FORMAT(1X,' ** ERROR ** -- INSUFFICIENT DEVELOPMENT TIME, ITLP=',
.I3,' J=',I3)
      RETURN
5030  CONTINUE
      WRITE(6,5031) ITLP,J
5031  FORMAT(1X,' ** ERROR ** -- INSUFFICIENT PRODUCTION TIME, ITLP=',
.I3,' I=',I3)
      RETURN
5050  CONTINUE
      WRITE(6,5051) ITLP,I,L
5051  FORMAT(1X,' ** ERROR ** -- INSUFFICIENT DEVELOPMENT TIME FOR SPACEC
.RAFT, ITLP=',I3,' I=',I3,' L=',I3)
      RETURN
5060  CONTINUE
      WRITE(6,5061) ITLP,I,L
5061  FORMAT(1X,' ** EPROP ** -- INSUFFICIENT DEVELOPMENT TIME FOR POWER
.SUPPLY, ITLP=',I3,' I=',I3,' L=',I3)
      RETURN
5070  CONTINUE
      WRITE(6,5071) ITIP,I,L
5071  FORMAT(1X,' ** ERROR ** -- INSUFFICIENT PRODUCTION TIME, ITLP=',
.I3,' I=',I3,' I=',I3)
      RETURN
      END

```

```

SUBROUTINE DISPLV
COMMON/PROCK/VA(10),XB(10),JMAX,IMAX,IPMAX,XDP(5),LMAX,NMAX,
.XPQW(50),XPQW2(50),IAC(50),XPSP(50),XMP(50),LMISS(50),XPLL(50),
.XCS,XFS,XMPS,XMLS,XMTT(20),XCT(20),XLT(20),XMP(20),XPT(20),
.XMPS(50),XM1(50),XM2(50),XM3(50),XM4(50),XM5(50),XM7(50),XIT(50),
.NAKM(50),XCOLA(50),XMT(50),KN(50),XYPSN(50),CALP(50),KR(50),
.XVRS(50),XPL(50),XUL(50),XDL(50),XM1S(20),XM2S(20),XM3S(20),
.XM4S(20),XM6S(20),XM7S(20),XM8S(20),XITS(20),NAKMS(20),IPTYP(20),
.IACS(20),XMAXP(20),MAXPS(20),XPWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDP(20),XCSTPR(20),XDCSTR(20),KRS(20),XYRSPS(20),
.XSCL(20),XCALPS(20),XGPOUP(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),YYPSPN(20),XYPSNS(20),XULP(20),XULSC(20),XULPL(20),
.XULSCL(20),IUP,CDFL,IACN(50),XMP(20)
COMMON/MMODL/MO(3),50)
COMMON/FLD/NEV1,NEV2,NEV3,NEV4,NEV5,NEV6,NEV7,NEV8,NEV9,NEV10,
.NEV11,NEV12,NEV13,NEV14,NEV15,NEV16,NEV17,NEV18,NEV19,NEV20,
.NEV21,NEV22,NEV23,NEV24,NEV25,NEV26,NEV27,NEV28,NEV29,NEV30,
.TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10
COMMON/LOCAL/IJMX(20),NPLIGT(50),JPMX(50,2),IUP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVMAX(20),LMISS(50)
COMMON/CHAR/CHAR(130)
COMMON/POINTS/POU(50)
COMMON/LOC2/XOCT(30,70),YCFR(30,70),XCF(30),XPV(5),INDX(50),
.XCFPS(30,20),NNON
DIMENSION XCT(20),YCT(20),LKNM(20),LFLAG(20),IULSCT(20),
.IULPCT(20),XCFPS(30,20)
EQUIVALENCE(XCFPS(1,1),XOCT(1,1))
REAL*8 POU
REAL*8 CHAR
INTEGER TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TR9,TR10
DIMENSION PWALL(10),PWRF(10),LVI(10),RECUR(10),DEVEL(10)
,POWMAX(10),XSTEP(10)
EQUIVALENCE(PWALL(1),RECUR(1)),(PWRF(1),DEVEL(1))
9992 FORMAT(1X,10A8)
9991 FORMAT(1X,A6,'=' , (1X,8G12.7))
C
ENTRY SDSPLV
IF(TR9.NE.1) GO TO 61

IF(TR1.EQ.1) WRITE(6,9992) POU(33)
WRITE(6,7500) 'NON'
7500 FORMAT(10X,I3,' MISSIONS WERE FLOWN NON-STANDARDIZED')
WRITE(6,7505) (INDX(N),N=1,NNON)
7505 FORMAT(1X,' THE FOLLOWING MISSIONS WERE FLOWN NON-STANDARDIZED --
'//10(2X,I2))
WRITE(6,9991) CHAR(15),(LMISS(J),J=1,JMAX)
WRITE(6,9991) CHAR(91),(PVMAX(L),L=1,LMAX)
WRITE(6,9991) CHAR(89),(CLMN(L),L=1,LMAX)
1) FORMAT(1X,'XCFPS',I3,'=' ,3(10(1X,G9.1)/))
LCOMIO=LMAX+NACN
DO 20 L=1,LCOMIO
WRITE(6,10) L,(XCFR(I,L),I=1,IMAX)
WRITE(6,30) L,(XCFPS(I,L),I=1,IMAX)
3) FORMAT(1X,'XCFPS',I3,'=' ,3(10(1X,G9.1)/))
WRITE(6,40) L,(XCFPS(I,L),I=1,IMAX)
4) FORMAT(1X,'XCFPS',I3,'=' ,3(10(1X,G9.1)/))
20 CONTINUE

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WRITE(6,50) (XCF(I),I=1,IMAX)
50  FORMAT(1X,'XCF = ',3(10(1X,39.1)/))
WRITE(6,60) (IP,YPV(IP),IP=1,IPMAX)
60  FORMAT(1X,'YPV',I2,' = ',G14.7)
C
C
61  CONTINUE
IF(NFV10 .EQ. 1) GO TO 7115
C
DO 7125 L=1,LMAX
DEVEL(I)=0.
RUCUR(L)=0.
LVL(L)=0
MYSTEP(L)=0
C
DO 7120 J=1,JMAX
IF(LMISS(J) .EQ. L) GO TO 7121
7120 CONTINUE
GO TO 7125
7121 CONTINUE
PMXP=PVMAX(L)
PMIS=PMYP
PFCUR(L)=RPWR1(PMIS,PMXP,L,LVL,P)
LI=KGROUP(L)
DEVEL(L)=(XCSTPM(LL)+XDCSTM(LL)*(PMXP-XMAXP(L)))
LVL(L)=LI
MXSTEP(L)=MAXPS(L)
7125 CONTINUE
C
WRITE(6,7100)
7100  FORMAT('1',////,'40','Standardized power subsystem/spacecraft',
.//,'49','unit cost information',
.//,'31','- power subsystem first unit development cost ($ millions)
. -',
.//,'32','-power subsystem first unit recurring cost ($ millions) -',
.//,'38','- number of power supply modules available -',
.//,'49','- power supply type -',
.//,'54','spacecraft',/)
L1=1
L2=10
7110 CONTINUE
IF(L2 .GT. LMAX) L2=LMAX
WRITE(6,7060) (L,L=L1,L2)
WRITE(6,7250) (DEVEL(L),L=L1,L2)
7250  FORMAT('0',T28,10(-3PF7.2,' ','))
WRITE(6,7251) (PFCUR(L),L=L1,L2)
7251  FORMAT(' ',T28,10(-3PF7.2,' ','))
WRITE(6,7252) (MXSTEP(L),L=L1,L2)
7252  FORMAT(' ',T28,10(2X,I2,3X,' ','))
WRITE(6,7252) (LVL(L),L=L1,L2)
IF(I2 .GE. LMAX) GO TO 7115
L1=L1+10
L2=L2+10
WRITE(6,7065)
7065  FORMAT(1X,/////)
GO TO 7110

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C
7115 CONTINUE
IF (NFBV11 .EQ. 1) GO TO 7040
WRITE(6,7000)
7000 FORMAT('1',////,T40,'Standardized spacecraft/mission power',
. ' information',
. //,T48,'- spacecraft max power (watts) -',
. //,T45,'- power allocated for mission (watts) -',
. //,T46,'- mission power requirement (watts) -',
. //,T39,'- ratio of power modules used to number available -')
WRITE(6,7055)
7055 FORMAT('0',//,T61,'mission'/T15,'spacecraft'/T18,'type')
J1=1
J2=10
7050 CONTINUE
IF (J2 .GT. JMAX) J2=JMAX
WRITE(6,7060) (J,J=J1,J2)
7060 FORMAT('+',T27,10(I6,3X))
DO 7015 L=1,LMAX
PMXD=PVMAX(I)
LFLG=0
DO 7020 J=J1,J2
POWMAX(J)=0.
PWFAIL(J)=0.
PWRREQ(J)=0.
LVL(J)=0
MXSTEP(J)=0
IF (IMISS(J) .NE. L) GO TO 7020
POWMAX(J)=PMXD
PMIS=XPOW(J)*(1.+TPTYP(I)*XPOW(J))
P=PWR1(PMIS,PMXD,L,LVLP)
MXSTEP(J)=MAXPS(L)
LVL(J)=LVLP
PWFAIL(J)=(I*VDP*PMXD)/MAXPS(L)
PWRREQ(J)=PMIS
LFLG=1
7020 CONTINUE
IF (LFLG .EQ. 0) GO TO 7015
WRITE(6,7025) L,(POWMAX(J),J=J1,J2)
7025 FORMAT('0',T18,I2,(T27,10(F7.1,' ', ')))
WRITE(6,7200) (PWFAIL(J),J=J1,J2)
7200 FORMAT((T27,10(F7.1,' ', ')))
WRITE(6,7200) (PWRREQ(J),J=J1,J2)
WRITE(6,7035) (LVL(J),MXSTEP(J),J=J1,J2)
7035 FORMAT((T27,10(I5,'/',I1,' ', ')))
7015 CONTINUE
IF (J2 .GT. JMAX) GO TO 7040
J1=J1+10
J2=J2+10
GO TO 7050

C
7040 CONTINUE
IF (NFBV12 .EQ. 1) GO TO 7086
WRITE(6,7070)
7070 FORMAT('1',////,T50,'Standardized spacecraft unit costs',
. //,T48,'- first unit recurring cost/mission -',
. //,T61,'($ millions)',
. //,T63,'mission',//,T15,'spacecraft',//,T18,'type')

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```

J1=1
J2=10
7090 CONTINUE
IF(J2 .GT. JMAX) J2=JMAX
WRITE(6,4005) (J,J=J1,J2)
DO 7075 L=1,LMAX
PMXP=PVMAX(I)
DEVEL(I)=0.
IFLG=0
DO 7080 J=J1,J2
RECUR(J)=0.
IF(LMISS(J) .NE. 1) GO TO 7080
RECUR(J)=PCTS(L,J,PMXP)
IFIG=1
7080 CONTINUE
WRITE(6,4010) I,(RECUR(J),J=J1,J2)
IF(IFIG .EQ. 1) DEVEL(L)=PCTS(L,PMXP)
7075 CONTINUE
IF(J2 .GE. JMAX) GO TO 7085
J1=J1+10
J2=J2+10
GO TO 7090
C
7085 CONTINUE
WRITE(6,7076)
7076 FORMAT (' ',//,/,T51,'- first unit development cost -',
.//,T60,'($ millions)',
.//,T61,'spacecraft',//)
L1=1
L2=10
7087 CONTINUE
IF(L2 .GT. LMAX) L2=LMAX
WRITE(6,4005) (L,L=L1,L2)
WRITE(6,4011) (DEVEL(L),L=L1,L2)
IF(L2 .GE. LMAX) GO TO 7086
L1=L1+10
L2=L2+10
GO TO 7087
7086 CONTINUE
IF(NFV13 .EQ. 1) GO TO 7230
I1=1
I2=10
IF (I2 .GT. IMAX) I2=IMAX
WRITE(6,4000)
4000 FORMAT(' ',T40,'standardized spacecraft yearly costs',
.//,T45,'(prior to cost spreading)',
.//,T49,'- recurring cost -',
.//,T48,'- development cost -',
.//,T40,'- power subsystem development cost -',
.//,T52,'($ millions)',//,T56,'year',//,T15,'spacecraft',//,T18,
. 'type')
1080 WRITE(6,4005) (J,I=I1,I2)
4005 FORMAT(' ',T30,10(I2,7X))
DO 1090 I=1,LMAX
WRITE(6,4010) I,(XCER(I,L),I=I1,I2)
4010 FORMAT(' ',T18,I2,I27,10(-3PF7.2,2X))
WRITE(6,4011) (XCER(I,L),I=I1,I2)
4011 FORMAT(' ',T27,10(-3PF7.2,2X))

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      WRITE(6,4011) (XCONS(T,I),I=I1,I2)
109) CONTINUE
      IF (I2 .EQ. IMAX) GO TO 723)
      I1=I1+10
      I2=I2+10
      IF (I2 .GT. IMAX) I2=IMAX
      WRITE(6,4020)
4020) FORMAT(' ',////////,' ')
      GO TO 1080
C
7230) CONTINUE
      GO TO 7210
1100) CONTINUE
      IF (NFEV17 .EQ. 1) GO TO 1120
      WRITE(6,4030)
4030) FORMAT('11',T42,'Standardized plus non-standardized spacecraft',
%//,T55,'total annual costs',
%//,T51,'(cost spreading included)',
%//,T57,'($ millions)')
      I1=1
      I2=10
1110) IF (I2 .GT. IMAX) I2=IMAX
      WRITE(6,3040) (T,T=I1,I2)
      WRITE(6,3050) (XCON(T),I=I1,I2)
      IF (I2 .EQ. IMAX) GO TO 1120
      I1=I1+10
      I2=I2+10
      GO TO 1110
C
1120) CONTINUE
      IF (NFE18 .EQ. 1) GO TO 4061
      WRITE(6,4060) (XPR(I),I=1,I2MAX)
4060) DO MAX('10',//////////,T40,'Standardized plus non-standardized ',
.'spacecraft',
%//,T52,'present value of costs',
%//,T58,'($ millions)',
%//,T16,'discount rate (%)',T35,5(2X,T4.1,4X))
      WRITE(6,3070) (XIV(I),I=1,I2MAX)
4061) CONTINUE
      RETURN
C
7210) CONTINUE
      DO 7215 J=1,JMAX
      IF (I4TOS(J) .EQ. 0) GO TO 7220
7215) CONTINUE
      GO TO 1100
7220) CONTINUE
C
C
      WRITE(6,81)
      IF (NFE9 .EQ. 1) GO TO 121
C
      WRITE(6,81)
81) FORMAT('11')
      IF (NFE1 .EQ. 1) WRITE(6,40900) 200(40)
      DO 70 J=1,JMAX
      WRITE(6,81) J, (XCON(T,J),I=1,I2MAX)

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80    FORMAT(1X,'RECURRING COST,XCFR',I3/1X,3(10(G9.2,1X)/))
      WRITE(6,90) J,(XCFR(I,J),I=1,IMAX)
90    FORMAT(1X,'DEV COST,XOXT',I3,' = '/1X,3(10(G9.2,1X)/))
70    CONTINUE
      WRITE(6,100) (XCF(I),I=1,IMAX)
100   FORMAT('0','XCF = '/1X,3(10(G9.2,1X)/))
      WRITE(6,120) (I2,XPV(I2),I=1,IPMAX)
120   FORMAT(1X,'XPV',I2,' = ',G14.7)
C
121   CONTINUE
      IF(NFV14 .EQ. 1) GO TO 240
      I1=1
      I2=10
200   IF (I2 .GT. IMAX) I2=IMAX
      N=IMAX
      I1=1
      I2=17
205   WRITE(6,3000) (I,I=I1,I2)
3000  FORMAT ('1',T43,'Non-standardized spacecraft yearly costs',
  %/,T51,'(prior to cost spreading)',
  .//,T55,'- recurring cost -',
  .//,T54,'- development cost -',
  %//,T58,'($ millions)',
  %//,T60,'(years)',
  %//,T15,'mission',T27,10(I2,6X))
210   IF (J2 .GT. JMAX) J2=JMAX
      DO 220 J=J1,J2
      IF(LMAX .NE. 0 .AND. LMISS(J) .NE. 0) GO TO 220
      N=N+1
      WRITE(6,3010) J,(XCFR(T,N),I=I1,I2)
3010  FORMAT('0',T17,T2,T24,10(-3PF6.2,2X))
      WRITE(6,3020) (XOXT(I,N),I=I1,I2)
3020  FORMAT(' ',T24,10(-3PF6.2,2X))
220   CONTINUE
      IF (J2 .EQ. JMAX) GO TO 230
      J1=J1+17
      J2=J2+17
      GO TO 205
230   IF (I2 .EQ. IMAX) GO TO 240
      I1=I1+10
      I2=I2+10
      GO TO 200
C
240   CONTINUE
      IF(LMAX .NE. 0) GO TO 1100
      IF(NFV15 .EQ. 1) GO TO 260
      WRITE(6,3030)
3030  FORMAT('1',T50,'Non-standardized spacecraft',
  %//,T54,'total annual costs',
  %//,T51,'(cost spreading included)',
  %//,T58,'($ millions)')
      I1=1
      I2=10
250   IF (I2 .GT. IMAX) I2=IMAX
      WRITE(6,3040) (T,I=I1,I2)
3040  FORMAT('0',T20,'year',T33,10(I2,7X))
      WRITE(6,3050) (XCF(I),I=I1,I2)

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3050  FORMAT(' ',T16,'annual cost',T30,10(-3P7.2,2X))
      IF (I2.EQ. IMAX) GO TO 260
      I1=I1+10
      I2=I2+10
      GO TO 250
?
260  CONTINUE
      IF(NP16.EQ. 1) GO TO 3071
      WRITE(6,3060) (XDP(I),I=1,IRMAX)
3060  FORMAT('0',//////////,T45,'Non-standardized spacecraft',
           &///,T48,'present value of costs',
           &///,T52,'(t millions)',
           &///,T16,'discount rate (%)',T35,5(2X,T4.1,4X))
      WRITE(6,3070) (YDV(I),I=1,IRMAX)
3070  FORMAT('0',T16,'present value',T33,5(-3P8.1,2X))
3071  CONTINUE
      RETURN
      END

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BLOCK DATA

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COMMON/PILOCK/YA(10),XB(10),JMAX,IMAX,IPMAX,XDR(5),LMAX,NMAX,
.XPCW(50),YPCWP(50),IAC(50),XPSP(50),XMPL(50),LMISS(50),XPLL(50),
.XCS,XPS,XMPS,XMLS,XMTT(20),XCT(20),XLT(20),XMPT(20),XFT(20),
.NMPS(50),YM1(50),YM2(50),YM3(50),YM4(50),YM6(50),YM7(50),XIT(50),
.NAKM(50),XSOLA(50),XMT(50),KN(50),XYRSN(50),CAIR(50),KR(50),
.XYRSR(50),XPL(50),XUL(50),XDLP(50),YM1S(20),XM2S(20),YM3S(20),
.XM4S(20),YM6S(20),YM7S(20),XM8S(20),YITS(20),NAKMS(20),IPTYP(20),
.IACS(20),XMAXP(20),MAXPS(20),XPWSS(20),XDM1S(20),XDM6S(20),
.XDM7S(20),XDPW(20),XCSTPR(20),XDCSTR(20),KRS(20),XYRSRS(20),
.XSCL(20),XCALRS(20),KGROUP(20),XCSTPN(20),XDCSTN(20),KNSP(20),
.KNS(20),XYRSPN(20),XYRSNS(20),XULP(20),XULSC(20),XULPL(20),
.XULSCL(20),IUP,CDEL,IACN(50),XXMP(20)
COMMON/FMODL/NO(30,50)
COMMON/FLOW/NFV1,NFV2,NFV3,NFV4,NFV5,NFV6,NFV7,NFV8,NFV9,NFV10,
.NFV11,NFV12,NFV13,NFV14,NFV15,NFV16,NFV17,NFV18,NFV19,NFV20,
.NFV21,NFV22,NFV23,NFV24,NFV25,NFV26,NFV27,NFV28,NFV29,NFV30,
.TR1,TR2,TR3,TR4,TR5,TR6,TR7,TR8,TP9,TP10
COMMON/LOCAL/IJMX(20),NPLGT(50),JPMX(50,2),IUP1,CLMN(20),
.SK1(20),SK6(20),SK7(20),PVMAX(20),MMTSS(50)
COMMON/CHAPAC/CHAP(130)
COMMON/ROUTNS/ROU(50)
INTEGER TR1,TR2,TR3,TR4,TR5,TR6,TP7,TR8,TP9,TR10
REAL*8 CHAP /'XA','XB','JMAX','IMAX','IPMAX','XDR','LMAX',
.'NMAX','NO','XPCW','XPCWP','IAC','XPSP','XMPL','LMTSS','XPLL',
.'XCS','XPS','XMPS','XMLS','XMTT','XCT','XLT','XMPT','XFT','NMPS',
.'XM1','XM2','XM3','XM4','XM6','XM7','XIT','NAKM','XSOLA','XMT',
.'KN','XYRSN','CAIR','KR','XYRSR','XPL','XUL','XDLP','XM1S','YM2S',
.'XM3S','XM4S','XM6S','XM7S','XM8S','YITS','NAKMS','IPTYP','IACS',
.'XMAXP','MAXPS','XPWSS','XDM1S','XDM6S','XDM7S','XDPW','XCSTPR',
.'XDCSTR','KRS','XYRSRS','XSCL','XCALRS','KGROUP','XCSTPN',
.'XDCSTN','KNSP','KNS','XYRSPN','XYRSNS','XULP','XULSC','XULPL',
.'XULSCL','IUP','CDEL','NFLOW','TR','L','J','JPMX','LFLAG','CLRT',
.'CLMN','PVMAX','PVMAX','CR1','CR2','IJMX','CMOL','FLG','CLM1',
.'DM1N','FMIS','LVLP','SK1','SK6','SK7','NPLGT','PNC','PX1',
.'NCT','IFLG1','IFLG2','JX','NFLT','DM1','DM2','DM6','DM7','RCST',
.'FENT','XPM1','XF1','XF','SF','SF1','TRNCST','RCST','RPWR1',
.'RPWR2','NUMSTX',' ',' '= '/
REAL*8 ROU/'MAIN','INIT','INPATH','INSTD','INDATA',
.'INNCN','PTHCHK','DATCHK','STDCHK','NONCHK','RSCHK',
.'DSCHK','FNCHK','DNCHK','SPRCAL','NPRCAL','SORT','ASSIGN',
.'OPMTX','PTRCT1','PTRCT2','RCTS','TCTS','RCTN','DCTN',
.'TCTN','DCFPS','DCFPS','DCFRN','DCFRN','RCFRS1','DCFRS1',
.'DCFRN1','DCFRN1','RPWR1','RPWR2',
.'STDCT','NONCT','SDSPLY','NDSPLY','ENTER','EXIT'/
DATA XA/10*0.0/,XB/10*0.0/
END

```

APPENDIX E

FITTING THE GENERALIZED COST
SPREADING FUNCTION TO DISCRETE
DATA

APPENDIX E

FITTING THE GENERALIZED COST SPREADING FUNCTION TO DISCRETE DATA

Within the body of the main program of the mathematical model cost spreading functions are analytically defined by two input arrays (XA_K and XB_K). Five general spreading functions have been defined (by specifying specific values for XA_K and XB_K); however, functions other than these may eventually be required. In order to provide for this possibility a stand-alone program for the Hewlett Packard 9820 has been developed which will accept arrays of x and y coordinates defining the points on a specific spreading function and reduce them to an equivalent set of input coefficients (XA_K and XB_K) for the main program. Thus, a spreading function can be sketched and the XA and XB coefficients which approximate the sketch determined.

This stand-alone program attempts to approximate the input arrays by the generalized equations given below

$$f(a,b,x) = (10b-4)x^5 + (10a-20b+5)x^4 + (10b-20a)x^3 + 10ax^2 \quad (1)$$

This is accomplished by selection of the values for the coefficients of a and b in such a way as to minimize the following error quantity.

$$\epsilon = \sum_{i=1}^N [Y_i - f(a,b,x_i)]^2 \quad (2)$$

where:

N = number of input points

(x_i, y_i) = coordinates of i^{th} input point

$f(a,b,x_i)$ = defined by Eq 1

The minimization operation is performed by assuming that a and b are independent variables, thus allowing the following conditions to be derived for the minimum of ϵ .

$$\frac{\partial \epsilon}{\partial a} = 0 \quad (3a)$$

$$\frac{\partial \epsilon}{\partial b} = 0 \quad (3b)$$

Conditions 3a and 3b can be reduced to the following equation which can be solved using a Newton iteration in two independent variables.

$$\sum_{i=1}^N [y_i - f(a, b, x_i)] \left[\frac{\partial f(a, b, x_i)}{\partial a} \right] = 0 \quad (4a)$$

$$\sum_{i=1}^N [y_i - f(a, b, x_i)] \left[\frac{\partial f(a, b, x_i)}{\partial b} \right] = 0 \quad (4b)$$

Solution of Equations 4a and 4b yield the input coefficients which can be used by the main program to reconstruct the desired cost spreading function.

Certain characteristics limit the programs total capability; however, their effect can usually be reduced once understood. First, the spreading function must be a normalized spreading function similar to that in the following figure.

$$\begin{aligned} \text{where: } & 0 \leq x \leq 1 \\ & 0 \leq y \leq 1 \\ & y(0) = 0 \\ & y(1) = 1 \end{aligned}$$

All input coordinates must be within the bounds specified and only five

points may be specified due to the restrictions imposed by the HP9820. However, due to the form of the generalized function given by Equation 1 the points $(0,0)$ and $(1,1)$ are always fit and therefore need not be specified. Second, the input points should be located so as to provide the best segmented linear fit for the curve being defined since this choice will tend to provide a better fit than most others. Third, not all functions can be fit accurately by the generalized function given by Equation 1, therefore, the variance of the approximation is given with each choice of coefficients so as to enable the user to determine the goodness of the fit. This quantity does not totally describe the accuracy of the fit and the user should verify that the input curve is approximated within certain tolerances by the final analytic expression.

Once the desired curve has been constructed and the appropriate points chosen on that curve the program will find the best fit according to the methods previously defined. The output coefficients from this program can then be used as inputs to the main program giving the user the ability to access this specialized spreading function within the main program.