Nasa CR 65445

FZM-4671-1
18 JULY 1966
VOLUME I
CONDENSED SUMMARY

COST MODEL

GENERAL DYNAMICS
Fort Worth Division

FZM-4671
18 July 1966
Volume I

C O N D E N S E D   S U M M A R Y

MANNED SPACECRAFT SYSTEMS
COST ~~MODEL~~

CONTRACT NAS9-3954

Prepared for the
MANNED SPACECRAFT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HOUSTON, TEXAS

APPROVED:

Dr. C. B. Moore
Chief of Operations Research

APPROVED:

T. E. Brents
Project Leader

GENERAL DYNAMICS
Fort Worth Division

F O R E W O R D

This document is the Condensed Summary of the results of the Manned Spacecraft Systems Cost Model Study. The study, Contract NAS9-3954, was performed by the Fort Worth Division of General Dynamics Corporation during the period beginning April 1965 and ending June 1966. The technical performance of the study has been under the supervision of the Office of Long Range Planning, Manned Spacecraft Center, National Aeronautics and Space Administration.

The complete results of the Cost Model Study are contained in the following volumes:

VOLUME 1 - CONDENSED SUMMARY

VOLUME 2 - SUMMARY

VOLUME 3 - TECHNICAL REPORT

VOLUMES 4, 5, & 6 - APPENDICES TO TECHNICAL REPORT

A C K N O W L E D G E M E N T S

This study has been conducted for the NASA Manned Spacecraft Center. The work was performed under the technical direction and assistance of Mr. D. E. Wagner, Technical Manager.

During the development of the Manned Spacecraft Systems Cost Model, significant contributions were made by the following General Dynamics/Fort Worth Division personnel:

T. E. Brents	Project Leader
C. E. Craig	Programming
C. E. Dreyfus	Model Implementation
F. M. Howe	Model Formulation and Implementation
J. S. McKnight	Project Consultant
C. B. Moore	General Direction and Consultation
J. W. Mossbarger	Cost Estimating Relationships
G. D. Self	Contingency Planning Submodel
M. F. Schwartz	Contingency Planning Model
G. G. Tharp	Cost Estimating Relationships

TABLE OF CONTENTS

1.0 INTRODUCTION

In undertaking the Manned Spacecraft Cost Model Study, the basic objective was the development of a mathematical model programmed for the IBM 7094; the model was to be designed to develop, on a timely basis, improved cost estimates of advanced manned spacecraft. In consonance with the study objective, the Fort Worth Division of General Dynamics has developed a model with the following characteristics:

- The model is capable of generating total costs attributable to NASA's Manned Spacecraft Center; the costs are divisible into research and development, recurring, and facilities costs.
- The model can be used to generate and to output costs in varying levels of detail, ranging from total program costs down to the cost of an individual spacecraft subsystem.
- In addition to a pure costing capability, the model can provide other data which are required in the evaluation of MSC plans, including current and future spacecraft funding requirements over time (annual and semiannual increments), MSC resource requirements, and cost effectiveness measures.

A detailed summary of the basic accomplishments of the Cost Model Study is presented in Section 5. In Section 6, General Dynamics' recommendations for future study are delineated. It should be noted that this document is a condensed summary of the study results. A companion document, the Technical Report, contains a detailed technical discussion of the results of study.

Concurrent with the Cost Model Study, MSC established a supporting Cost Analysis Study which was conducted by another contractor. In this Cost Analysis Study, cost data was collected and analyzed and subsequently used in developing the cost estimating relationships for the Manned Spacecraft Cost Model. Consequently, the initial results obtained from the operation of the Cost Model are influenced by the data inputs from the Cost Analysis Study. The work performed in the Cost Analysis Study is described in the final reports on that study.

2.0 COST MODEL CHARACTERISTICS

A cost model is essentially a systematic procedure which is used to predict costs. The basic tasks undertaken in developing and operating a spacecraft are considered by the model in a logical and orderly manner. Cost model characteristics are depicted in Figure 1. These basic tasks are further divided into subtasks that are related to the characteristics of the spacecraft, the modules of the spacecraft, and the subsystems associated with the modules. The cost implications of various spacecraft technologies, such as batteries vs fuel cells, should be considered in the case of each subtask.

A properly constructed model can be used to generate complete costs because it provides an orderly and logical procedure for considering all pertinent cost-sensitive factors. Cost estimates from other sources are often inadequate, not because the costs presented are inaccurate, but because the cost is incomplete.

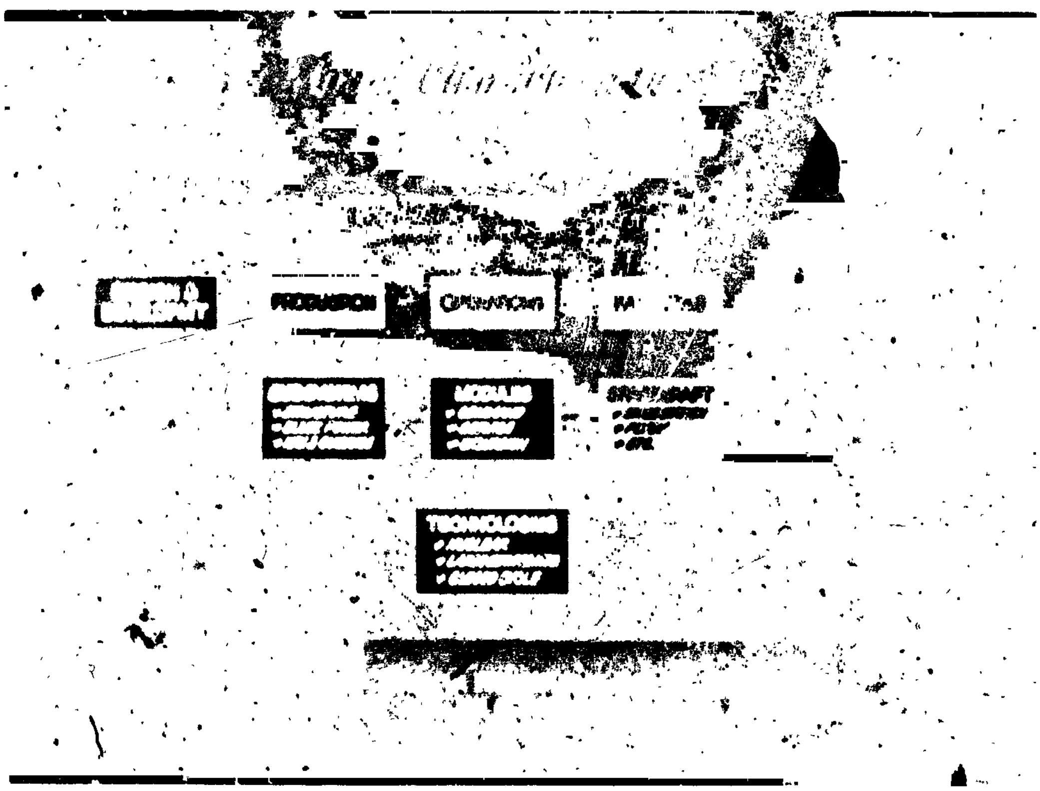

Figure 1

Cost model estimates are also consistent because, by the use of equations, a given variable is always treated as an identical value. In addition, the methodology assumes that a consistent set of procedures will be applied to every costing problem.

Although the model could be used to generate costs by hand computations, a quantum increase in computational speed can be obtained by programming the model for use with a computer. A rapid computational speed means that a very rapid assessment can be made of the cost implications of potential variations in spacecraft design, schedule, and program considerations.

3.0 MANNED SPACECRAFT COST MODEL CONCEPT

The Manned Spacecraft Cost Model provides the user with an analytical tool that combines numerous complex costing techniques with the accuracy, speed, and convenience of modern digital computers and programming techniques. These analytical elements have been combined into a generalized model (refer to Figure 2) which is capable of successfully handling most problems encountered in costing conceptual spacecraft. These computational capabilities have grown out of the model concept depicted in the adjacent figure. The major elements of this concept are the basic model structure, library, inputs, the outputs, and a Contingency Planning Model.

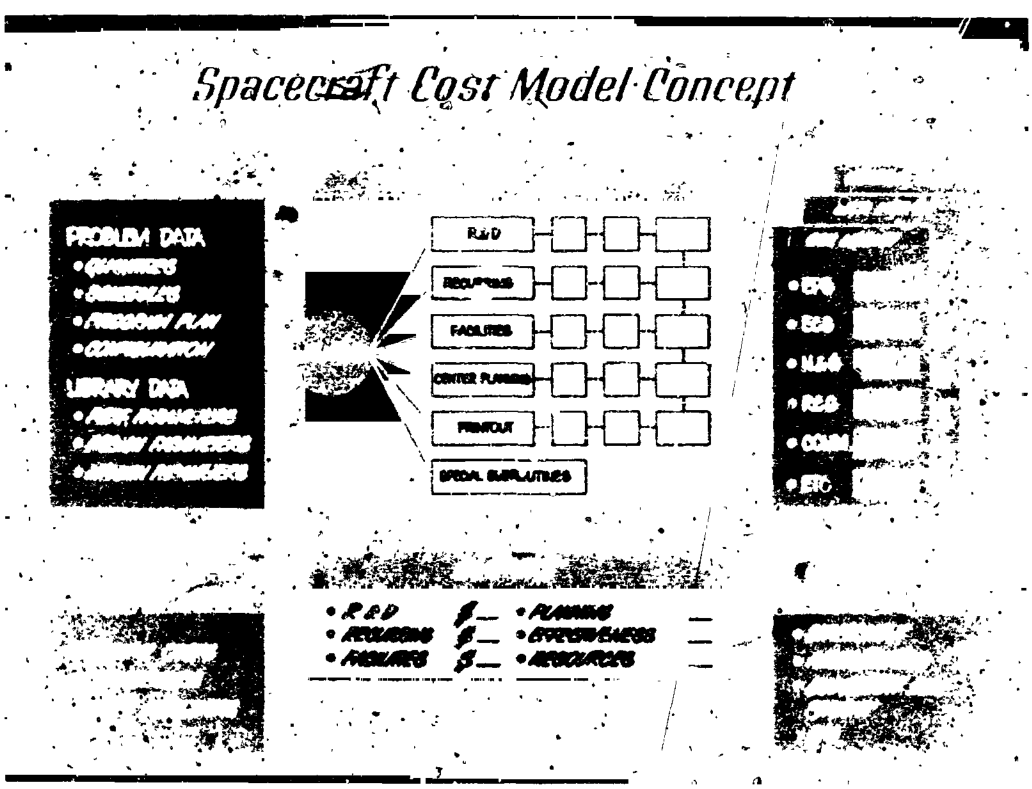

Figure 2

3.1 OUTPUTS

Model outputs range all the way from total program cost down to the cost of major development tasks for individual subsystems. Cost outputs are available by subsystem, module, and spacecraft for each program element within three main subdivisions: Research and Development, Recurring, and Facilities. These costs can be obtained in either totals or spread over time to indicate funding requirements.

The model can be used to output a number of items other than costs: hardware purchased in the R&D and Recurring phases; MSC personnel requirements; and inputs and estimating relationships used in a given problem.

All of the model outputs discussed above are optional features; any one option, any combination of the options, or all options may be exercised at the discretion of the analyst to fulfill the requirements of any given study. The exercising of these options is accomplished by means of appropriate inputs and by use of the Printout Submodel which is located within the basic model structure.

3.2 BASIC MODEL STRUCTURE

3.2.1 Printout Submodel

The Printout Submodel allows the model user to choose the amount of information to be printed on a given program. For cursory analyses, summary reports of total R&D, Recurring, and Facilities costs at the spacecraft, module, and subsystem level can be obtained. In the more detailed analysis, semi-annual costs for all cost categories at all levels can be made available as a printout. Numerous intermediate levels of printout are available. The existence of the Printout Submodel makes it possible to retain all problem runs on magnetic tape for reuse and removes the requirements for storage of printouts which are not actually necessary to the immediate task.

3.2.2 Center Planning Submodel

Another submodel within the basic model structure, the Center Planning Submodel, also can operate off of magnetic output tape. In this submodel, inputs used are the cost data generated by the Research and Development and Recurring Submodels. The Center Planning Submodel computes the center personnel requirements at MSC by major center function (e.g., Program Office, Flight Crew Operation, R&D Personnel, etc.); these personnel requirements are expressed in terms of civil service personnel and contractor support personnel.

3.2.3 R&D Submodel

The Research and Development Submodel computes all costs associated with the design and development of subsystems, modules, and spacecraft required to meet a mission objective. These costs include not only design costs but also (1) costs for sustaining engineering, tooling, ground and flight testing, recovery operations, and manufacturing spares and (2) costs for hardware used prior to a manned flight.

3.2.4 Recurring Submodel

The Recurring Submodel computes all hardware and spares requirements and operating costs associated with the initiation and maintenance of manned missions.

3.2.5 Facilities Submodel

The Facilities Submodel computes the cost of all facilities bought during the program under consideration. Included are any facilities required for the subsystems, modules, and/or spacecraft in the R&D program as well as those facilities required during the operational phase; provisions are made, also, for additions to the Mission Control Center.

All of the above-mentioned submodels are tied to additional subroutines which have been designed to handle special costing problems such as those associated with production learning curves, recovery and reuse, cost-inflating procedures, funding computation, and cost effectiveness.

3.3 LIBRARY AND PROBLEM DATA

The Research and Development, Recurring, and Facilities Submodels operate from instruction and information contained in libraries and problem data. As a result of the multipurpose applications of Cost Model, the number of instructions and information requirements are many and cover a wide range of data. In order to facilitate the inputting process and in order to minimize the time spent on the inputting task, most of the required data for a problem has been incorporated into libraries. Library data have the virtue of being inputted only once after which they are stored and available for all program runs.

Model libraries are subdivided into general, specific, and cost estimating relationships. General data includes items such as funding parameters that are generally unchanging from one spacecraft program to another. Specific library data include design, performance, and mission parameters that are used to define specific subsystems, modules, and spacecraft. Some of those parameters in turn are used by the cost estimating relationships (CER's) library subdivision. The CER library contains equations which are used to estimate the cost elements of given spacecraft; these cost elements are expressed as functions of design, performance, and mission parameters.

Some information cannot be conveniently kept in library form; these are problem data that must be input each time a problem is run. Problem data include such information as the identification of the spacecraft to be costed, cost inputs, and computational options; these data are divided between required data (which total less than 10 items per problem) and optional data (which number more than 75 items).

3.4 CONTINGENCY PLANNING MODEL

The Contingency Planning Model operates independently of the rest of the Manned Spacecraft Cost Model. This experimental model, which was delivered to MSC early in the contract, is used to estimate changes in baseline cost when these changes result from such contingencies as stretchouts, accelerations, cost sharing, and budgetary constraints.

4.0 MODEL APPLICATIONS

A discussion of possible model applications is contained in the following section. Of all the results of the study, those results of paramount interest and importance are the potential applications of the model. It is believed that these applications can best be illustrated by example problems. These problems represent a wide range of spacecraft types and costing problems and were used to validate the model logic, library data, and estimating relationships. These representative problems, taken together, are not an exhaustive list of applications but were selected to typify the problems that will be encountered most frequently. Included are typical problems related to absolute cost analysis, cost sensitivity, budget planning, and other special factors.

The costs presented herein should not necessarily be construed as the actual or ultimate costs of the spacecraft programs or of the program components used as examples. The Manned Spacecraft Cost Model was designed to be sensitive to variations in design parameters, mission parameters, and program variables such as quantities and timing. In the following sections, it will be shown that the ultimate cost of a mission or spacecraft, can vary markedly depending on the choice of parameters and variables. Therefore, the costs presented herein can be considered to be accurate in light of the assumptions made concerning mission parameters and program variables.

4.1 ABSOLUTE COSTS

The model will be used most frequently to obtain the absolute costs of a given spacecraft configuration, thus allowing NASA to verify the reliability and completeness of estimates obtained from external sources. The model also provides a common or standard measure for evaluating costs of competing design concepts. In addition to evaluating external estimates, the model complements NASA's internal spacecraft design capability by providing the means for producing a quick assessment of the costs of a given design; this assessment can be made prior to disclosure of the design outside NASA.

Examples of the type of absolute costs that can be obtained with the model are presented in Figure 3. The costs and model inputs contained in the figure were extracted from a model check problem in which a MORL-type of space station is used as the example; an examination of the figure will disclose that the largest single component of these costs is subsystem-level R&D costs.

The composition of the space station subsystem R&D costs are shown in Figure 4 which is, in actuality, a reproduction of a computer output sheet. The figure illustrates the amount of data generated by the model. These include not only the cost of each subsystem installed in this particular space station but also estimates for the major subsystem development tasks (such as design and development, test articles, etc.).

Figure 3

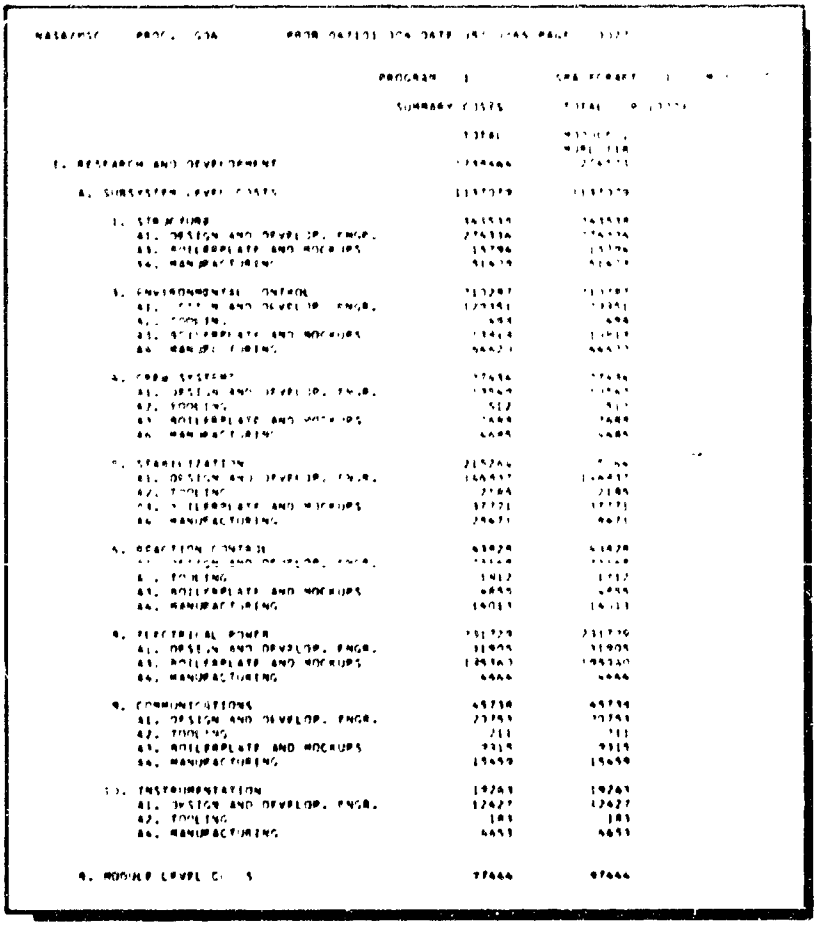

Figure 4

4.2 COST SENSITIVITY

By use of the model, it is possible to assess the sensitivity of absolute costs to variations in program considerations. The model was deliberately designed to be sensitive to changes in design, schedule, quantities, development philosophy, and technology. It is precisely these factors about which there is the greatest uncertainty at the start of a new spacecraft program and during the latter stages of existing programs. The model structure, and its associated estimating relationships, permit the identification of those factors which are most cost sensitive and which allow reasonable bounds to be set upon spacecraft program cost.

The sensitivity of the model to design and performance considerations is illustrated if the subsystem level R&D costs for a Mars mission module (in Figure 5) are compared with those costs previously presented for the MORL. Total subsystem level R&D for MORL is $1.137 Billion as compared with $4.468 Billion for Mars

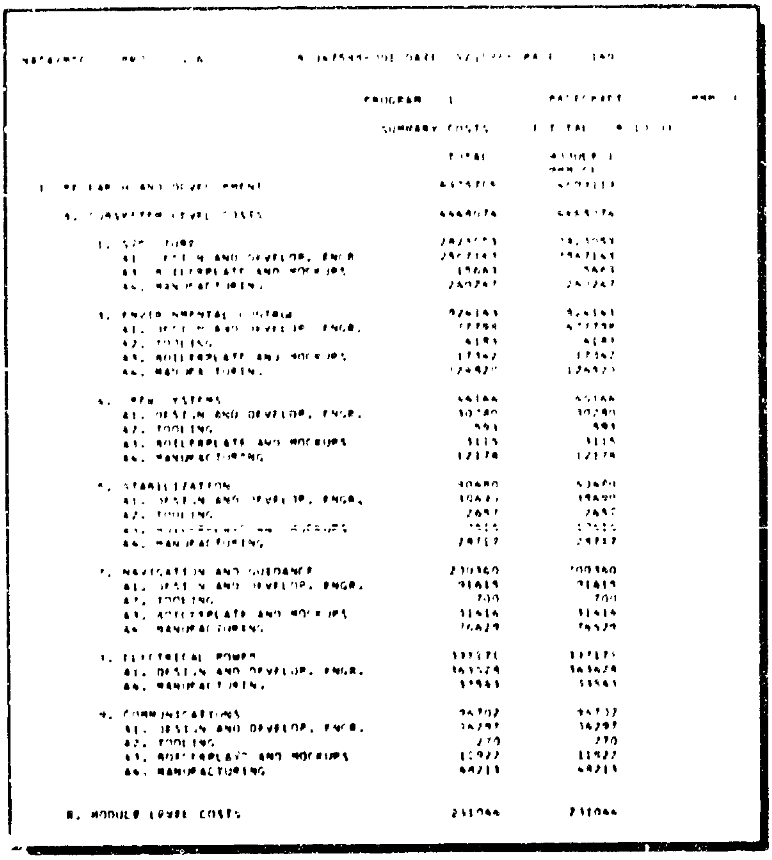

Figure 5

mission module. This differential results from the differences in design which are a product of the more stringent demands placed on the mission module. The mission module must provide support for eight men for 420 days under deep space conditions without any possibility of resupply or outside help. In contrast, the MORL supports six men for 90 days with the possibility that the crew can safely abort any time and return to earth in a matter of hours. The Mars Mission Module factors, taken together, result in more severe demands being made on structure, electrical power, environmental control, and communications; these are the subsystems that show the greatest cost increase over comparable elements in the MORL.

An example of the sensitivity analyses attainable are portrayed in Figure 6. This figure is used to summarize the results obtained from the model when the number of operational space stations is varied. Increasing the number of stations from one to three results in a $700 million increase in total cost. The change

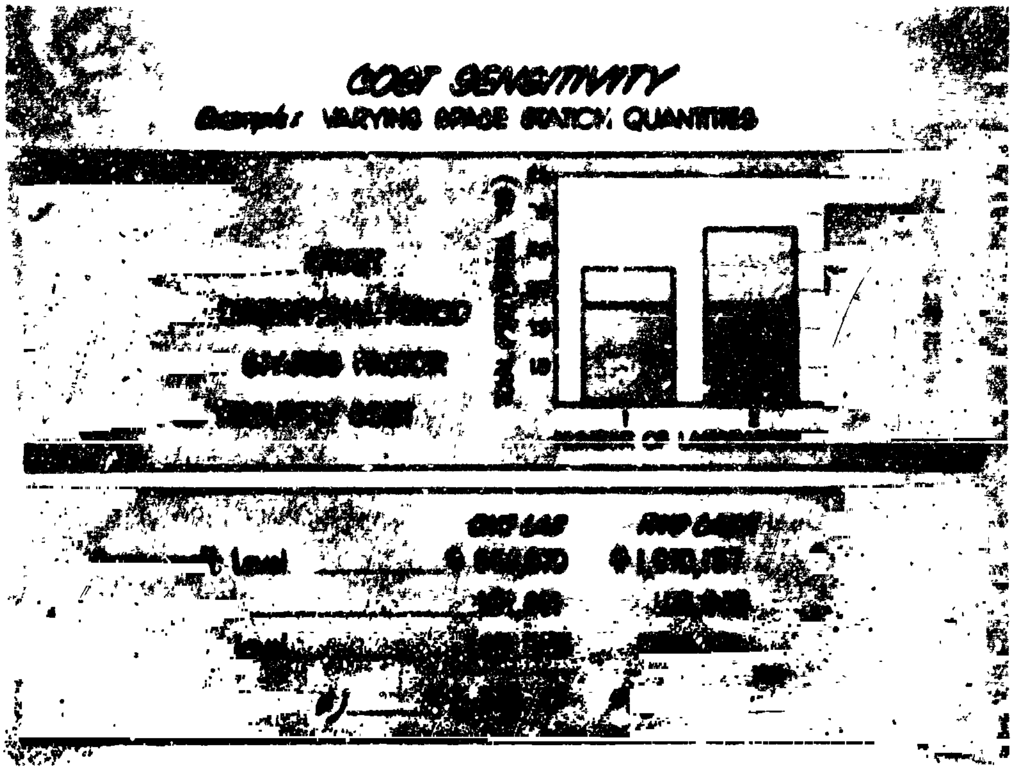

Figure 6

in total cost is attributable to (1) higher subsystem level costs, and (2) the increasing spacecraft level cost which is due to greater mission control requirements.

4.3 MISSION ANALYSIS

Use of the model can greatly facilitate mission analysis. In this area, the model may be used in the following possible applications:

1. Establishment of the costs of competing missions which are equally attractive on other grounds

2. Assessment of the economies which result from the use of the "building block approach" to the performance of a given mission

3. Evaluation of specified mission modes.

An example of the latter application is shown in Figure 7. Presented in Figure 7 are the results of model estimates of the cost of one approach to performing a manned Mars mission: a Mars flyby which is followed by a Mars landing expedition. Figure 8 (a reproduction of output of the model) depicts major spacecraft elements and their costs for the landing expedition.

4.4 CENTER PLANNING

The model also provides NASA with a center planning capability by means of which long range center personnel estimates can be obtained in a fraction of the time required by usual methods. Thus the model permits the rapid estimation of changes in personnel requirements which have come about from changes in either (1) the composition of spacecraft programs managed by MSC or (2) Center policy or both of these factors. The output of the model is characterized as being fitted to functional lines and as being in sufficient detail so that it can be matched with the current MSC organization. A sample of the output is shown in more detail in Figure 9.

4.5 FUNDING APPLICATIONS

Through the use of the model, consideration can be given to the funding implications of a mix of both current and future programs; thus the model provides a tool for integrating long range technical planning with financial planning. Although the model does not provide the detailed funding data required for program control purposes, it can provide information for use in answering questions that are frequently asked of NASA program control offices. An example of this application is shown in Figure 10. In this figure, model outputs of the annual expenditures for a Mars flyby mission have been imposed on Apollo program estimates. As a result of relatively minor changes in inputs, other funding measures (such as new obligational authority or commitments) could be generated on an annual or semi-annual basis for the program mix shown in the example.

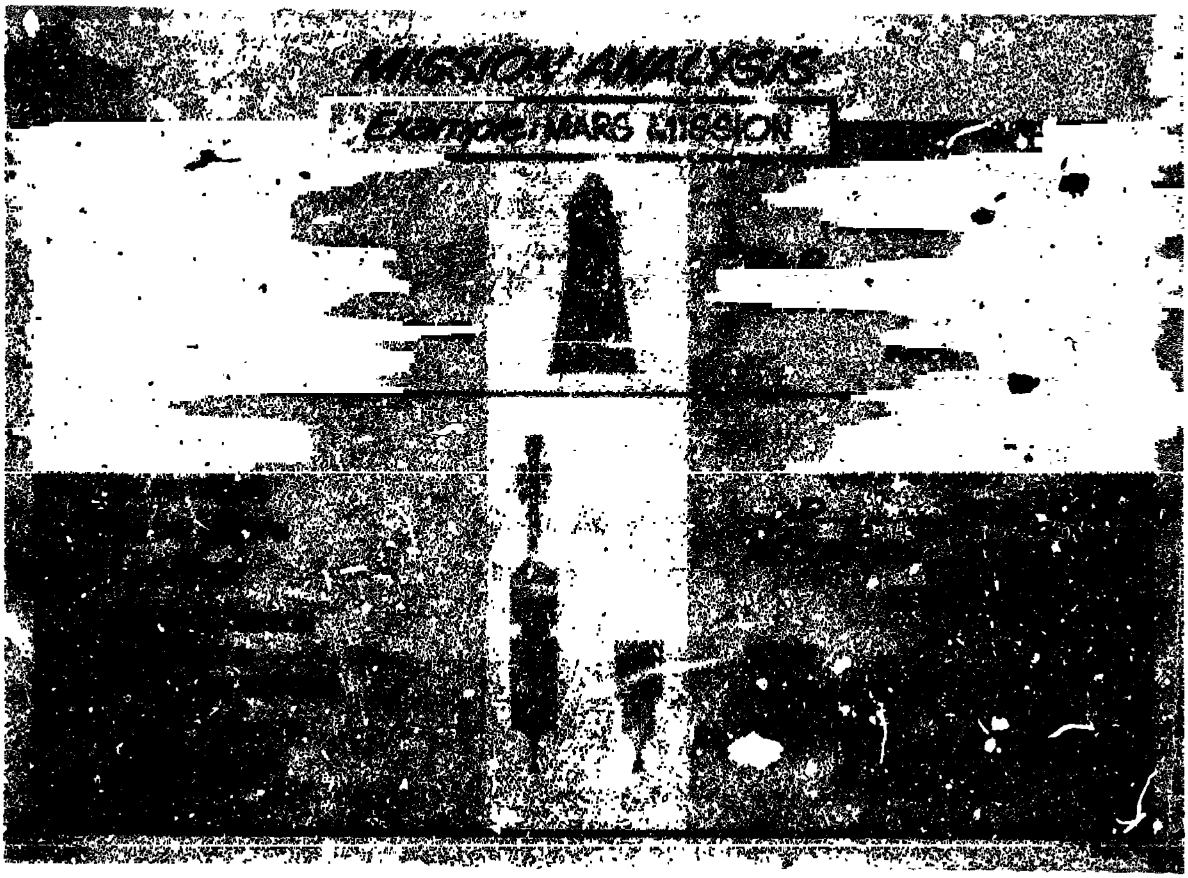

Figure 7

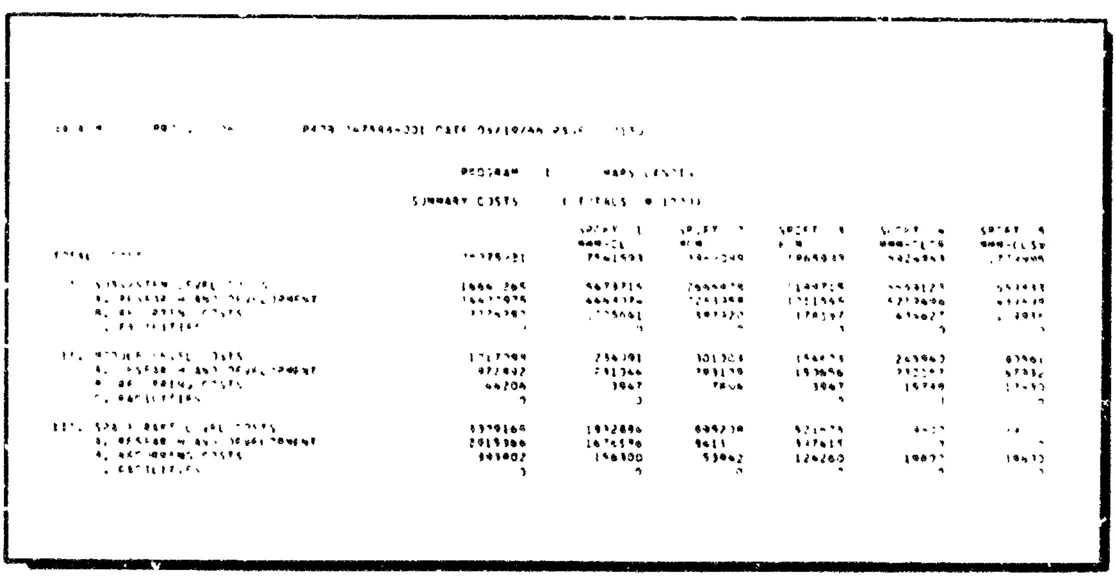

Figure 8

NASA/MSC PROC. G06 PROR 001400-001 DATE 05/04/66 PAGE 0079

TIME - 1989.5 CENTER

	CIVIL SERVICE		CONTRACTOR SUPPORT	
	COST	PERSN.	COST	PERSN.
TOTAL	63490	6349	150726	13605
I. PROGRAM OFFICES	9024	902	9024	902
II. ENGINEERING AND DEVELOPMENT	0	0	0	0
A. STAFF	0	0	0	0
B. ADVANCED TECHNICAL PLANNING	0	0	0	0
C. COMPUTATION AND ANALYSIS	0	0	0	0
D. SUBSYSTEMS	0	0	0	0
1. STRUCTURE	0	0	0	0
2. PROPULSION	0	0	0	0
3. ENVIRONMENTAL CONTROL	0	0	0	0
4. CREW SYSTEMS	0	0	0	0
5. STABILIZATION	0	0	0	0
6. REACTION CONTROL	0	0	0	0
7. NAVIGATION + GUIDANCE	0	0	0	0
8. ELECTRICAL POWER SYSTEM	0	0	0	0
9. COMMUNICATIONS	0	0	0	0
10. INSTRUMENTATION	0	0	0	0
11. LAUNCH ESCAPE	0	0	0	0
12. RECOVERY SYSTEM	0	0	0	0
13. ADAPTER	0	0	0	0
III. ADMINISTRATION	31654	3165	75074	9607
A. STAFF	4535	454	22675	2268
B. PROCUREMENT	9024	902	9024	902
C. PERSONNEL	4535	454	22675	2208
D. RESOURCE MANAGEMENT	9024	902	9024	902
E. SERVICE	4535	454	22675	2268
IV. FLIGHT CREW OPERATIONS	27	3	27	3
V. FLIGHT OPERATIONS	18250	1825	18250	1825
A. STAFF	6000	600	6000	600
B. MISSION PLANNING	4000	400	4000	400
C. MISSION CONTROL	2000	200	2000	200
D. LANDING AND RECOVERY	250	25	25	25
E. FLIGHT SUPPORT	6000	600	6000	600
VI. OFFSITE TEST OPERATIONS	0	0	0	0
VII. OTHER TECHNICAL STAFF	4535	434	22675	2268
VIII. OTHER R+D			0	
IX. SUPPORTING DEVELOPMENT			0	
X. ADMINISTRATIVE FACILITIES			22675	

Figure 9

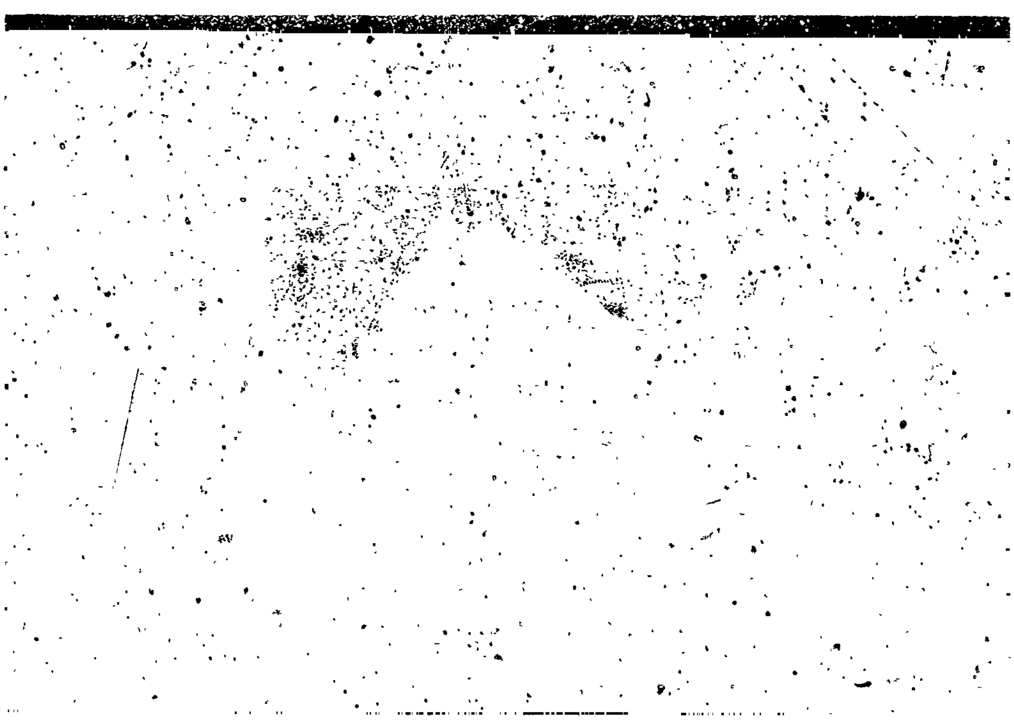

Figure 10

5.0 SUMMARY OF MAJOR STUDY ACCOMPLISHMENTS

The major accomplishments of the Cost Model Study are summarized below:

1. A comprehensive set of cost categories and a corresponding model structure were established. The structure and categories account for all significant elements of spacecraft cost and are sufficiently generalized as to be applicable to all types of spacecraft. Both recurring and nonrecurring costs are accounted for, and it is possible to collect various levels of cost aggregations from subsystem through programs.

2. A separate and independent model, which may be used to evaluate up to eight program contingencies, was programmed and delivered to MSC early in the study.

3. Cost estimating relationships were developed in terms of the following advanced technologies: nuclear power, nuclear propulsion, large liquid propulsion, and advanced service module structures.

4. Procedures were incorporated which can be used to modify or manipulate basic costs to reflect special costing situations, such as design changes, multiple learning curves, and inflation.

5. Provisions were made to accommodate cost estimating relationships that reflect different subsystem technologies and/or varying levels of input availability.

6. Special subroutines were developed to account for situations unique to spacecraft costing. These special provisions include a reusability subroutine that can be used to estimate the cost of reusing spacecraft; in the subroutine, such factors as turnaround time, number of reuses, and probability of reuse are taken into consideration. Another subroutine is designed to deal with the problem of computation and allocation of joint

costs associated with mission planning and control.

7. Growth potential has been provided in a manner such that, without reprogramming the model, the level of computation of costs may be changed, and cost estimating relationships may be updated as new data becomes available.

8. Two unique submodels were developed: the Printout Submodel (in which unusual flexibility in printout options is offered) and a Center Planning Submodel (in which MSC personnel and funding requirements are generated).

9. An improved method of generating funding or spreading costs over time was developed; this method provides for funding at two different levels, is completely generalized, and requires an absolute minimum in terms of amount of inputs.

10. A multiple spacecraft costing capability was provided by means of which it is possible to compute and display the costs of up to 16 different spacecraft in a single problem run.

11. A concept was developed which can be used to minimize re uired inputs for a given problem run.

12. The model has been validated by a comprehensive series of check problems. Model logic has been checked out by hand computation, subroutine machine computation, and by integrated machine computation. In this latter step, consideration was given to all costing situations that can reasonably be expected to be encountered.

13. The model has been implemented, and it is operating in a routine manner at the Manned Spacecraft Center.

6.0 RECOMMENDATIONS FOR FUTURE STUDY

Five months of checkout have verified that the cost model structure is sound. However, preliminary investigations by General Dynamics indicate that additional work on most of the model's estimating relationships seems warranted. While the current relationships are the best available, additional effort could be profitably spent on refining the relationships and the data from which they were developed. In particular the following steps should be taken: (1) continue analysis of the division between subsystem variable and non variable cost, (2) further evaluate module and spacecraft level cost and in particular GSE cost, and (3) evaluate all CER's with respect to advanced technologies.

While operation of the program is satisfactory, minor alterations to provide additional gross cost spreading functions and to incorporate a print/plot submodel would enhance use of the model.