General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Systems Cost/Performance Analysis (Study 2.3)
Final Report

Volume I: Executive Summary

Prepared by
ADVANCED MISSION ANALYSIS DIRECTORATE
Advanced Orbital Systems Division

27 September 1974

Prepared for

OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546

Contract No. NASW-2575

Systems Engineering Operations
THE AEROSPACE CORPORATION

SYSTEMS COST/PERFORMANCE ANALYSIS
(STUDY 2. 3) FINAL REPORT

Volume I: Executive Summary

Prepared

B. H. Campbell

B. H. Campbell
NASA Study 2. 3 Manager
Advanced Mission Analysis
   Directorate

Approved

R. H. Herndon

R. H. Herndon, Assoc. Group
   Director
Advanced Mission Analysis
   Directorate
Advanced Orbital Systems Division

FOREWORD

This report documents The Aerospace Corporation effort on Study 2.3, Systems Cost/Performance Analysis, performed under NASA Contract NASW-2575 during Fiscal Year 1974. The effort was directed by Mr. B. H. Campbell. Mr. R. D. Kramer, Marshall Space Flight Center and Mr. R. R. Carley, NASA Headquarters were the NASA Study Directors for this study. Their efforts in providing technical direction throughout the duration of the study are greatly appreciated.

This volume is one of three volumes of the final report for Study 2.3. The three volumes are:

Volume I	Executive Summary
Volume II	Systems Cost/Performance Model
Appendix	Data Base
Volume III	Programmer's Manual and User's Guide

Volume I summarizes the overall report. It includes the relationship of this study to other NASA efforts, significant results, study limitations, and suggested additional effort.

Volume II provides a detailed description of the Systems Cost/ Performance Model. It also includes the model checkout and the results for three payload test cases. The Data Base is provided in the Appendix to Volume II.

Volume III provides a detailed description of how the Systems Cost/Performance Computer Program is organized and operates. The program listing, detailed flow charts and user restrictions are included.

ACKNOWLEDGMENTS

CONTENTS

PRECEDING PAGE BLANK NOT FILMED

1. INTRODUCTION

As the space program matures into an applications industry, greater emphasis will be placed on improving the ability to predict the effect of program requirements on cost and schedules. Cost estimating techniques that give greater insight earlier in the program cycle are required. As a step in this direction, this study was initiated to identify and quantify the interrelationships between and within the performance, safety, cost, and schedule parameters for unmanned, automated payload programs. These data would then be used in support of the over-all NASA effort to generate program models and methodology which would provide the needed insight into the effect of changes in specific functional requirements (performance and safety) on the total vehicle program (cost and schedule).

Previous cost modeling approaches fall into one of two basic categories: "bottom-up" or "top-down". The "bottom-up" approach, which is tied to the development of a specific system, depends on detailed estimates of tasks, material costs, manpower requirements, and schedules. The total cost estimate is then obtained by summing the individual costs.

"Top-down" models use CER (cost estimating relationship) approaches to estimate the cost of a specific system. In those models, the CERs are related to distinct parameters such as weight, power, and pointing accuracy. The deficiency of the CERs lies in the fact that, although they identify the cost drivers, they do not model why and how the costs are driven by the parameters.

Since CERs have not been completely successful in meeting the prime criterion of determining sensitivity of cost to changes in program requirements, top-down approaches were judged unacceptable for a cost/performance model. Hence, it was thought that a model oriented from the bottom-up could lead to fulfillment of this criterion.

2. OBJECTIVES

The FY 1974 Study 2.3 had three objectives. The first objective was to refine and improve the cost/performance methodology which was developed during the preceding fiscal year's study (see Ref. 2-1). The same two-step process of first establishing hardware designs and then estimating costs and schedules was retained. However, incomplete portions of the methodology such as the cost and schedule models were to be improved.

The second objective was the application of the cost/performance methodology to the following vehicle subsystems:

a. Stabilization and Control (S&C)

b. Auxiliary Propulsion Subsystem (APS)

c. Communications, Data Processing and Instrumentation (CDPI)

d. Electrical Power Subsystem (EPS)

    1. Sources

    2. Conditioning and Distribution

e. Thermal Control Subsystem (TCS)

f. Structure

The product of this effort is the Systems Cost/Performance Model.

The third objective was to implement the Systems Cost/Performance Model as a digital computer program which would be capable of operating on the MSFC Univac 1108 with only minor modifications necessitated by differences between the Aerospace CDC 7600 and the MSFC Univac 1108. The resulting program would be used by MSFC to perform initial program planning, cost/performance tradeoffs, and sensitivity analyses for mission model and advanced payload studies.

3. RELATIONSHIP TO OTHER NASA EFFORTS

The FY 1974 Study 2.3 makes extensive use of the FY 1973 Study 2.3, System Cost/Performance Analysis, results. The cost/performance methodology developed during the preceding year's effort was improved and refined. The improved methodology was used to develop a model applicable to payload subsystems.

The System Cost/Performance Model's data base formulation was based on the REDSTAR data base currently in use at MSFC. The REDSTAR system is the result of a 1972 fiscal year study (Ref. 3-1).

4. APPROACH

One of the first tasks in this study was to define the spacecraft generically by determining the functions performed by each spacecraft subsystem and the functions performed by specific hardware types within each subsystem. Obviously, interfaces between subsystems determined some of the functions to be performed. The outline of functions to be performed had to be complete in that potential subsystem designs, for the most part, are related directly to the functions they are required to perform.

Block diagrams were developed for all generally used subsystem configurations. The block diagrams consisted of the equipment types used in each configuration and illustrated the functions performed by the equipment. Since there may be an infinite number of block diagram variations, certain general block diagrams were established that were valid for most designs.

A design algorithm was developed which performed the function of selecting preconfigured subsystem designs satisfying the input system or subsystem requirements. This implies that, as part of the vehicle design algorithm, a complete set of alternative designs has been established from which to choose.

Given a specific design meeting the input requirements, the hardware required to implement such a design is selected from available off-the-shelf hardware which is contained in the data base. Obviously, the model must be capable of differentiating between hardware components of the same type and determining which hardware component has the characteristics to satisfy all of the requirements.

In order to have a workable algorithm, the list of input data necessary to select a design and to size the necessary equipment has been established. The input data would normally include subsystem performance requirements, interface requirements, and any other data necessary to make design decisions.

A data base consisting of information on off-the-shelf hardware was established. The data content which is associated with each hardware component consists of four categories of information:

a. Performance

b. Safety (Reliability)

c. Cost

d. Schedule

The four types of data contain sufficient information to allow the equipment selection algorithm to select specific pieces of equipment and to provide the necessary output data describing the design. The data were collected from in-house, Air Force, and NASA sources. Cost data were based on seven specific satellite programs.

The Systems Cost/Performance Model was implemented as a digital computer program. The program was written in the language of Fortran IV for the Aerospace CDC 7600 computer and adapted for the MSFC Univac 1108 computer. The program includes the Systems Cost/Performance Model and the related data base.

Two forms of model checkout were performed. The first was a set of computer runs to ensure that both the logic and arithmetic models were accurate and complete and that all submodels were interfacing properly. The second set of computer runs was limited to a few special runs selected for the purpose of comparing the Systems Cost/Performance Model against other existing models and against actual payload programs.

5. SYSTEMS COST/PERFORMANCE MODEL

5.1 GENERAL

The general concept of the Systems Cost/Performance Model is illustrated in Figure 5-1. The user of the Cost/Performance Model must pply certain program data which would normally include the payload performance requirements as well as general information necessary to select a payload design. The technical portion of the model consists of a two-step process: the first step is to select subsystem configurations which are acceptable to the user, and the second step is to select equipment from a data base to mechanize the subsystem configuration. The reliability portion of the model adds redundancy to the design so that the reliability requirements are met. The resulting output of the technical model is a number of payload designs which meet or exceed the input requirements. The acceptable designs are specified down to the subsystem component (assembly) level. The cost and schedule required to design, build, and operate each payload are estimated by summing up the individual cost and schedule allocations based on each end item assembly specified as part of the particular design.

The technical portion of the Systems Cost/Performance Model is depicted in Figure 5-2. The expanded detail summarizes the inputs required by each subsystem. Most importantly, the interaction between subsystems as a design problem is illustrated. In order to design the Stabilization and Control (S&C) Subsystem, the vehicle weight, dimensions, and moments of inertia must be known. Design of the Auxiliary Propulsion Subsystem (APS) requires knowledge of the total impulse and thrust levels from S&C. Design of the Data Processing Subsystem requires knowledge of the telemetry and data processing requirements for each piece of equipment in the vehicle. Design of the Communication Subsystem requires knowledge of the command and communication requirements
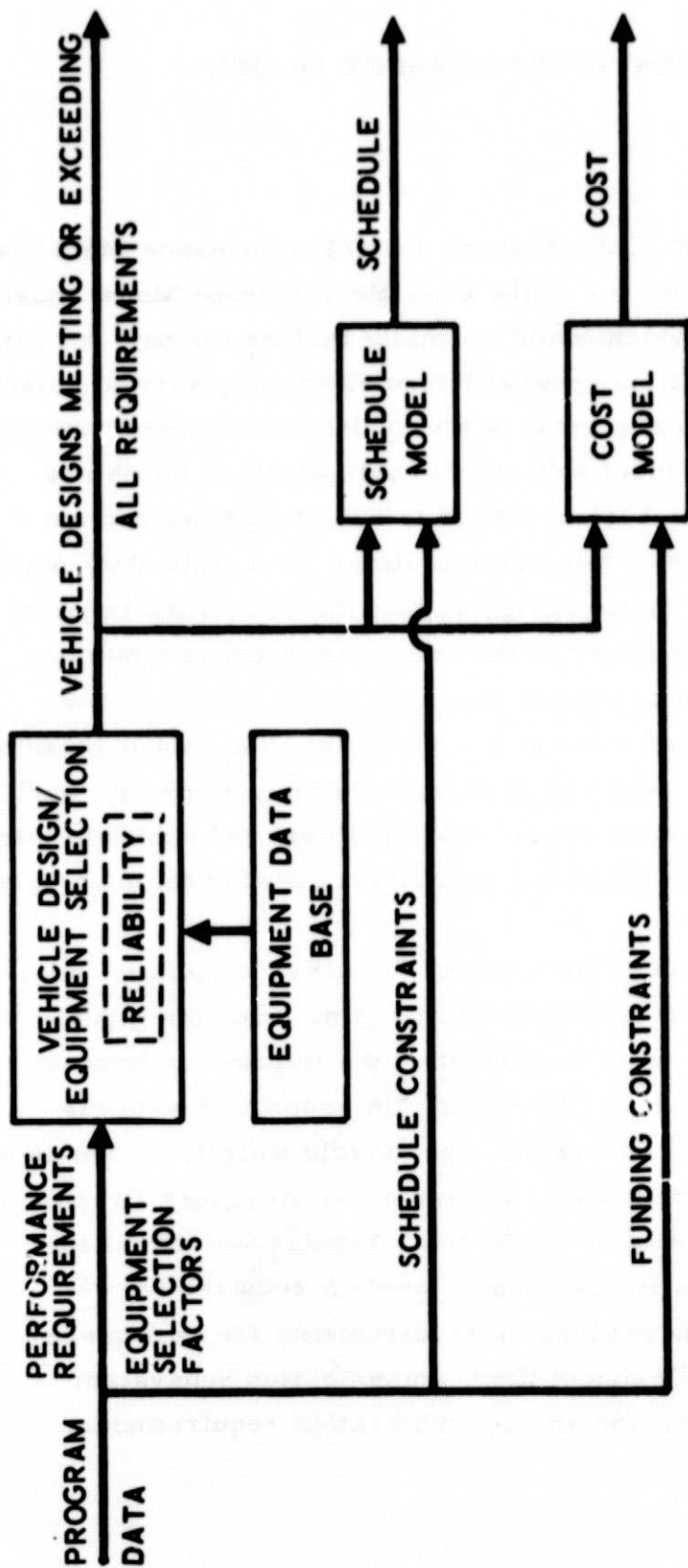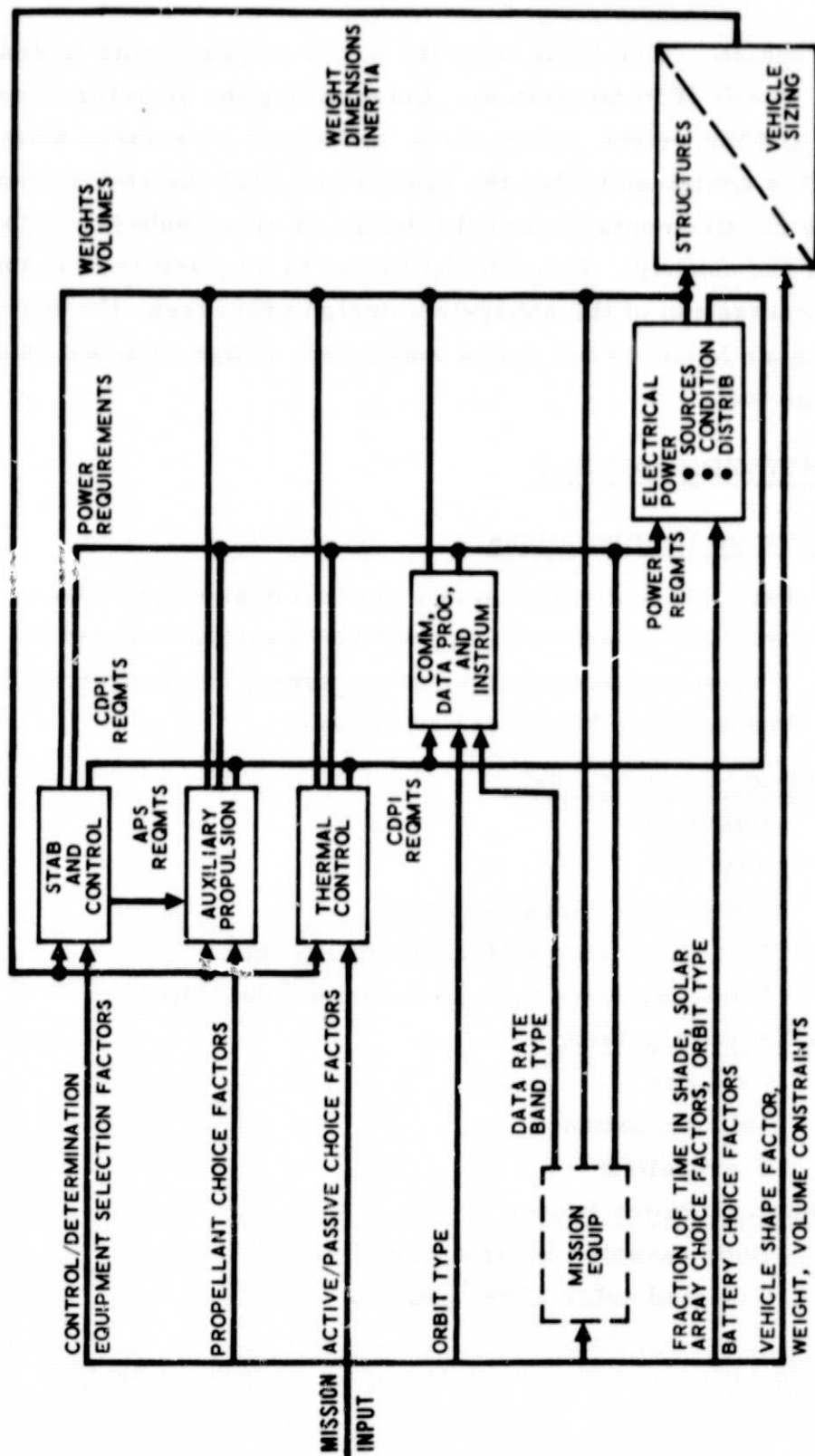
5-1

Figure 5-1. Systems Cost/Performance Model

Figure 5-2. Vehicle Design/Equipment Selection

for the entire vehicle. One must know the power requirements to design
the Electrical Power (EP) Subsystem. Determining the structural makeup
of the vehicle and the weight, dimensions, and inertias requires some in-
sight into what is contained within the vehicle and what the environment is.
The reliability requirements impact the design of every subsystem through
the addition of redundancy. The principal point to be made here is that by
modeling the interaction of the subsystem design processes, the Systems
Cost/Performance Model is not only a subsystem design tool, but is also
a system design tool.

5.2   SUBSYSTEM MODELS

5.2.1   Subsystem Configurations

A subsystem configuration is a general design type which is
developed mechanically by selecting appropriate equipment listed in
the data base. The subsystem configurations (types) incorporated in the
Systems Cost/Performance Model are as follows:

a.   Stabilization and Control
1.   Dual spin
2.   Yaw spin
3.   Three-axis mass expulsion
4.   Mass expulsion with control moment gyros
5.   Mass expulsion with pitch momentum wheel

b.   Auxiliary Propulsion
1.   Cold gas
2.   Monopropellant
3.   Bipropellant

c.   Electrical Power Source
1.   Body-mounted solar arrays
2.   Oriented solar array paddles

d. Electrical Power Conditioning

    1. Shunt regulation

    2. Shunt and discharge regulation

    3. Series load regulation

e. Communications

    1. Separate uplink and downlink

    2. Unified link, common antenna

    3. Unified link, separate antennas

    4. Unified link, common antenna, plus separate downlink

    5. Unified link, separate antennas, plus separate downlink

f. Data Processing

    1. General purpose processor

    2. Special purpose processors

g. Thermal Control

(Dependent upon other subsystems and component requirements)

h. Vehicle Shapes

    1. Cylinder

    2. Box

    3. Sphere

i. Structure

    1. Semi-monocoque

j. Redundancy

    1. Single system

    2. Dual system

5.2.2 Equipment Description

The model selects equipment for a specific design in one of three ways:

a. Most equipment is selected from the data base on the basis of technical performance.

b.   Some equipment which cannot be differentiated on the basis of technical performance is called up from the data base on a first-called basis in order to provide a complete design description. *

c.   Certain equipment is not amenable to being cataloged in the data base. This equipment is identified and specific parameters are determined. Examples include the wiring harness and the Thermal Control Subsystem components.

An example of an equipment description in the data base is provided in Table 5-1.

5.2.3   Design Algorithms

The design algorithms for all subsystems are summarized as follows:

a.   Stabilization and Control Subsystem

   1.   Selects attitude measurement equipment

   2.   Selects momentum exchange equipment

   3.   Computes attitude control thrust level

   4.   Computes total impulse required

b.   Auxiliary Propulsion Subsystem

   1.   Selects thruster equipment

   2.   Selects propellant equipment

   3.   Selects pressurant equipment

c.   Data Processing Subsystem

   1.   Selects computer or one digital telemetry unit per communication downlink

   2.   Selects command distribution equipment

d.   Communication Subsystem

   1.   Selects communication equipment

e.   Electrical Power Subsystem

   1.   Sizes solar array

   2.   Selects batteries and voltage regulation equipment

   3.   Selects power conditioning equipment based on requirements of all other selected equipment

---

*It is proposed that this category be eliminated in future models by differentiation of all equipment as suggested in paragraph a.

f.   Thermal Control Subsystem

    1.   Sizes thermal mass, insulation, heaters, radiators, louvers, and heat pipes

g.   Vehicle Sizing

    1.   Estimates structural weight

    2.   Estimates thermal control weight

    3.   Estimates mechanism, booms, and electrical harness weight

    4.   Sums total vehicle weight

    5.   Estimates payload adapter weight

    6.   Estimates vehicle dimensions

    7.   Estimates moments of inertia

h.   Structural Subsystem

    1.   Determines actual wall thickness based on optimum weight design

    2.   Determines stringer size and spacing

    3.   Determines frame size and spacing

    4.   Sizes end covers and center plate (if applicable)

    5.   Sizes mission bay and solar array extensions

The user must specify the following inputs:

a.   Vehicle orientation

b.   Orbit description

c.   Mission lifetime

d.   Attitude control requirements

e.   Powered flight thrust level

f.   SGLS or USB compatibility requirement

g.   Range and range rate requirement

h.   Structural material description

i.   Launch loads environment

j.   Maximum diameter, length and weight

k.   Mission equipment description

Table 5-1. Data Base Example

Subsystem:	Auxiliary Propulsion (0808)
Configurations:	Monopropellant
Equipment Type:	Thruster (TRW 404620)

Performance

    Technical Characteristics

(1)	Thrust level (N)		18
(2)	Pulse life (cycles)		93,000
(3)	Inlet pressure (N/m^2)		4.14×10^6
(4)	Total impulse (N-sec)		6.49×10^4
(5)	ISP (sec)		230
(6)			
(7)			
(8)			
(9)			
(10)			

Power

Average Power (watts):	(near zero)
Maximum Power (watts):	5.5
Minimum Power (watts):	0.0
Nominal Voltage (volts):	28.0
Maximum Voltage (volts):	32.6
Minimum Voltage (volts):	26.0
Converter/Inverter Requirement (flag):	N.A.

Weight (Kg):	0.3
Volume (cc):	1700

Vibration

Randon (g, rms):	19.5
Non-Random (g):	10.5

Temperature

Maximum (deg K):	322
Minimum (deg K):	278
Pressure (N/m^2)	(Unknown)

Table 5-1. Data Base Example (Continued)

Performance (continued)

    CDPI

        Power Switching Commands (No.):   0
        Time Tagged Commands (No.):   0
        Other Commands (No.):   0
        High Rate Telemetry
            Number of Analog Points (No.):   0
            Number of Digital Points (No.):   0
            Sample Rate (sec^{-1}):   0
            Word Length (bits):   0
        Low Rate Telemetry
            Number of Analog Points (No.):   2
            Number of Digital Points (No.):   0
            Sample Rate (sec^{-1})   1
            Word Length (bits):   8

Safety

    Failure Model (flag):   5
    Failure Parameters
        Failure Rate or Mean ($\times 10^{\pm 9}$ hr):   1700
        Standard Deviation ($\times 10^{+9}$ hr):   N.A.
        Dormancy Factor (N.D.):*   0.1
    Total Number of Redundant Elements (No.):   12

Cost

    Design Engineering ($1000):   127
    Test and Evaluation ($1000):   150
    Unit Production ($1000):   9
    Reference Quantity (No.):   4
    Factor (N.D.):   1

Schedule

    Development Lead Time Constant (months):   3.0
    Development Lead Time Variable (months):   1.0
    Qualification Lead Time Constant (months):   1.5
    Qualification Lead Time Variable (months):   0.1
    State-of-Art Factor (N.D.):   1.0

*Non-dimensional

5.3   RELIABILITY MODEL

As a result of satisfying the input performance requirements, a finite number of designs are established by the Cost/Performance Model. The next step in processing these designs requires the use of the reliability equations. These equations are categorized as to reliability assessment, failure detection probability, and false alarm probability.

The first of these equations, the reliability assessment, is used to calculate the reliability of each configuration. This is done at the element level, i.e., each identifiable subsystem component. Failure rate information stored in the equipment data base for each component is extracted as needed by the model. The failure rates are then combined by the reliability equations to calculate total reliability for a given mission duration. The calculated reliability of each particular design is evaluated against the specified level provided as the model input. However, the design is not discarded if it does not meet the specified reliability level; instead, a search for the least reliable element is initiated. The criterion for least reliable is that element which, if made redundant, results in the largest increase in reliability or in mean mission duration per unit weight or cost increase. Upon identification, the least reliable element is paralleled by an identical unit and the system reliability is recalculated. The evaluation and paralleling process continue until the redundancy exceeds a specified limit. If the system still does not meet the specified reliability, the system is deleted from consideration as a viable single-string system. However, if it does meet or surpass the required reliability level, the system failure detection and false alarm probabilities are also calculated. The process described above continues until each design stored as a result of meeting performance requirements has been processed.

The procedure described above constitutes one-half of the total Reliability Model. Following completion of the basic scheme, the whole procedure is repeated with each design mechanized as an active/standby

(dual string) system. The term active/standby refers here to a completely separate system in addition to modular levels of redundancy.

The required input data includes:

a.   Mission life

b.   System reliability

c.   Basis for selecting redundancy

The output information supplied by the Reliability Model includes the redundancy required for each component and the amount of expendables (propellant) required.

5.4   COST MODEL

The Cost Model consists of cost equations which process cost information associated with each subsystem component. The required input data includes the number of qualification vehicles and flight vehicles.

The Cost Model adds up the cost information for the following categories for every piece of equipment (up to 39 types) selected from the data base:

a.   Design engineering

b.   Test and evaluation

c.   Production engineering

d.   Unit production

Cost Estimating Relationships (CERs) are used to estimate the costs for components which are not amenable to cataloging, including:

a.   Structure

b.   Thermal control

c.   Wiring

d.   Power conditioning equipment

e.   Solar arrays

f.   Propellant tanks

The nonrecurring cost for each component takes into account design, development, the effects of redundancy, and yearly price changes. The average recurring cost for each equipment component is adjusted to

account for labor, materials, and yearly price changes. If more than one unit is to be built, a learning curve is used to account for reduced unit cost as additional quantities are built. Remaining system cost categories including:

a. Tooling and test equipment

b. Quality control

c. System engineering and integration, and

d. Program management

are estimated on the basis of predetermined percentages of the total of each of the four basic component cost categories.

The total nonrecurring cost is the sum of the nonrecurring costs for all of the system components. The total recurring cost is the sum of the products of the equipment quantities and the appropriate average recurring costs. The total spacecraft cost is obtained by summing the total recurring and nonrecurring costs and then adding in the mission equipment cost and contractor's profit.

5.5   SCHEDULE MODEL

Schedule equations are used to estimate the amount of time required to develop an operational system. In general, the estimates of the schedule lead times are functions of the hardware selected by the Cost/ Performance Model. The justification for such an approach lies in the fact that specific equipment components provide an indication of the complexity of the system and, hence, a measure of the time required to complete the activities associated with the system.

The model performs the following operations:

a. Computes the development and qualification lead times for each component.

b. Computes the development and qualification lead times for each subsystem.

c. Computes the system lead time.

d. Determines the critical path.

e. Computes the total program duration.

The Schedule Model output includes the various lead times, the total program duration, and the critical path.

5.6   COMPUTER PROGRAM

The Systems Cost/Performance Model has been implemented as a digital computer program. The program is written in the language of Fortran IV, as adapted to The Aerospace Corporation's CDC 7600 computer and MSFC's Univac 1108 computer. The program includes the Cost/Performance Model and the related data base.

The Systems Cost/Performance Computer Program incorporates four techniques to make the program as efficient as possible while retaining maximum versatility. The first technique is to pre-sort the equipment data base according to attributes specified by the program user. This technique is desirable in order to allow the program to select equipment from the data base on the basis of the first piece identified which satisfies the requirements.

The second technique consists of having the program always do a "macro" search of combinations of major subsystem configurations. As an example, one combination of major subsystem configurations would be a three-axis stabilized payload using cold gas propellant, oriented solar array paddles, shunt power regulation, and so forth. The subsystem configurations have been specified in Paragraph 5.2.1.

The third technique is to mechanize the digital program to have the capability to try all combinations (micro-search) of equipment in any single subsystem, if requested by the user. The user must specify the configuration types for each of the other subsystems to exercise this option. The program will select, design, and print out all acceptable combinations of equipment for the specified subsystem. This technique or option allows the subsystem specialist to perform detailed trade studies.

Because the program may identify a large number of design combinations which satisfy the input requirements, a post-sort routine (the fourth technique) is included which sorts the acceptable designs according to attributes as specified by the user.* This technique provides the computer program user with the designs listed in an organized fashion.

---

*The post-sort routine is not currently in the computer program, but can be added very easily.

Hence, the process of finding the "best" design out of all of the possible contenders is performed by the program.

The general sequence followed by the computer program is to read the input requirements, make one pass through the subsystem design algorithms, determine the required redundancy, and then make a second pass through the subsystem design algorithms with the data obtained from the first pass. Redundancy is not altered on the second pass primarily because the Reliability Model is extremely time-consuming. Cost and schedule are estimated for each acceptable design. *

5.7   SIGNIFICANT RESULTS

The major accomplishment of the FY 1974 effort was the development of a model possessing the ability to design unmanned, automated payloads. Subsystem, safety, cost, and schedule models were developed. Each of these models interfaces properly with the remainder of the model. The model is self-sufficient in that no intermediate steps need be performed by the user. The Systems Cost/Performance Model has been implemented as a digital computer program and is operational on The Aerospace Corporation's CDC 7600 and IBM 370-155 computers. **

Three test cases were used to check the Cost/Performance Model and the operation of the computer program. The three test cases were:

a.   Defense Satellite Communication System (DSCS-II)

b.   Earth Resources Technology Satellite (ERTS-A)

c.   Orbiting Solar Observatory (OSO-I)

The test results were reviewed at the system, subsystem and assembly levels. Table 5-2 compares the actual subsystem weights for DSCS-II with weights for the design generated by the Model.

The results of these three test cases indicate that the current Model is capable of estimating spacecraft program costs with reasonable accuracy. The error in the total cost estimate (using preliminary CERs) is less than 23% relative to the actual DSCS-II costs. Table 5-3 compares

---

*The six CERs in the Cost portion of the computer program are preliminary versions and will be updated to correspond to the documented CERs under a follow-on contract.

**The Cost/Performance Model is expected to be operational on MSFC's Univac 1108 computer in the near future.

Table 5-2. DSCS-II Weight Estimate Comparison

Subsystem	Weight (kg)		
	Estimated by Model	Actual Weight	Difference (%)
Structures	148.7	129.7	+3.4
Thermal Control	7.0	17.6	-1.9
Communication, Data Processing and Instrumentation	29.3	58.7	-5.2
Electrical Power (incl. Distribution)	186.8	147.8	+6.9
Stabilization and Control	73.0	55.2	+3.1
Auxiliary Propulsion	50.0	13.7	+6.4
Expendables	50.8	55.2	-0.8
Mission Equipment	82.1	82.1	-
Total Payload	627.7	560.0	+11.9
Adapter	7.7	6.7	+0.2
Launch Weight	635.4	566.7	+12.1

Table 5-3. DSCS-II Cost Estimate Comparison

	Model Estimates ($1000)	Subsystem CERs* ($1000)
DDT&E	(61, 370)	(61, 610)
Spacecraft	29, 070	29, 310
Mission Equipment	32, 300	32, 300
Investment	(63, 151)	(49, 610)
Spacecraft	43, 111	29, 570
Mission Equipment	20, 040	20, 040
Operations	(2, 573)	(4, 540)
Contractor Fee	(5, 053)	(4, 439)
Total	(132, 147)	(120, 199)

*The subsystem level cost estimates were generated by the current payload cost estimating model, PALCM.

the cost estimates for DSCS-II generated by the Model with the equivalent cost estimates generated by subsystem CERs. For these program checkout cases, the model results are consistent with conventional cost-versus-weight CERs.

At the same time, the model provided insight into the effect of other variables (e.g., reliability) on payload cost. Figure 5-3 presents the cost estimates generated by the Model as a function of payload reliability. The cost estimates are relatively insensitive to change in payload reliability at low levels due to the inherent reliability of a single string system. However, attempts to increase reliability substantially cause costs
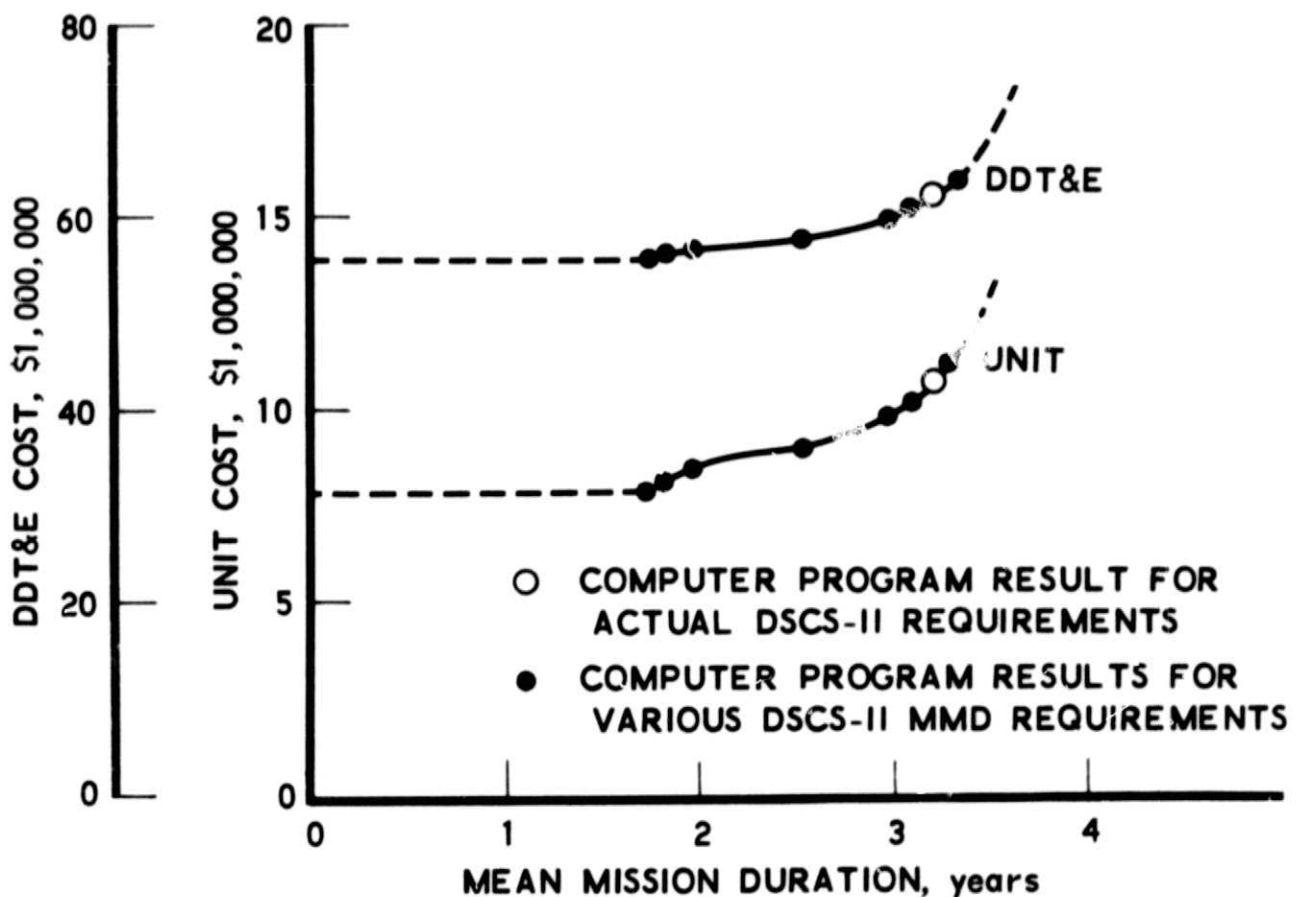

Figure 5-3. DSCS-II Cost versus Extended Life

to turn upward, reflecting the diminishing returns and increasing costs of adding redundancy. The cost curves generated by the Model provide more accuracy than the current CER approaches which are restricted to straight-line approximations about the nominal values.

Generally speaking, the Cost/Performance Model should exceed the performance of "top-down" models. The Model uses a "bottom-up" approach and, therefore, designs the payload at the assembly level. Greater accuracy is achieved by the very nature of the more detailed design. This accuracy will be reflected in the cost and schedule model estimates. A second attribute of the Cost/Performance Model is the completeness of the design specified. Pieces of equipment are not forgotten and redundancy is automatically included in the specified design. In addition, the impact of all subsystem interfaces and interactions is properly modeled. The net result is a payload design which is as accurate and complete as one from a Pre-Phase A study and which is available to the Cost/Performance Computer Program user immediately.

Because of the detailed nature of the Model, the potential uses of the System Cost/Performance Model exceed those for "top-down" models. The following uses of the model are suggested:

a. Establish specific payload designs and the related costs and schedule to meet the program requirements.

b. Determine the sensitivity of the design and its costs and schedules to changes in requirements.

c. Perform trade studies to identify optimal designs.

d. Develop standardized designs using a data base consisting of standardized equipment.

e. Identify low cost designs using a data base consisting of off-the-shelf equipment.

f. Use current Model to establish mathematical relationships within and between performance, safety, cost, and schedule without the use of a discrete data base.

g. Perform modularity studies by modifying the Model to assign equipment to modules.

The Model can readily be expanded in capability to perform many other studies as well.

The computer program aids the designer in performing trade studies and simplifies the achievement of a balanced system design. If fully developed, the Model can become a versatile tool in terms of preliminary program planning and in actual program management.

6. STUDY LIMITATIONS

This year's modeling activity was limited to unmanned, automated payloads. There was no attempt to incorporate the effect or influence of the Shuttle system on the design of payloads.

Funding limitations prevented application of the Systems Cost/Performance methodology to mission equipment and to ground support equipment and operations. The Schedule model was deemphasized for the same reason.

The focus of the current study was on developing a model rather than on augmenting a data base. Only after the model was successfully developed and proven as a useful tool could data collection be justified at such a detailed level. Most importantly, the current Model is limited in the range of payload designs it can generate by the limited number of equipment in the data base. Accuracy of the cost estimates is limited by the relatively limited amount of cost data which could be reduced and processed to support the data base cost entries.

7. SUGGESTED RESEARCH AND ADDITIONAL EFFORT

It is recommended that the Model be thoroughly verified and validated. The most useful validation procedure would be to use the Model on test cases selected from historical programs, operational programs, and new starts. Historical and current programs provide the most accurate data with which to validate the Model. New start programs will test the applicability of the Model as a preliminary planning tool.

The focus of the current study was on developing a model rather than augmenting a data base. On the other hand, lack of adequate data hindered the development of the FY 1974 model. The Cost Model must be considered preliminary and the Schedule Model cannot be considered operational until sufficient data has been collected to improve and validate the model. Hence, successful use of the Systems Cost/Performance Model depends entirely on the collection of performance, safety, cost, and schedule data at the subsystem component (assembly) level.

Although the Model is operational, there are a number of improvements which should be implemented. The suggested improvements in the subsystem, reliability, cost, and schedule models are listed below:

a. Subsystem Models

    1. Stabilization and Control

        (a) Incorporate a magnetic torquer in the model.

    2. Data Processing

        (a) Incorporate data compression in General Purpose Processors.

        (b) Incorporate a tape recorder in the model.

        (c) Incorporate an algorithm for selecting Command Distribution Units.

    3. Communications

        (a) Expand the model from the Air Force's Space Ground Link System (SGLS) to include NASA's Unified S-Band (USB), S-Band and VHF equipment.

    (b) Expand the model to apply to interplanetary missions.

   4. Structures

    (a) Incorporate a truss structural configuration.

 b. Reliability Model

   1. Incorporate mission equipment in the model with provision for increasing redundancy of the mission equipment.

   2. Incorporate a model of pulse-operation (short duration) modules.

 c. Cost Model

   1. Improve the accuracy and applicability of the data base and CERs by collecting and processing additional data.

   2. Develop CERs for equipment not previously flown.

   3. Model the relationship between cost and schedule.

 d. Schedule Model

   1. Improve the approach and accuracy of the model by collecting and processing additional schedule data.

   In general, it is recommended that the fiscal year 1975 effort include extension of the model to other space vehicle systems; improvement of the data base to be acceptable for performance, safety, cost, and schedule analyses; testing of the capability of the model to predict space vehicle interrelationships; and a user review to evaluate the potential of the model to assist in programmatic change control such as configuration management.

REFERENCES

2-1   System Cost and Performance Analysis (Study 2.3), Final
        Report, Volumes I and II, Report No. ATR-74(7333)-1,
        The Aerospace Corporation (28 September 1973).

3-1   Application of Engineering Cost Analysis, Report No.
        PRC D-2087, Planning Research Corporation (September
        1972).