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T E C H N I C A L   R E P O R T

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

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F O R E W O R D

This document contains 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 AND 6	APPENDICES TO TECHNICAL REPORT

ACKNOWLEDGEMENTS

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 Model
M. F. Schwartz	Contingency Planning Model
G. G. Tharp	Cost Estimating Relationships

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1.0 INTRODUCTION AND SUMMARY

1.1 STUDY OBJECTIVES

In undertaking the Cost Model Study, the basic objective was the development of a mathematical model programmed for the IBM 7094; this model was to be designed to develop, on a timely basis, improved cost estimates of advanced manned spacecraft. More specifically, the objective of the study was defined as the development of a model with the following characteristics:

1. The model was to have the capability of generating total costs attributable to NASA's Manned Spacecraft Center; these costs were to be divisible into research and development, recurring, and facilities costs.

2. The model was to be used to generate and to output costs in varying levels of detail ranging from total program costs down to costs of an individual spacecraft subsystem.

3. In addition to a pure costing capability, the model was to provide other data which is required in the evaluation of MSC plans; this "other data" was to include current and future spacecraft funding requirements over time (annual and semiannual increments), MSC resource requirements, and cost effectiveness measures.

Concurrent with the Cost Model Study, MSC also established a supporting Cost Analysis Study which was to be conducted by another contractor. In this Cost Analysis Study, cost data was collected and analyzed and subsequently used to develop cost estimating relationships for the Manned Spacecraft Cost Model. The work performed in the Cost Analysis Study is described in the final reports of that study.

It should be noted that the initial results obtained from the operation of the Cost Model are influenced by the data inputs from the Cost Analysis Study.

1.2 SUMMARY OF STUDY ACCOMPLISHMENTS

In conducting the Cost Model Study, the Fort Worth Division of General Dynamics was able to demonstrate the achievement of all of the study objectives. Major accomplishments are summarized below:

1. A comprehensive set of cost categories and corresponding model structure was 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 non-recurring costs are accounted for, and it is possible to collect various levels of cost aggregations from subsystems 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 required 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 used in a series of actual costing exercises. In these exercises, the model's sensitivity to various design, performance, and mission parameters has been demonstrated. In addition, the model has proved to be a valuable tool in mission analysis by assisting in the determination of optimum mission modes and evaluation of competing missions.

14. The model has been implemented and is fully operational at the Manned Spacecraft Center.

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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 2-1. 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

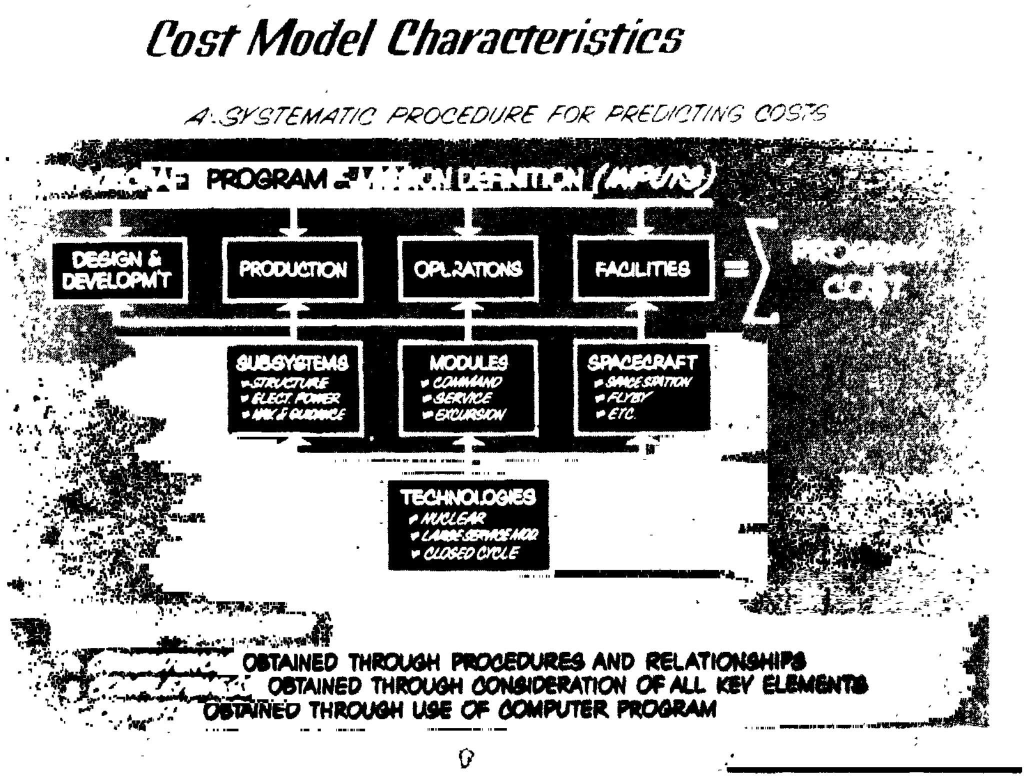

Figure 2-1

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. 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 M A N N E D S P A C E C R A F T C O S T M O D E L C O N C E P T

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 3-1) 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.

Spacecraft Cost Model Concept

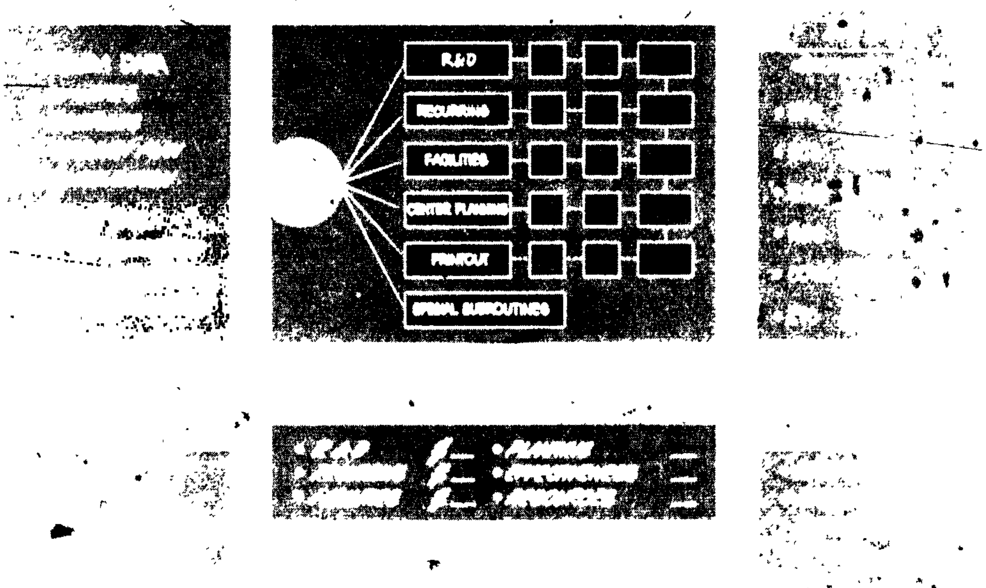

Figure 3-1

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

Five submodels comprise the basic model structure. The principal characteristics of these submodels are discussed in the subsequent paragraphs.

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 the 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 use in 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 OUTPUTS

The outputs of the model are listed and defined in the paragraphs that follow. The standard output is the summary reports; in these reports, cost data is provided according to a prescribed order on an unfunded or unspread basis. In addition to the summary reports, there are several other groups of print options which provide funding reports, center planning reports, and other reports (such as input data which may be used to facilitate the analysis of the cost outputs). The remainder of the section will be devoted mainly to discussions of the basic cost categories considered in the summary report. Most other cost outputs are either summations or manipulations of these basic cost categories.

4.1 COST OUTPUTS

The model can be used to compute, accumulate, and print out several different levels of costs. These levels correspond to hardware components of a mission: subsystem, module, spacecraft, and program. The different levels of model computation are in Figure 4-1.

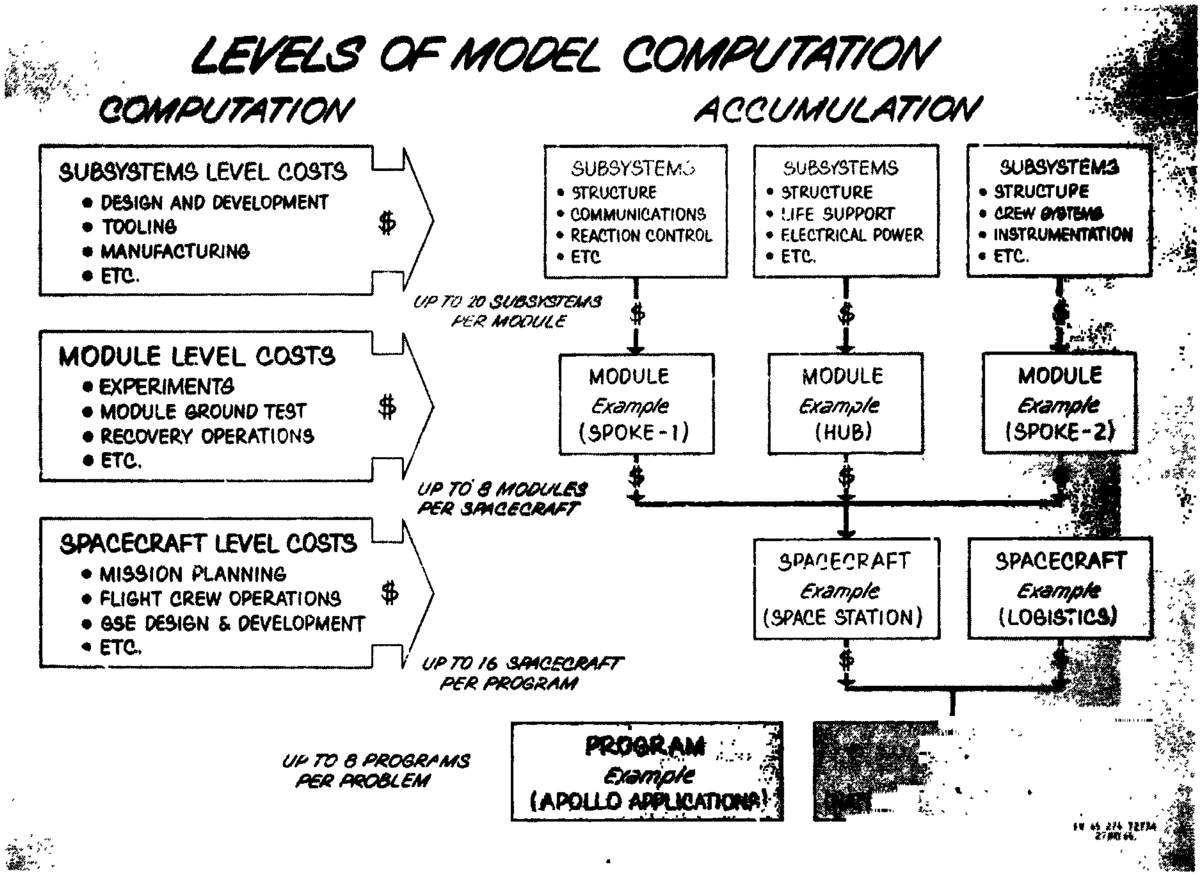

Figure 4-1

The subsystem level is the most detailed level at which costs are computed. 13 different subsystem types may be considered by use of the model:

Structure	Navigation and Guidance
Propulsion	Electrical Power
Environmental Control	Communication
Crew Systems	Instrumentation
Stabilization	Launch Escape
Reaction Control	Recovery
	Adapter

The model may be used, also to compute costs for secondary units of any of the foregoing subsystems provided the total number of primary and secondary subsystems in any one module does not exceed 20.

The module level is the next higher level of cost computation within the model. A module is considered to be a set of subsystems separate and, for costing purposes, severable from some other set of subsystems which belong to the same spacecraft. The module level was established primarily to account for costs which cannot be allocated to specific subsystems and which may occur more than once for a given spacecraft.

Some costs are not attributable to either subsystems or modules; the spacecraft level was established to account for such unallocated costs. A spacecraft is defined as a collection of modules capable of flight or operation independent of some other set of modules.

There is also a program level computation; computation at this level, however, is restricted essentially to estimating the operating costs for the Mission Control Center.

In addition to computing at these levels, the model may be used also to accumulate the costs at each level. Thus, all subsystem costs for a given module are attributable to that module, all module costs for a given spacecraft are attributable to that spacecraft, etc.

For each of the foregoing levels, several sets of cost categories have been established. There is a category set for each major submodel: Research and Development, Recurring, and Facilities. A list of these categories and a generalized definition for each category is presented below. The definitions are generalized because they are applicable to all types of spacecraft and subsystem technologies. A few deviations from these definitions exist due to the availability of data and the results of the related Cost Analysis Study. These deviations are described in the section on cost estimating relationships and are further discussed in the Cost Analysis Study technical report.

4.2 RESEARCH AND DEVELOPMENT COST OUTPUTS

The Research and Development outputs by subsystem are divided into four categories: Design and Development, Engineering, Tooling, Boilerplate and Mockups, and Manufacturing (refer to Figure 4-2). Each of these categories reflects the direct and indirect costs of both prime contractors and subcontractors.

Design and Development costs include the engineering costs associated with development of a man-rated subsystem; included are the costs of design, technical direction, and inplant

	PROGRAM 1 SUMMARY COSTS	MARS MISSION (TOTALS * 1000) SPCFT 1 MMM	SPCFT 2 MCSM
I. RESEARCH AND DEVELOPMENT	6353473	3262411	3091062
A. SUBSYSTEM LEVEL COSTS	3736110	1943822	1792288
1. STRUCTURE	961432	454935	506496
A1. DESIGN AND DEVELOP. ENGR.	449483	212987	236496
A2. TOOLING	18290	9178	9112
A3. BOILERPLATE AND MOCKUPS	30969	15491	15478
A4. MANUFACTURING	462690	217280	245410
2. PROPULSION	239368	0	239368
A1. DESIGN AND DEVELOP. ENGR.	33945	0	33945
A2. TOOLING	544	0	544
A3. BOILERPLATE AND MOCKUPS	9944	0	9944
A4. MANUFACTURING	194934	0	194934
3. ENVIRONMENTAL CONTROL	1145787	1048520	97266
A1. DESIGN AND DEVELOP. ENGR.	836660	784694	51966
A2. TOOLING	12776	12020	756
A3. BOILERPLATE AND MOCKUPS	26784	17489	9295
A4. MANUFACTURING	269567	234318	35248
4. CREW SYSTEMS	37107	18694	18414
A1. DESIGN AND DEVELOP. ENGR.	23936	12118	11918
A2. TOOLING	416	222	195
A3. BOILERPLATE AND MOCKUPS	2194	1168	1026
A4. MANUFACTURING	10561	5185	5376
5. STABILIZATION	80461	0	80461
A1. DESIGN AND DEVELOP. ENGR.	39565	0	39565
A2. TOOLING	2293	0	2293
A3. BOILERPLATE AND MOCKUPS	8993	0	8993
A4. MANUFACTURING	29610	0	29610
6. REACTION CONTROL	384525	99088	285437
A1. DESIGN AND DEVELOP. ENGR.	98202	30878	67324
A2. TOOLING	5074	1707	3366
A3. BOILERPLATE AND MOCKUPS	13610	4579	9031
A4. MANUFACTURING	267640	61923	205717
7. NAVIGATION AND GUIDANCE	290613	149095	141517
A1. DESIGN AND DEVELOP. ENGR.	136062	69625	66437
A2. TOOLING	862	471	391
A3. BOILERPLATE AND MOCKUPS	39170	21620	17550
A4. MANUFACTURING	114519	57379	57140
8. ELECTRICAL POWER	256750	0	256750
A1. DESIGN AND DEVELOP. ENGR.	79440	0	79440
A3. BOILERPLATE AND MOCKUPS	163200	0	163200
A4. MANUFACTURING	14110	0	14110

Figure 4-2

testing. Also are included the variable or sustaining engineering costs attributable to ground test modules and unmanned flight modules.

Tooling includes the cost of design and manufacture of initial tooling used in the manufacture of each subsystem.

Boilerplate and Mockups includes the cost of mockups and also prototype hardware that is not installed in complete or nearly complete hardware items.

Manufacturing costs include those costs incurred in the fabrication, assembly, and module installation of subsystems and subsystems spares used on modules other than man-rated modules.

Module level R&D categories are shown in Figure 4-3.

<u>Module Ground Test</u> includes all costs except those for hardware related to the simultaneous testing of more than one subsystem.

<u>Site Activation</u> costs include prime contractor's non-recurring changes such as planning and training related to initiation of flight activity at the launch site.

PROGRAM 1 MARS MISSION			
	SUMMARY COSTS	(TOTALS * 1000)	
		SPCFT 1 MMM	SPCFT 2 MCSM
9. COMMUNICATIONS	193250	102947	90303
A1. DESIGN AND DEVELOP. ENGR.	70543	37865	32678
A2. TOOLING	468	264	203
A3. BOILERPLATE AND MOCKUPS	20657	11664	8993
A4. MANUFACTURING	101582	53154	48428
10. INSTRUMENTATION	130427	70542	59885
A1. DESIGN AND DEVELOP. ENGR.	68268	36223	32045
A2. TOOLING	513	301	213
A4. MANUFACTURING	61646	34019	27628
12. RECOVERY	16390	0	16390
A1. DESIGN AND DEVELOP. ENGR.	11759	0	11759
A2. TOOLING	196	0	196
A4. MANUFACTURING	4435	0	4435
B. MODULE LEVEL COSTS	318659	158715	159944
1. NON-FLIGHT TEST RECURRING	252155	133776	118380
A2. MODULE GROUND TEST	108032	61714	46318
A3. EXPERIMENTS	69291	34645	34645
A4. LAUNCH SITE SUPPORT	74833	37416	37416
2. FLIGHT TEST RECURRING COSTS	66504	24939	41565
A2. FLIGHT TEST	66504	24939	41565
C. SPACECRAFT LEVEL COSTS	2298704	1159875	1138830
1. GSE	1567810	816912	750899
A1. GSE DESIGN AND DEVELOPMENT	1567810	816912	750899
2. FLIGHT CREW OPERATIONS	423294	250683	172611
3. MISSION CONTROL	307600	92280	215320

Figure 4-3

Flight Test includes the flight variable costs of prime contractor launch site support during Research and Development.

Experiments accounts for all non-recurring cost associated with experiments including design and development, prototype production, support equipment, and flight hardware.

Recovery Operations encompasses those contractor costs which pertain to recovery of R&D modules incurred by the Department of Defense but reimbursed by NASA.

Residual Costs include all other costs not accounted for in all other R&D categories.

Mission Control Systems includes the cost of contractor support of the mission planning planning and control activities associated with flight operations.

Flight Crew Operations includes the cost of designing and producing simulators and training aids used in training both ground and flight personnel.

GSE Design and Development includes the cost of design, manufacture, and installation of ground support equipment used for checkout, service, and handling of the spacecraft and its components.

4.3 RECURRING COST OUTPUTS

The recurring cost categories are used to account for all costs (except facilities costs) which are incurred from the first man-rated spacecraft to program completion. These categories are generally analogous to those for R&D and, in many instances, the categories represent a continuation of activities and costs initiated during the R&D phase. At the subsystem level, refer to Figure 4-4, the type of subsystem remains unchanged; the subdivision of subsystem cost, however, has been altered by eliminating the purely developmental categories.

PROGRAM 1 MARS MISSION

SUMMARY COSTS (TOTALS * 1000)

	SUMMARY COSTS	SPCFT 1 MMM	SPCFT 2 MCSM
II. RECURRING COSTS	869532	449630	419902
A. SUBSYSTEM LEVEL COSTS	436558	233143	203415
1. STRUCTURE	127119	65724	61395
A1. SUSTAINING ENGINEERING	45951	23294	22657
A2. MANUFACTURING	38259	19877	18393
A3. SPARES	42909	22554	20356
2. PROPULSION	36838	0	36838
A1. SUSTAINING ENGINEERING	4951	0	4951
A2. MANUFACTURING	15110	0	15110
A3. SPARES	16777	0	16777
3. ENVIRONMENTAL CONTROL	106425	96210	10215
A1. SUSTAINING ENGINEERING	49995	45906	4090
A2. MANUFACTURING	26376	23479	2997
A3. SPARES	30053	26826	3227
4. CREW SYSTEMS	4353	2357	1996
A1. SUSTAINING ENGINEERING	2460	1327	1133
A2. MANUFACTURING	891	482	409
A3. SPARES	1001	548	454
5. STABILIZATION	8476	0	8476
A1. SUSTAINING ENGINEERING	3882	0	3882
A2. MANUFACTURING	2181	0	2181
A3. SPARES	2413	0	2413
6. REACTION CONTROL	54874	15610	39264
A1. SUSTAINING ENGINEERING	9492	3270	6222
A2. MANUFACTURING	21440	5774	15665
A3. SPARES	23942	6565	17376
7. NAVIGATION AND GUIDANCE	45836	25519	20318
A1. SUSTAINING ENGINEERING	23257	13017	10240
A2. MANUFACTURING	10597	5832	4765
A3. SPARES	11983	6670	5313
8. ELECTRICAL POWER	2340	0	2340
A2. MANUFACTURING	1109	0	1109
A3. SPARES	1231	0	1231
9. COMMUNICATIONS	26405	15164	11241
A1. SUSTAINING ENGINEERING	7776	4438	3338
A2. MANUFACTURING	8765	5018	3746
A3. SPARES	9864	5708	4157
10. INSTRUMENTATION	21342	12559	8783
A1. SUSTAINING ENGINEERING	10710	6139	4571
A2. MANUFACTURING	5012	3011	2001

Figure 4-4

Sustaining Engineering includes all variable engineering and development costs associated with subsystems used in man-rated spacecraft; the sustaining engineering cost is, essentially, a continuation of the sustaining engineering activity initiated during R&D.

Manufacturing is identical in content to R&D manufacturing costs except that spares are broken out and are considered separately.

Spares accounts for the cost of complete subsystems (backup units) and piece parts used to support man-rated spacecraft.

Launch Site Support includes all variable costs incurred by prime contractors at the launch site in support of flights of man-rated spacecraft.

Reconditioning includes the costs of all parts and labor used to recondition reusable modules. The reconditioning process includes the tasks of transportation, disassembly, inspection, refurbishment, and acceptance test.

Experiments encompasses the total costs of manufacture and installation of experiments in man-rated modules.

Recovery Operations are those contractor costs which are related to recovery of man-rated modules; these costs are incurred by the Department of Defense but are reimbursed by NASA.

Residual includes all other recurring costs not accounted for in other categories.

Mission Control costs are analogous to the costs previously described under a similar heading in Research and Development; in the Recurring Cost outputs, however, mission control costs pertain to man-rated spacecraft.

Flight Crew Operations accounts for those variable and recurring costs incurred by prime and associate contractors in support of crew training.

4.4 FACILITIES COST OUTPUTS

Because facilities represent a relatively small share of the total cost, the categories in this submodel are limited in number. A total is provided for all subsystem-related facilities and for all module-related facilities respectively. The cost of such items as propulsion test stands, antenna facilities, and nuclear electric system facilities are grouped under the subsystem facilities heading. Module facilities would include such items as environmental chambers and manufacturing facilities. Provisions have been made also to subdivide spacecraft facilities between flight operations and other facilities. Flight operations facilities encompass additions to buildings and equipment associated with the Mission Control Center.

Also included in the summary report group are several other output formats which may be used to summarize the detail cost categories. One of these formats displays total cost for each subsystem type by module, spacecraft, and program. Another output format displays total costs by submodel and by computational level for spacecraft and for programs; this format is shown in Figure 4-5.

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PROGRAM * SPACECRAFT . MMM

SUMMARY COSTS (TOTALS * 1000)

	TOTAL	MODULE 1 MMM
TOTAL COST	371:041	2339627
I. SUBSYSTEM LEVEL COSTS	2176965	2176965
A. RESEARCH AND DEVELOPMENT	1943822	1943822
B. RECURRING COSTS	233143	233143
C. FACILITIES	0	C
II. MODULE LEVEL COSTS	162662	162662
A. RESEARCH AND DEVELOPMENT	158715	158715
B. RECURRING COSTS	3947	3947
C. FACILITIES	0	0
III. SPACECRAFT LEVEL COSTS	1372415	0
A. RESEARCH AND DEVELOPMENT	1159875	0
B. RECURRING COSTS	212540	0
C. FACILITIES	C	0

Figure 4-5

Funding reports are available on an optional basis in levels of detail corresponding to those for summary reports. An example of one form of funding report is shown in Figure 4-6. In this figure, the research and development funding distribution is shown for a Mars flyby program and its spacecraft components.

Two other forms of output, both of which reflect computational options, also are available. These options are cost effectiveness and Center Planning. The cost effectiveness output closely resembles cost output formats except the data are printed in floating point format. The Center Planning output is shown in Figure 4-7. The format for this submodel is used to display MSC Civil Service and supporting contractor cost and personnel requirements on a quasi-organizational basis.

Several other reports are available for use as an aid in evaluating the cost outputs and for diagnostic purposes. These reports include a first unit cost report, a cost estimating relationship report, and an input data report.

The first unit cost report lists the first unit manufacturing cost, sustaining engineering cost, and the sum of these costs for each module considered in a problem. This information supplements the standard cost outputs which present manufacturing and sustaining engineering cost for blocks of modules purchased.

PROGRAM 1 MARS MISSION

RESEARCH AND DEVELOPMENT

(TOTALS * 1000)

TIME	CUM. TOTAL	TOTAL	SCRFT 1 MMM	SCRFT 2 MCSM
1966.5	20482	20482	14724	5758
1967.0	77145	56663	40723	15940
1967.5	162917	85673	61550	24122
1968.0	270327	107509	77204	30305
1968.5	392500	122174	87686	34488
1969.0	557226	164726	111222	53504
1969.5	784062	226836	143485	83351
1970.0	1349561	565498	325320	240178
1970.5	2241524	891964	478829	413135
1971.0	3073930	832405	429725	402680
1971.5	3734722	660792	332078	328715
1972.0	4244203	509481	248898	260583
1972.5	4896112	651909	315756	336153
1973.0	5441327	545216	269288	275928
1973.5	5811916	370588	120154	250434
1974.0	6168195	356279	180624	175656
1974.5	6353473	185278	25146	160133
TOTAL		6353473	3262411	3091062

Figure 4-6

TIME - 1977.5

	CENTER			
	CIVIL SERVICE		CONTRACTOR SUPPORT	
	COST	PERSN.	COST	PERSN.
TOTAL	37763	3776	96809	8092
I. PROGRAM OFFICES	8533	853	8533	853
II. ENGINEERING AND DEVELOPMENT	917	92	917	92
A. STAFF	229	23	229	23
B. ADVANCED TECHNICAL PLANNING	229	23	229	23
C. COMPUTATION AND ANALYSIS	229	23	229	23
D. SUBSYSTEMS	229	23	229	23
1. STRUCTURE	106	11	106	11
2. PROPULSION	0	0	0	0
3. ENVIRONMENTAL CONTROL	0	0	0	0
4. CREW SYSTEMS	96	10	96	10
5. STABILIZATION	0	0	0	0
6. REACTION CONTROL	0	0	0	0
7. NAVIGATION + GUIDANCE	0	0	0	0
8. ELECTRICAL POWER SYSTEM	27	3	27	3
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	25158	2516	57526	5753
A. STAFF	2697	270	13487	1349
B. PROCUREMENT	8533	853	8533	853
C. PERSONNEL	2697	270	13487	1349
D. RESOURCE MANAGEMENT	8533	853	8533	853
E. SERVICE	2697	270	13487	1349
IV. FLIGHT CREW OPERATIONS	352	35	352	35
V. FLIGHT OPERATIONS	0	0	0	0
A. STAFF	0	0	0	0
B. MISSION PLANNING	0	0	0	0
C. MISSION CONTROL	0	0	0	0
D. LANDING AND RECOVERY	0	0	0	0
E. FLIGHT SUPPORT	0	0	0	0
VI. OFFSITE TEST OPERATIONS	106	11	106	11
VII. OTHER TECHNICAL STAFF	2697	270	13487	1349
VIII. OTHER R+D			1201	
IX. SUPPORTING DEVELOPMENT			1201	
X. ADMINISTRATIVE FACILITIES			13487	

Figure 4-7

In the cost estimating relationship report, each relationship used in a problem is printed as is the cost generated by each application of the relationship. This output is extremely useful (1) in dealing with a new group of relationships being incorporated into the model and (2) in analyzing other cost outputs.

Another report format, available to the user describes both library and problem data used as inputs for a given problem. This information is available for each subsystem, module, spacecraft, and program considered in a problem. In Figure 4-8, such an output pertaining to the Apollo Command module structure is shown. For this subsystem, the information printed includes subsystem identification, estimating relationship identification as well as spares factors, design change factors, and other factors for use in adjusting costs. Learning curve slopes and indicators (as to whether or not cost were input or computed) are shown in the middle of the figure. The values for design and performance parameters are presented at the bottom of the figure.

```
          TYPE    1
          CER GROUP NUMBER          10
          PRODUCTION UNIT NUMBER FOR ENTERING PRODUCTION LEARNING CURVE          0.
          NUMBER OF THIS SUBSYSTEM USED IN BOILERPLATE TESTING       1.
          FACTOR FOR COMPUTING SUSTAINING ENGINEERING AS A PERCENT OF D+D ENGINEERING COST    -1.00000
          SPARES FACTOR - PERCENTAGE OF HARDWARE COST          0.

          ADJUSTMENT FACTOR FOR RECURRING SUSTAINING ENGR.      1.00000
          NUMBER OF BACKUP UNITS BOUGHT                              8.
          SPARES FACTOR - OPERATIONAL MISSIONS                  0.

          DESIGN CHANGE
               SUSTAINING ENGINEERING FACTOR      0.                 0.
               HARDWARE FACTOR                    0.                 0.
               FIRST UNIT                         0.                 0.
               LAST  UNIT                         0.                 0.

          LEARNING CURVE            SL1        BP1         SL2        BP2         SL3
          SUSTAINING ENGINEERING    0.90000          0.    0.               0.    0.
          PRODUCTION                0.88000          0.    0.               0.    0.
          REFURBISHING              1.00000          0.    0.

                  TYPE OF COST               IND    COST

          D+D ENGINEERING COST                0       -1.
          TOOLING COST                        0       -1.
          INPLANT TESTING COST                0       -1.
          BOILERPLATE HARDWARE COST           0       -1.
          SUSTAINING ENGINEERING COST         0       -1.
          HARDWARE COST                       0       -1.
          REFURBISHING                        0       -1.
          SUBSYSTEM FACILITY TYPE 1           0       -1.
          SUBSYSTEM FACILITY TYPE 2           0       -1.
          SUBSYSTEM FACILITY TYPE 3           0       -1.

          FACILITY TYPE        NO. NEW FAC.
               .                    1.
               2                    1.
               3                    1.

                                                PHYSICAL AND PERFORMANCE DATA

          WGTS     0.53750000E 04
          SHKL     0.11120000E 02

   THE FOLLOWING ERRORS WERE ENCOUNTERED ON  SUBSYSTEM   -  CM-STRUC
         ERROR    504       WARNING ONLY
         ERROR    506       WARNING ONLY
         ERROR    510       WARNING ONLY
```

Figure 4-8

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5.0 BASIC MODEL STRUCTURE

In the following section, the basic model structure is described. This structure is composed of five submodels: R&D, Recurring, Facilities, Center Planning, and Printout; associated special subroutines are also included in the structure. Each of these submodels and subroutines is discussed with respect to its purpose, its basic computational sequence, and its computational processes.

In the description of the computational processes, certain categories of cost (such as systems integration) are described. A careful reading of the output section will reveal that these categories are not defined therein. This anomoly results from the fact that currently there are no cost estimating relationships developed exclusively for these categories. The costs for systems integration and related categories are currently computed with other costs categories. However, in both the Cost Model Study and the Cost Analysis Study, it was concluded that these categories should be considered in future investigations of spacecraft costs. As a consequence, provisions for these categories have been incorporated in the computational process in anticipation of future requirements.

A full understanding of the operation of the Research and Development, Recurring, and Facilities submodels (which are described in subsequent paragraphs of this section) is dependent upon having a general knowledge of the features of the special subroutines. Most of these subroutines are used in common by the three submodels at times when certain computational options are specified. In the interest of supplying this needed understanding, the discussion of the subroutines precedes that for the submodels.

5.1 SPECIAL SUBROUTINES

The operation of the special subroutines is described in the following section. All but one of these subroutines - Cost Effectiveness - is used to service the R&D, Recurring and Facilities submodels. When certain model options are exercised, the subroutines alter or manipulate the costs generated by these three submodels. The Cost Effectiveness subroutine, on the otherhand, is used in a special way; this routine generates an independent model output based on the results obtained from the three submodels.

5.1.1 Funding Subroutine

One of the major options within the model is the estimation of spacecraft funding requirements. This is accomplished by spreading or distributing cost estimates generated by the model over time. By variation in inputs and library data, various measures of funding (such as expenditures or new obligational authority) can be generated on an annual or semiannual basis.

The development of procedures that are flexible, easily input, and capable of generating realistic funding distributions has been a formidable problem in cost modeling. Until the Spacecraft Cost Model, this problem had never been entirely solved.

The major ingredients of the solution proffered by the Manned Spacecraft Cost Model are the library concept and the PEPT (Proportion Expenditure - Proportion Time elapsed) concept. The library data, in combination with problem inputs, determines the time over which costs are to be spread. The PEPT concept is used to determine the distribution of the costs over this time span.

In more detail, the funding process is as follows: Within the general library are contained spreading parameters and lags for all cost categories and beginning and ending milestones for categories which cannot be logically tied to some other event in the program. Milestones are input or used for spreading in several different ways. Each module is required to have two major inputs indicating the start and finish of R&D activity for that module. These two inputs are entered as actual years. Other milestones for subsystem and module cost categories are input as percentages of the module R&D time completed. A set of inputs generally applicable to each level is input once. Additional inputs are required only for special funding cases that deviate from the average program activity. For spacecraft level costs, the milestone inputs are percentages of the time completed from the beginning R&D milestone of the earliest module to the ending R&D milestone of the last module on the spacecraft.

After a cost has been computed in the model and has been located in time by the respective milestone, the program will spread the cost on the basis of a predetermined funding distribution which approximates obligational authority grants and expenditures of funds for similar items or operations previously required in the aerospace program. The model will first determine the number of intervals prior to the use of a hardware or facility item or prior to the initiation of an operation (such as ground testing, acceptance testing or a flight) for which obligational authority is granted. From this point, the model determines the value of parameters which are input to the model and which are used to spread the cost by the following equation.

$$E\left[p, q\ (T)\right] = \frac{\int_{o}^{T} X^{P-1}(1-X)^{q-1}\, dx}{\int_{c}^{1} X^{P-1}(1-X)^{q-1}\, dX}$$

where: X is the definite variable of integration (assuming values from 0 through 1).

T represents the proportion of time which has elapsed for the program.

E $\left[p, q(T)\right]$ represents the cumulative percent of cost expended through T.

To obtain the cost associated with each interval, the cumulative curve for (T-1) is subtracted from the cumulative curve to T for each interval associated with the cost being computed.

The symbols p and q are used to define inputs which determine the point of inflection for the cumulative expenditure curve; p and q can be values from .1 through 10.0. For a normal density function, p and q are both 2. In other non-cumulative curves, for example, the larger p becomes, the more skewed is the curve to the left; the larger q becomes, the more rapidly the curve approaches very low values for each progressive time interval.

As noted earlier, some cost categories <u>do not</u> require milestone inputs. Immediately following is a list of costs which <u>do</u> require a beginning milestone input from which the lag operates and an ending milestone input through which the cost is spread.

Spacecraft Costs

Total Spacecraft Related Cost

Flight Crew Operations

Total GSE

Support Equipment Design and Development

Support Equipment Manufacture and Installation

Module Costs

Total Module Related Costs

Non-Flight Recurring Costs

Module Ground Test

Experiments - R&D

Launch Site Support

Flight Recurring Cost

Subsystem Costs

Design & Development Engineering

Tooling

Inplant Testing

Boilerplate Hardware

All other costs are related to the beginning of design and development, flight test, the operational phase, or some other event and are time-sequenced within the model logic.

5.1.2 Learning Curve and Design Change Subroutines

The capability to apply learning to Research and Development costs is available at four separate points in the computational process of the R&D Submodel. The individual costs in which the learning concept appears are Manufacturing and Sustaining Engineering at the subsystem level and Systems Installation and Recovery at the module level. In the Recurring Submodel, this subroutine is applied to Sustaining Systems Installation, Sustaining Engineering Manufacturing, and Recovery costs. The computation of the learning process is basically the same for all costs against which it is applied. The learning curve procedure used is based upon the modified Wright theory and is discussed more fully below. There are three possible slopes for each curve, and an optional capability is provided for increasing cost as a result of a design change which covers a block of hardware units.

In order to fully utilize the learning process when design change requirements are included, it may be necessary to provide up to nine inputs for each subsystem. These inputs include three exponents to be used in determining slopes, two breakpoints, an optional input to be used in entering the learning curve at some point other than first unit, a percentage change in cost due to design change, and a first and last unit to which this increased cost is applicable. If unit manufacturing cost is input rather than computed with a cost estimating relationship, two additional inputs are required: the unit number, and the cost of that unit.

To calculate cost with either positive or negative learning, the model uses the integral of $y = aX^b$ where y is cost at unit X, a is cost at unit 1, and b is the ratio of ln m/ln 2 (m being the slope of the learning curve). The resulting equation is shown below.

$$\text{Cost of block of units between } X_1 \text{ and } X_2 = \frac{a}{b+1}\left[(X_2+.5)^{b+1} - (X_1+.5)^{b+1}\right]$$

This equation is valid when applied to units on a learning curve with one slope. For multiple sloped learning curves, the equation is applied to the number of units on each learning curve. In this case, the total hardware cost is the sum calculated in terms of each learning curve.

If a design change occurs and is of such magnitude as to be relfected in cost values, the cost of the block of units over which this change is noticeable is multipled by (1 + DCF).

DCF is the percent of cumulative average unit cost that the design change is estimated to increase. The design change feature is provided for use in manufacturing, sustaining engineering, and system installation computation.

In manufacturing computations, cost can be input or computed for any production unit. The model will then be used to compute a first unit cost by backing up the learning curve. In all cases, on the basis of the first unit cost, a computation is made of the total cost of subsystems needed to meet the overall module ground test and flight test hardware requirements. This computation is done in terms of blocks of units and/or by the time interval when funding is required. When cost is computed for blocks of hardware, these blocks may be located on any single learning curve or may be extended over one or both breakpoints.

The model also provides the capability to calculate the cost of subsystems common to separate modules, spacecraft, and programs whenever these subsystems are indicated to be dependent upon one another. When commonality is considered, data on spacecraft are provided as input in the order in which the spacecraft are developed. The hardware requirements for all dependent spacecraft and programs for each time period in the problem are then summed before cost is computed. After the manufacturing cost has been computed for each interval, the cost is then allocated to the appropriate spacecraft and programs.

5.1.3 Inflation Subroutine

The capability to inflate the results is an optional feature of the Spacecraft Cost Model; this option is actuated by inputting a base year from which costs are either inflated or deflated. The model provides the capability to input a separate adjustment factor for the R&D, Recurring, and Facilities Submodels. Values being used currently are .03, .03, and .02 respectively. These values were derived in 1965 and care was taken to insure that special application was made to aerospace industry-related resources; the values are not based on general aggregate economic indexes such as cost of living or wholesale prices.

Costs are inflated according to the following equation:

$$(1 + F)^{(CY-BY)\ TU}$$

where: F = inflation adjustment factor

CY = current year (year in which calculations are being made)

BY = base year input

TU = computational interval (.5 for six months or 1.0 for a year)

The adjustment routine is not tied directly to the Spacecraft Cost Model but is operated as a portion of the Printout Submodel. The effect of the arrangement is to provide flexibility in using the tape storage feature. If the subroutine is exercised, all costs will be inflated; however, after costs are inflated for one problem run, it is still possible to obtain other uninflated printouts on the same problem.

5.1.4 Recovery Subroutine

In the Spacecraft Cost Model, reconditioning cost is computed for each mission in which a reusable module is involved. The recovery subroutine is used to determine (1) the amount of and the time when new hardware should be purchased for reusable modules and (2) the number of modules to be refurbished in each interval. The procedure begins at the first interval of the operational phase with the computation of minimum inventory in time t for the first reusable module occurring in the program.

$$NI(t) = \frac{\lambda\left[OPL(t)\right]}{TU(52)}$$

where

λ = module turnaround time

$OPL(t)$ = number of operational flights in t

TU = computing interval (.5 = six months, 1.0 = annually).

This computation is repeated for each time interval and retained in storage for further use.

As minimum inventory is computed for each interval, the model also computes an estimated number of non-reusable modules based on reliability magnitude and growth parameter inputs. This computation is retained in storage for each time period and as a total for the program. The model then computes average probability of recovery for the module based on the following:

$$P(Rec) = 1 - \frac{NR}{\sum OPL(t)}$$

where

NR = estimated number of non-reusables.

On the basis of the above computations and an input value for average number of reuses, the total number of wear-outs is computed and allocated over the program. The model then determines at what interval in the program wear-outs begin occurring. The maximum number of modules needed to meet the schedule requirements (without carrying any forward from interval to interval) is computed as the sum of the minimum inventory, the number of non-reusables, and the number of wear-outs. The summation is retained in storage for each time period for use in the following computations.

In the next step, the model computes the number of modules required in each interval when inventory carry-overs are considered. To do this computation, the model determines if the number of modules brought forward from the previous interval is greater than the number required. If it is greater, the number carried to the next interval is the number brought forward plus what is needed for use in this interval. If the number is less than that required, the model carries forward only the minimum inventory computed earlier and computes and retains a new value for what is required in this interval but could not be obtained from inventory. This new value is then compared with the minimum production rate input (MPR) to determine the number of modules to be purchased in time t. If the number required is equal to or greater than MPR, the model indicates that MPR modules should be bought; if the number required is less than the MPR figure, the model indicates that only the number actually required should be bought.

In the final computation, the number of modules to be refurbished in each time interval is produced. This number is the number of flights less the non-reusables less the wear-outs.

5.1.5 Adjustment Factors

Two types of adjustment factors are used in the Manned Spacecraft Cost Model. The first type include Recurring Submodel factors which are applied to the costs that are initially generated in the R&D Submodel and that continue to be used in the computations throughout the recurring phase. These costs include sustaining engineering, mission control, and mission planning and analysis. If conditions affecting these costs warrant an increase or decrease in the value of cost categories at the time that the recurring phase begins, the model user inputs an adjustment factor which can either increase or decrease this baseline cost. The two major factors which would influence these costs are an accelerated flight schedule or changes in program objectives.

The second type of adjustment factors is directly related to CER's and is independent of program phase. Each relationship has a factor assigned to it which is automatically applied every time the equation is used. This method of adjustment removes the necessity of inputting an adjustment with each CER and, in so doing, lessens the possibility of input errors. In both cases, if the model user does not input a value for the factor, the factor is set equal to one in the program (i.e., no adjustment) and computation is continued.

5.1.6 Cost Effectiveness Subroutine

Cost effectiveness can be computed on an optional basis within the model. If the option is exercised, the user has available a wide latitude concerning the types of effectiveness to be computed because the application of cost effectiveness to spacecraft is still in the formative stages. At this time, there is no universal measure of effectiveness that is applicable to all types of spacecraft. Accordingly, the measure of effectiveness is treated as an input. It is anticipated that measures of effectiveness peculiar to a given type of spacecraft may soon be developed.

The mechanics of computing various measures of cost effectiveness can be briefly described. The cost effectiveness computation is based on reliability magnitude and growth parameters input by the model user. These parameters are used to determine the probability of success obtainable at the end of the R&D flight test program. With probability values and the flight schedule, the model computes incremental effectiveness in each time interval of the operational program in which a flight occurs. This incremental effectiveness measure is computed by multiplying the number of missions accomplished by the effectiveness measure input for a mission.

Direct operating cost (DOC) effectiveness is computed for each spacecraft by dividing total recurring cost for each interval by that interval's increment in effectiveness. A cumulative direct operating cost effectiveness is computed by dividing the cumulative recurring cost by the cumulative effectiveness.

Total cost effectiveness is then computed by adding total R&D and total facilities cost to each interval of recurring cost. Total cost effectiveness and cumulative cost effectiveness are then computed for each spacecraft.

After these computations have been accomplished for each spacecraft in the problem, costs and payloads delivered are summed for each program. DOC effectiveness, cumulative DOC effectiveness, total cost effectiveness, and cumulative total cost effectiveness are computed for each program in the problem.

5.2 RESEARCH AND DEVELOPMENT SUBMODEL

The objective of this submodel is to generate estimates of all costs incurred during development of a spacecraft; facilities costs are excepted. During the course of the study, development costs have been generally defined as a non-recurring cost or as those costs incurred in the program up to production of man-rated spacecraft. The model logic, however, is sufficiently flexible to accommodate other definitions of R&D costs such as those costs incurred in the program through completion of manned development flights.

The R&D Submodel initiates the computational sequence of the Spacecraft Cost Model. The analyst may by-pass R&D if recurring and/or facilities costs are of singular interest.

Within the Submodel, costs are estimated at three independent levels and are categorized for printout as shown on the following list.

<u>Subsystem Level</u>

Design and Development

Inplant Testing

Sustaining Engineering - R&D

Tooling

Boilerplate Hardware

Manufacturing - R&D

<u>Module Level</u>

Systems Integration - R&D

Module Ground Testing

Experiments - R&D

Site Activation - R&D

Residual - R&D

Systems Installation - R&D

Flight Test - R&D

Recovery Operations - R&D

Non-Flight Test Recurring - R&D

Flight Test Recurring - R&D

<u>Spacecraft Level</u>

Mission Planning and Analysis

Mission Control

Design and Development of Checkout Equipment and Other GSE

Manufacture and Installation of Checkout Equipment and Other GSE

Total GSE Cost

Flight Crew Operations - R&D

Total Spacecraft - Related R&D

The summation of costs accumulated in the above categories is "total spacecraft R&D cost". The summation of these costs in terms of all spacecraft on a program gives "total program R&D cost".

The remainder of the section describing the Research and Development submodel is divided into two parts. The first part describes the overall computational sequence in the submodel; the second part describes processes by which each cost in the foregoing list is computed.

The computational sequence is depicted in Figure 5-1. An examination of the figure will disclose that the model user must identify all elements of the problem: the programs, spacecraft, modules and subsystems. On the basis of the identified elements, the submodel then determines if funding is to be computed. If funding is required, milestones and cost spreading parameters will be extracted from libraries for each category listed. The computational sequence begins at the subsystem level where hardware requirements for ground and flight testing and spares

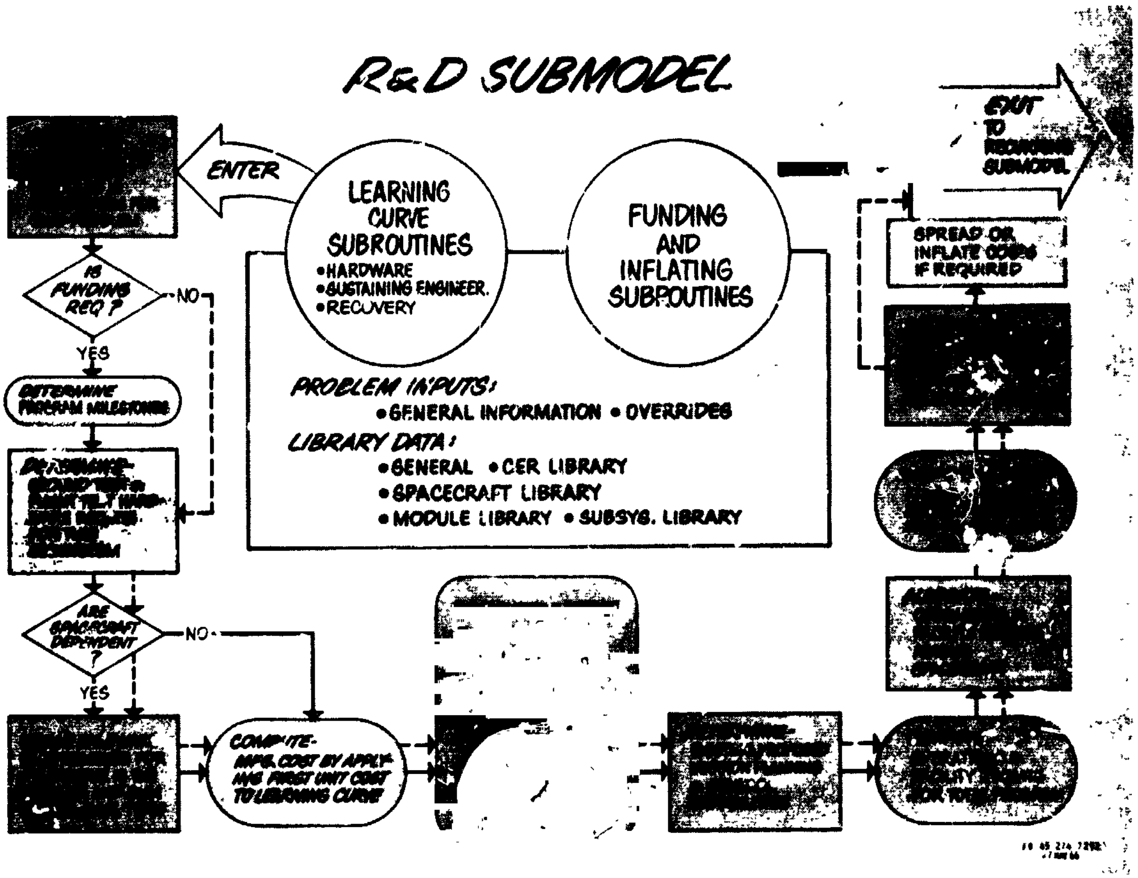

Figure 5-1

are determined. If spacecraft are dependent (i.e., spacecraft use common subsystems), the program searches all spacecraft in a problem to find where common subsystems are used.

Hardware requirements for each type system are totaled. From this total, Manufacturing and Sustaining Engineering cost are computed on given learning curves, and the costs then allocated among the participating spacecraft. Spares are computed and then added to Manufacturing to be printed out. From this point onward, the submodel computes Design and Development, Initial Tooling, and Boilerplate Hardware Costs.

When all subsystems in a problem have been evaluated, module level costs are computed on the basis of each category listed above for each module defined in the problem. Systems Installation cost is computed in the same manner used to compute Manufacturing and Sustaining Engineering costs. Recovery Operations is also computed on a learning curve and is added into total cost for every flight test.

When module level costs have been computed, the program determines spacecraft related costs. On the basis of mission and planning duration inputs, the model computes total costs accruing to the Mission Control Center for Planning and Control; these total costs are then allocated evenly over each time interval and are spread among the spacecraft simultaneously occupying the control center. All other spacecraft-related costs are computed and the program is transfered to an accumulation process. All R&D cost for each time period are summed and retained in storage for use in the cost-effectiveness subroutine which may be activated at the end of all other model computations.

The model also provides an inflation subroutine which is executed in conjunction with the printout submodel.

When all R&D costs are determined, the model program reads in operational requirements and begins computation of Recurring Costs.

5.2.1 Design and Development

The cost printed out under the Design and Development heading is the summation of three inputs or three CER's or any combination of inputs and CER's. The three costs comprising this category are D&D engineering, R&D sustaining engineering, and inplant testing. In addition the total D&D cost for each subsystem is added to the tooling cost for each subsystem and the sum is retained for use in CER computations of the module ground test and GSE costs.

If the funding option is exercised, D&D cost is lagged to the interval when obligational authority is granted prior to the beginning of the R&D phase of the subsystem and then spread forward to the ending milestone input as the last interval of R&D for the subsystem.

5.2.2 Inplant Testing

The Inplant Testing cost is a total test program cost input or CER computation which is spread between two milestone inputs and a lag input. Currently, space is provided for an Inplant Testing CER, the value of which is added into Design and Development Engineering before printout.

5.2.3 Sustaining Engineering - R&D

Sustaining Engineering cost (see D&D Engineering) is computed at the subsystem level in a manner comparable to the computation of Manufacturing cost (described later) in that there is available a three-sloped learning curve and design change cost option. Either the input cost or the CER which is used to initiate the computation of Sustaining Engineering is always considered to be the cost for the first unit bought in the problem. The computation of Sustaining Engineering starts at the beginning of the module ground test and continues through the end of the flight test program. If funding is considered for each time period, the cost is spread from the period when obligational authority is granted through the time during which the hardware is used for ground or flight testing.

5.2.4 Tooling

Tooling is an R&D cost computed or input at the subsystem level and retained in storage with D&D Engineering for use in CER's which are applied in other categories. Funded tooling cost is dependent upon two milestone inputs and a lag input.

5.2.5 Boilerplate Hardware

Boilerplate hardware cost is estimated at the subsystem level. In this estimation process, the cost of one piece of hardware is input or computed and then is multiplied by the number of boilerplate units input by the model user. Funded cost for this category is dependent upon beginning and ending milestone inputs and upon a lag factor input. No learning is assumed on boilerplate hardware production.

5.2.6 Manufacturing - R&D

Manufacturing cost is input or computed by subsystem and is determined for a given unit on the learning curve. If this unit is other than unit number one, the program backs up the learning curve to the first unit cost before computation of Manufacturing cost begins on the hardware required in the problem. The learning curve has three possible slopes.

Computation of Manufacturing cost begins with units consumed in module ground testing. The total number of ground test units is determined from inputs and, if funding is desired, spread over the length of the ground test program by the PEPT (Proportion Expenditure Proportion Time) curve in which, when half of the ground testing is complete, 66.1% of ground test hardware has been purchased. Manufacturing cost is then computed for every time period in the module ground test, flight test, and operational programs in which a test or launch occurs. Research and Development spares, computed as a percent of Manufacturing cost, is added to Manufacturing cost to obtain the total Manufacturing printed out. Spares used in the operational phase are computed in the Recurring submodel.

The cost of hardware which is used in common by two or more spacecraft is computed for each interval on a total units basis and then allocated among the spacecraft in the program and/or problem.

Increases in Manufacturing cost due to design change are computed by inputting the beginning and ending numbers of the block of hardware units to which this change applies and by inputting the estimated percent increase in cost per unit of hardware. The model then computes Manufacturing cost for each interval and continuously checks to determine if a design change has occurred on the units purchased in that interval. When the program reaches the point where the cost is increased, Manufacturing cost is computed and the design change percentage of this cost is then added to the Manufacturing cost to obtain the total cost for that interval. The model has the capability to compute two design changes within a problem.

5.2.7 Systems Integration - R&D

System Integration is a total cost computation or total cost input which is spread from the first time period of design and development of the module structure through the last time period of flight test. If the beginning milestone of structure design and development is omitted, spreading of Systems Integration begins in the time period designated by the first major module milestone, which (in most cases) will be the same or very close to the interval for the beginning of structure design and development. Currently, however, there are no available estimating relationships for R&D Systems Integration and this cost is included in the structures engineering categories.

5.2.8 Module Ground Testing

Cost for module ground testing is an input or computation for the total ground test program. The cost is spread by two milestone inputs and a lag input.

5.2.9 Experiments - R&D

Experiments is a total cost computation or total cost input which is spread by two milestone inputs and a lag input.

5.2.10 Site Activation - R&D

Site Activation is computed or input as a total cost per module and spread by two milestone inputs and a lag input.

5.2.11 Residual - R&D

Residual cost is computed or input as a total cost per module. This cost can be spread from the beginning of module structure design and development through the end of flight test. If the beginning structure milestone is omitted, Residual cost is spread from the beginning module R&D milestone. If flight test is omitted, Residual cost is spread through to the last period of module R&D.

5.2.12 Systems Installation - R&D

Two modes of computation exist for Systems Installation cost. The first mode is comparable to the Manufacturing cost computation in that the capability of using a three-sloped learning curve is available. The cost is computed at the module level for "ship sets" of systems rather than for individual sub-systems. The Installation cost which is computed or input to initiate computation is always considered to be for the first ship set. To compute funding, the cost for each interval is lagged back to the time when obligational authority is granted and spread forward to the time of launch.

The second method of computation is the application of a percentage to the structure Manufacturing cost per time interval; this Manufacturing cost will have been spread and retained in storage.

In both cases, computation of Systems Installation begins with the first interval of module ground test and continues through the end of the flight test program. At the present, this category is not used and all costs in this category are being estimated in structures Manufacturing cost.

5.2.13 Flight Test - R&D

This cost is input or computed for one flight test at the module level. For funding computation in each time period of the flight test program, the cost is multiplied by the number of flights scheduled, lagged back to the interval in which obligational authority is granted, and spread forward to the time of launch.

5.2.14 Recovery Operations - R&D

Recovery Operations cost is input or computed in terms of the recovery of one module. Every recoverable module in a spacecraft incurs a recovery cost for each flight. A two-slope learning curve is available for computing Recovery Operations cost. This cost can be spread from the interval in which obligational authority is granted through the time of flight.

5.2.15 Non-Flight Test Recurring - R&D

If total module R&D cost is not input, and if individual R&D module costs for non-flight related categories are not input nor computed, then Non-Flight Test Recurring cost can be input. This cost is the sum of System Integration, Module Ground Test, Experiments, Site Activation, and Residual costs. If funding is to be computed, this cost is spread from two milestones and a lag input. After this computation has been made, the program proceeds to Flight Test Recurring costs and checks to see if a similar total cost is input.

5.2.16 Flight Test Recurring - R&D

If total module R&D cost is not input and if R&D module costs are not input or computed for Systems Installation, Flight Test, or Recovery Operations, then a total value for Flight Test Recurring costs can be input. Also this cost can be spread between two milestone inputs and a lag input. After completion of this computation, the program transfers to Spacecraft costs.

5.2.17 Mission Planning and Analysis

Before the program can compute Mission Planning and Analysis cost, schedules of all missions, R&D as well as operational, must be scanned to determine the number of spacecraft which are simultanecusly using available mission capacity. For each spacecraft, the model user inputs an estimated planning duration which indicates the number of weeks prior to launch that Mission Control Center capacity will be required. The computer program examines each time period beginning with the first interval for planning the earliest mission of the first spacecraft in the problem and ending with the last interval for planning the last mission of the spacecraft with the latest scheduled mission.

Two alternative methods of computation exist for determining available mission capacity. In both cases, the initial available capacity is input for the beginning of the program. Subsequently, if the first alternative path is taken, the model user may input the total new capacity that NASA planners intend to add. The year in which the capacity is to be built is input along with this new capacity figure. Regardless of the number of missions being planned simultaneously, no capacity will be added until the computation process reaches the year which has been input. At this point, the total amount of new capacity will be added regardless of the missions scheduled. If this option is by-passed, the program will automatically add new capacity whenever mission planning requirements exceed available capacity by a predetermined number of missions input to the model. Each time new capacity is added, the available capacity is updated for the following time intervals. Model users may elect to input a maximum capacity figure which will stop the automatic process whenever available capacity reaches this maximum number.

Mission Planning and Analysis cost is input or computed for one unit of capacity. Total planning and analysis cost is then computed for each time period and is dependent on the amount of planning capacity in existence during each period. After the amount of capacity in existence and the total cost is determined, the model sums the number of missions in the planning phase for each interval in the problem. The Mission Planning and Analysis cost is then allocated among the spacecraft which are in the planning phase at the same time by dividing the number of missions scheduled for planning for one spacecraft by the total number of missions scheduled for planning for all spacecraft in that interval. This ratio is then multiplied by the total cost. In this process, total Mission Planning and Analysis cost is the same as long as capacity is constant, but the amount attributed to individual spacecraft may vary depending upon (1) the number of programs and spacecraft being considered in the problem and (2) the mission dates of the spacecraft.

The cost is spread from the time obligational authority is granted through the time of launch.

5.2.18 Mission Control

Computation of this cost is comparable to the procedure followed for Mission Planning and Analysis cost. The only difference is that the model user inputs a mission duration time interval which indicates the number of weeks after launch that a particular spacecraft will occupy mission control capacity. The capacity input for mission planning and the capacity input for mission control purposes are not interchangeable once the model user has indicated how much capacity is available for each of these tasks.

Mission Control cost is also spread from the time when obligational authority is granted through the time of launch.

5.2.19 Design and Development of Checkout Equipment and Other GSE

This cost category is made up of two cost inputs or two CER computations: one for checkout equipment and one for other GSE. The two costs are summed before printout or spreading. When funding is to be computed, the total cost is spread by two milestone inputs and a lag input.

5.2.20 Manufacture and Installation of Checkout Equipment and Other GSE

This cost category is made up of two cost inputs or two CER computations: one for checkout equipment (which is multiplied by the number of sets of equipment to be purchased) and one for Other GSE (which is multiplied by the number of sets of Other GSE to be purchased). The number of sets of checkout equipment and other GSE are inputs. The two cost figures are added together before printout or spreading. The total cost is spread by two milestone inputs and a lag input. Currently the cost in this category is being estimated by the CER's for GSE Design and Development.

5.2.21 Total GSE Cost

Total GSE cost is an input at the spacecraft level and is the sum of Design and Development cost and Manufacture and Installation cost for checkout equipment and other GSE. The cost can be spread between two milestone inputs and a lag input.

5.2.22 Flight Crew Operations - R&D

This cost is a total R&D related input or computation made at the spacecraft level. If the funding option is exercised, this cost is spread by two milestone inputs and a lag input.

5.2.23 Total Spacecraft-Related R&D

Total Spacecraft-Related R&D cost is a gross cost input which includes Flight Crew Operations, Mission Planning and Analysis, Mission Control, Checkout Equipment and Other GSE Design and Development, and Checkout Equipment and Other GSE Manufacture and Installation costs. The cost can be spread by two milestone inputs and a lag input.

5.3 RECURRING SUBMODEL

Costs computed in this section of the Spacecraft Cost Model are (1) those costs associated with the manufacture and maintenance of man-rated or operational spacecraft and (2) those costs associated with mission planning, control, and recovery-related activities incurred from the initial planning of the first manned mission through the last interval of the final mission scheduled for a spacecraft.

The Recurring Submodel is an optional feature and may be bypassed. If the submodel is activated, the program follows a set pattern for time-sequencing costs. All non-variable costs, such as Flight Crew Operations, are tied to the first and last program intervals in which a flight occurs. Variable costs, such as Manufacturing, are tied to actual flight dates. Variable and non-variable recurring costs are intermingled and are categorized for printout as shown below.

<u>Subsystem Level</u>

Sustaining Engineering-Recurring
Manufacturing-Recurring
Spares-Recurring

<u>Module Level</u>

Systems Integration-Recurring
Systems Installation-Recurring
Acceptance Testing
Launch Site Support
Recovery-Recurring
Reconditioning
Experiments-Recurring
Residual-Recurring

Spacecraft Level

Flight Crew Operations-Recurring
GSE Spares and Maintenance
Mission Planning and Analysis & Mission Control Cost-Recurring

The computational sequence for this submodel is summarized in Figure 5-2. These costs computed on the basis of a learning curve in the R&D Submodel, continue to be computed in this manner in the Recurring Submodel although a different curve slope may be used for operational hardware; the use of the different curve slope is described under the special subroutine discussion. In the Recurring Submodel, the learning curve is entered after the unit number which is the sum of module ground tests plus flight tests. This continuity between the two program phases is maintained even in those cases when R&D is not computed. The exception to this interface of learning curves occurs in the instance of refurbishing cost which is computed only in the Recurring Submodel. If refurbishment cost should reflect learning, the computation begins with the first man-rated spacecraft recovered.

There are other differences between the two submodels in terms of the calculation of spares and experiments costs. Recurring spares include all backup units plus a percentage of manufacturing cost. Sustaining engineering is calculated on a per production unit basis which includes back-up units (spare subsystem units). Recurring experiments cost is computed for each flight and is summed for printout.

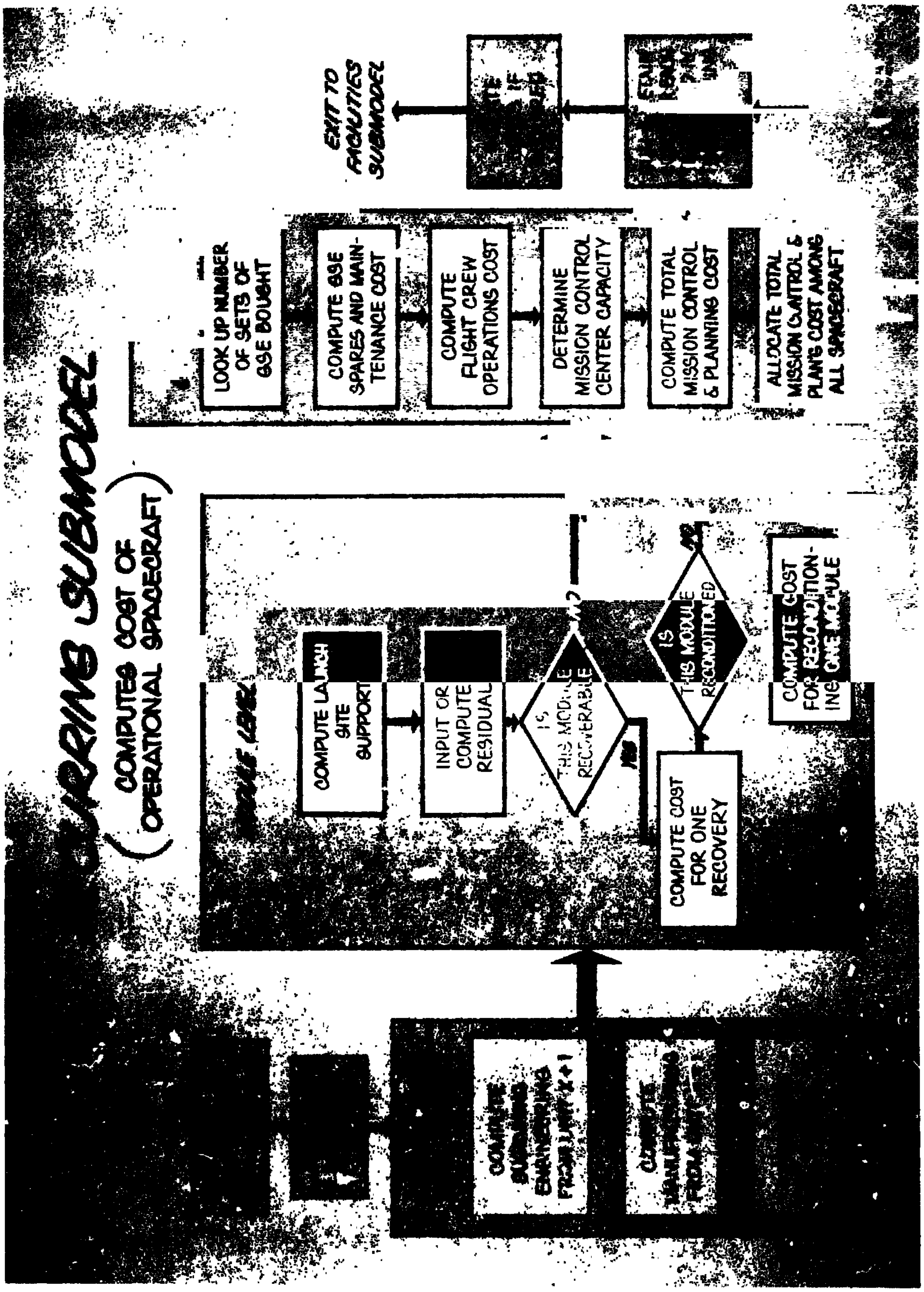
SUBMODEL
(COMPUTES COST OF OPERATIONAL SPACECRAFT)
LOOK UP NUMBER OF SETS OF GSE BOUGHT
COMPUTE GSE SPARES AND MAIN-TENANCE COST
COMPUTE FLIGHT CREW OPERATIONS COST
DETERMINE MISSION CONTROL CENTER CAPACITY
COMPUTE TOTAL MISSION CONTROL & PLANNING COST
ALLOCATE TOTAL MISSION CONTROL & PLAN'S COST AMONG ALL SPACECRAFT
EXIT TO FACILITIES SUBMODEL
INPUT OR COMPUTE RESIDUAL
NO
YES
COMPUTE COST FOR ONE RECOVERY

Figure 5-2

If non-funded recurring costs are requested, the model calculates funded costs but prints only the totals; such a calculation and printout requires the inputting of beginning and ending dates but facilitates the computation of hardware requirements and refurbishing cost. It also results in more valid mission control and planning costs especially when missions are of long duration.

Upon completion of the recurring phase for all spacecraft and programs included in a problem, the model begins computation of facilities costs.

In the remaining discussion of the Recurring Submodel, the computation of individual recurring cost categories is described.

5.3.1 Sustaining Engineering - Recurring

The cost of Sustaining Engineering is a continuation of the learning curve computation begun in the R&D Submodel. This cost is computed in each interval of the operational program for each unit of hardware purchased including backup units. Design change and operational program adjustment factors are available as explained in the description of Manufacturing Cost. When funding is required, the engineering cost for each unit is spread from the period in which either obligational authority or funding is initiated through the last period of the mission in which the hardware incurring the Sustaining Engineering cost is involved.

5.3.2 Manufacturing - Recurring

Manufacturing cost of operational hardware is simply a continuation of the computation begun in the R&D phase; an additional feature is the availability of an adjustment factor which can be used as a multiplier of the cost taken from the learning curve if conditions warrant a constant increase or decrease from the originally assumed cost pattern. Before manufacturing cost can be determined, however, a total production cost per time interval is computed. The number of hardware units used for this computation is dependent on three factors: (1) the number of backup units bought for each subsystem; (2) the flight schedule; and (3) if the module is reusable, module turnaround time and the probability of recovery. To arrive at the manufacturing cost, the value of the backup units is subtracted out of production cost. Cost for backups is added to the spares category. The design change options described for R&D Manufacturing also are available for Recurring Manufacturing. In the computation of this cost, it is acceptable to include R&D and operational units in the same design change block if conditions warrant.

When the funding option is exercised, the manufacturing cost for each interval of the operational program is spread from the time obligational authority is granted (which is the time of flight minus a lag input) through the last period of the mission in which the hardware is involved.

5.3.3 Spares - Recurring

Spares cost for operational hardware is composed of the cost of backup units plus a percentage of manufacturing cost to account for the cost of piece parts. The model user inputs the total number of backup units purchased for each subsystem in the problem. When funding is required, the total number of units is spread by a normal pepts curve (p = 2.0, q = 2.0) from the beginning through the end of the operational program. The number of backups in each time interval is then added to the number of other hardware requirements; production cost is then computed on the learning curve. When production cost is determined for an interval, the backup units are subtracted out and manufacturing cost is the remainder. Backup hardware cost is then added to a percentage of manufacturing cost. This total is printed out under the heading of spares.

Spares cost is spread from the time obligational authority or expenditures is initiated through the last period of the mission in which the hardware is involved.

5.3.4 Systems Integration - Recurring

This cost is a total input or CER computation for the operational program and is processed at the module level. Although computation provisions are included in the model, currently there are no CER's for computing system integration cost. Provision also has been made to lag and spread the cost from the interval when obligational authority or expenditures is initiated prior to the beginning of the operational program through the last time period of the program.

5.3.5 Systems Installation - Recurring

There are no CER's for computing systems installation cost. If such CER's were available, this cost computation would be a continuation of the process initiated in the R&D program. Installation cost is computed for each new module purchased in the operational phase, but this cost is not computed for any backup systems which are purchased. If funding is required, costs generated in each time interval are lagged and spread from the interval in which obligational authority is granted through the time when the hardware (on which the installation cost is incurred) is used.

5.3.6 Acceptance Testing

In the event that cost is to be considered, acceptance test cost is input or computed for the testing of one module. Also inputted is an acceptance test factor used to indicate the percent of modules flown which will be tested. This test factor is multiplied by the cost of one test, and the result is in turn multiplied by the number of flights in time t. If the funding option is exercised, the cost is lagged and spread from the period when obligational authority is granted through the time when the module is used.

5.3.7 Launch Site Support

The model user has an option to input or compute this cost on a per flight basis or on the basis of total cost for the program. In the program, a check is first made to see if the per flight cost option is taken; if it is, the number of flights in each interval is multiplied by the cost. The cost for each interval is spread from the time when obligational authority is first granted or expenditures start through the time when the flight occurs.

If the cost is computed or input as a total, the cost is lagged and spread from the interval in which obligational authority is granted or expenditures start prior to the beginning of the operational program through the last time period of the program.

5.3.8 Recovery - Recurring

Recovery cost is also a continuation of the computation begun in the R&D phase. The resulting cost is spread from the time of flight (minus a lag input) through the last time interval of the mission in which the module is involved.

5.3.9 Reconditioning

Reconditioning cost is an optional computation and can be bypassed even though a module is classified as reusable. If the model user chooses to compute the cost, he then has the option to compute it at the module or subsystem level. At both levels, a cost for reconditioning the first operational module of the program is input or computed. A two-sloped learning curve is available for the module and for each subsystem. The unit numbers used to locate the cost on the curve for each time interval are determined by subtracting the number of modules which are too badly damaged for reuse and the number of modules worn out from the number of flights in the time interval. Wear-outs and non-reusables are discussed under the heading of Recovery Subroutine located at the end of these cost category computation descriptions.

If the subsystem level computation is chosen, the costs for all subsystems on the module are added together to obtain total reconditioning cost.

If funding is required, the cost for each interval is lagged and spread from the interval when obligational authority is granted or expenditures initiated through the last period of the mission in which the module is involved.

5.3.10 Experiments - Recurring

Experiments cost is input or computed for one mission. The total cost of experiments is determined by multiplying the input by the number of flights in each interval of the operational program. The cost computed in each period is lagged and spread from the time when obligational authority is granted through the period in which the flight occurs.

5.3.11 Residual - Recurring

Residual cost is a total input or CER computation for the program on the module level. When the funding option is exercised, the cost is spread from the time obligational authority is granted prior to the operational program through the last interval in which a flight occurs.

5.3.12 Flight Crew Operations - Recurring

This cost is computed at the spacecraft level but is handled in the same manner in which Residual cost computations are made.

5.3.13 GSE Spares and Maintenance

This cost is the sum of two costs: (1) spares and maintenance for checkout equipment and (2) spares and maintenance for other GSE. These two component costs are input or computed (if CER's were available) as a program total or as a percent of manufacturing and installation cost of checkout equipment and other GSE computed in the R&D program. The total cost is lagged and spread from the time when obligational authority is granted prior to the operational program through the last interval of the program.

5.3.14 Mission Planning and Analysis and Mission Control Cost - Recurring

The computation for these costs follow the same path indicated for the R&D program. An adjustment factor is available for each cost; this factor will change the initial input or CER computation used in the R&D phase. If the R&D and Operational phases overlap, the requirements for both are added together to determine total MCC capacity in use in any time interval. After the capacity for the interval is determined, the R&D and Operational requirements are then separated and their respective costs computed.

5.4 FACILITIES SUBMODEL

At the time the Cost Model Study was made, spacecraft facilities had accounted for a relatively small portion of total spacecraft program costs. With the exception of manufacturing facilities, the majority of the facilities used in current spacecraft programs are located at MSC and, presumably, will be available for use in future programs. In general, facilities requirements and costs are highly dependent upon the particular program under consideration. Considerations affecting facilities costs include (1) mission requirements and design characteristics of the spacecraft in question and (2) the availability and applicability of existing facilities.

Because of its relatively low cost significance and formidable estimating problems, facilities costing has received only cursory attention in past and present studies.

As a result of the foregoing considerations, emphasis in the formulation of the Facilities Submodel has been placed upon simplicity and flexibility. Provisions have been made to consider a variety of facility types with the expectation that only a few types may be costed in a given problem. As has been indicated in Figure 5-3 the submodel sums and prints costs in the following categories:

Total Subsystem Facilities

Total Module Facilities

Total Spacecraft Facilities
- Flight Operations Facilities
- Other Spacecraft Facilities

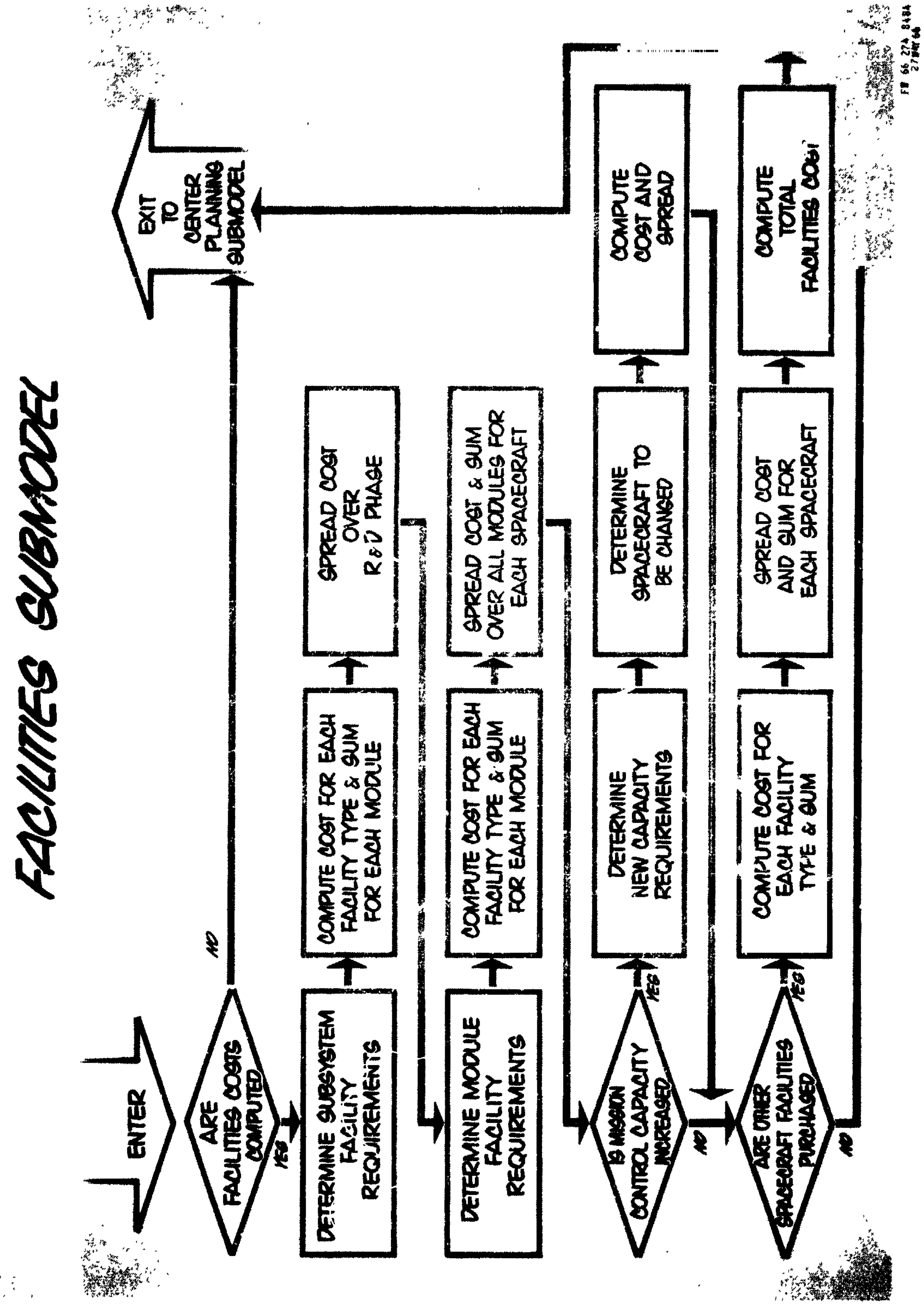
FACILITIES SUBMODEL
ENTER
ARE FACILITIES COSTS COMPUTED
YES
NO
EXIT TO CENTER PLANNING SUBMODEL
DETERMINE SUBSYSTEM FACILITY REQUIREMENTS
COMPUTE COST FOR EACH FACILITY TYPE & SUM FOR EACH MODULE
SPREAD COST OVER R&D PHASE
DETERMINE MODULE FACILITY REQUIREMENTS
COMPUTE COST FOR EACH FACILITY TYPE & SUM FOR EACH MODULE
SPREAD COST & SUM OVER ALL MODULES FOR EACH SPACECRAFT
IS MISSION CONTROL CAPACITY INCREASED
YES
NO
DETERMINE NEW CAPACITY REQUIREMENTS
DETERMINE SPACECRAFT TO BE CHANGED
COMPUTE COST AND SPREAD
ARE OTHER SPACECRAFT FACILITIES PURCHASED
YES
NO
COMPUTE COST FOR EACH FACILITY TYPE & SUM
SPREAD COST AND SUM FOR EACH SPACECRAFT
COMPUTE TOTAL FACILITIES COST

Figure 5-3

For all 13 subsystems considered in the cost model, the capability exists to compute at least one type of facilities cost. Funding of subsystems facilities has been tied to R&D milestones because requirements for these facilities will be generated mainly during subsystem development.

At the module level an estimating capability has been provided for 10 different facility types. Because the costs for some of these facility types, such as additional manufacturing facilities or recovery and reconditioning facilities, may be incurred after development has been completed. Funding is based upon milestone inputs in real time.

At the spacecraft level, the costs for flight operations facilities used in mission planning and control are estimated. The cost for this facility category are derived from requirements generated in the R&D and Recurring submodels. Provisions have been made for computing the cost of eight other types of spacecraft related facilities. As with module facilities, funding is based on real time inputs.

Because facilities costs are so highly problem-dependent, the selection of facilities to be costed is treated as a problem input.

5.4.1 Subsystem Facilities

Each subsystem has three facility types, any one or all of which may be costed for each subsystem. The cost which is input or computed is for one facility. If more than one facility is required, the model user inputs the total number which is then multiplied by the facility cost. For spreading purposes, the cost is tied to the beginning and ending milestones of the respective subsystem design and development. To compute funding requirements, each cost is lagged to the time when obligational authority is granted prior to the beginning milestone indicated above and is spread through the ending milestone for design and development. Total facility cost for all subsystems on a module is all that is printed; therefore, after spreading the cost, the computer program sums the cost for all subsystems in a module in terms of each time interval in the module R&D phase.

5.4.2 Module Facilities

Each module in a problem has ten possible facility types. For any or all types, the model user can input up to four dates in which the facility will be bought and the number of facilities required on each of those dates.

The cost for one facility of each type required is input or computed and then multiplied by the number required in each interval. For funding, the cost is spread from the time obligational authority is granted through the time when the facility is required. The cost for all ten types is summed before printout.

5.4.3 Spacecraft Flight Operations Facilities (MCC Capacity)

To compute the cost of additional planning and control capacity for the Mission Control Center, the computer program retains all capacity increases which occurred in the computation of Mission Planning and Analysis cost and Mission Control cost in the R&D and operational phase; the spacecraft to which this addition is attributed is also retained. The cost of one unit of planning capacity and one unit of control capacity is input or computed at the program level. The total cost for this category is then obtained by multiplying the increase in capacity in each interval by the respective costs of the one unit of capacity. The two costs obtained are then added and spread from the time obligational authority is granted for each addition through the time interval in which each unit is added to existing capacity.

There are two methods used in determining which spacecraft will be charged with capacity increases. In the first case, if the model user inputs the total additional capacity required, he also inputs the year when it is added and the spacecraft to which it is charged. If the increase in capacity is determined automatically, the spacecraft that enters the planning or control phase last immediately prior to or concurrent with the increase is charged with the new capacity.

5.4.4 Other Spacecraft Facilities

In addition to Flight Operations Facilities, each spacecraft has eight other possible facility types. The cost for these facilities is computed in the exact sequence followed in computing module facilities.

5.5 PRINTOUT SUBMODEL

To maximize the utility of computer time and problem results, an optional print routine has been provided for use with the Spacecraft Cost Model. By means of this option, the analyst is able to print cost data from problems which have been run at an earlier date and retained on magnetic tape.

When a problem is initiated on the SCM, the program ascertains if it is a new problem in which costs will be computed or the problem has already been executed and requires only selection and printing operations. To actuate the printout submodel, the model user inputs only three items: (1) the tape identification number which was assigned when the problem was computed, (2) the identification of the libraries used in the computation, and (3) the problem number assigned at the time of computation.

The printout submodel and the computational sequence are mutually exclusive; therefore, each problem run must be used for one purpose or the other and can never be used for both ends.

5.6 CENTER PLANNING SUBMODEL

The Center Planning submodel is used to generate annual MSC funding and personnel estimates as a function of the level of activity being managed by MSC and various policy coefficients. Submodel outputs are generated by Program and Center and are displayed on a quasi-organization basis. With the exception of two categories, funding and personnel outputs are divided between civil service and supporting contractor activities.

Most of the inputs for the Center Planning submodel are furnished by the cost outputs of the other submodels: R&D, Recurring, and Facilities. By means of this cost output, the magnitude of the space programs under MSC cognizance is measured. The relationship between the overall magnitude of the spacecraft programs and the levels of MSC activity is expressed by a set of policy coefficients. An additional set of policy coefficients is also used to divide the MSC activity between contractor and civil service portions. The two sets of policy coefficients are contained in a general library and thus are input only if changes are desired.

In the remainder of this section, brief descriptions are offered of the detailed computations which are completed within the submodel.

To accomplish each of the following 26 functions, the model uses coefficients expressing the relationship (a) between cost model output and MSC operating cost and (b) the percent of the MSC operating cost which is incurred by civil service personnel. Contractor support cost is determined within the model by multiplying MSC cost in (a) above by 1 - (b).

Center Function	Annual Values Used from The Spacecraft Cost Model
1. Program Office	The sum of all total program costs in each problem.
<u>Engineering & Development</u>	
2. Staff	Total subsystem design and development and sustaining engineering cost.
3. Advanced Technical Planning	Total subsystem design and development and sustaining engineering cost.
4. Computation & Analysis	Total subsystem design and development and sustaining engineering cost.
<u>Subsystem</u>	
5. Structure	Design and development plus R&D and recurring sustaining engineering cost for the respective subsystems.
6. Propulsion	(same as above)
7. Environmental Control System	(same as above)

8. Crew Systems
9. Stabilization and Control
10. Reaction Control
11. Navigation and Guidance
12. Electrical Power System
13. Communications
14. Instrumentation
15. Launch Escape System
16. Recovery System
17. Adapter

Design and development plus R&D and recurring sustaining engineering cost for the respective subsystems.

18. Procurement — Sum of all total program costs in each problem.

19. Resource Management — Sum of all total program costs in each problem.

20. Flight Crew Operations — R&D plus recurring Flight Crew Operations.

<u>Flight Operations</u>

21. Staff — Mission Planning and Mission Control cost for R&D and Recurring.

22. Mission Planning — R&D and Recurring Mission Planning and Analysis Cost.

23. Mission Control — R&D and Recurring Mission Control and Analysis Cost.

24. Landing & Recovery — Recovery cost for R&D and Recurring.

25. Flight Support — Mission Planning and Mission Control cost for R&D and Recurring.

26. Offsite Test Operations | Design and development cost of structures and propulsion systems.

For computing the four functions listed below, the submodel uses coefficients expressing (a) the percentage of total civil service personnel cost in the above 26 functions that is attributed to the following categories and (b) the percentage of total contractor support personnel cost in the above categories which is attributed to the following.

Administration - Staff

Administration - Personnel

Administration - Service

Other Technical Staff

The final three functions in the Center Planning Submodel require only one input. For the first two functions, the input is a percentage of total nonvariable cost which serves as the basis for giving a value for contractor support costs in terms of "Other R&D" and "Supporting Development." The last category, "Administrative Facilities," requires as an input, a percentage of the total civil service personnel cost in the first 26 categories listed.

For all Center functions, with the exception of the last three discussed, the model computes the number of people represented by the MSC cost of civil service and contractor support. This is accomplished by inputting an estimated average annual salary of civil service personnel and a similar value for contractor support personnel. These salary inputs are divided into their respective MSC cost values and the model then prints personnel costs and numbers of people for each Center function.

The submodel is programmed to operate independently of the other submodels by the use of cost data stored on magnetic tape. This feature will permit the evaluation of the effects of policy alternatives upon a standard mix of spacecraft programs without the necessity of rerunning the cost model for each alternative.

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6.0 INPUTS

During the formulation of the model, particular care was taken with input organization and procedures. General Dynamics' prior experience with large generalized models suggested that the utility of a model is determined as much by the ease with which it may be input as by the validity of its results. In the case of the spacecraft cost model, potential input problems were aggravated by the requirement that all major spacecraft subsystems were to be considered explicitly in the costing processes; this means that, in a costing exercise such as a Mars landing, data must be input not only for the 5 spacecraft and 10 modules performing the mission but also for the 52 separate subsystems installed.

In anticipation of these multiple input problems, input procedures were streamlined (1) through the use of multipurpose inputs, (2) by extensive use of inputs that are either "0" or "1", and (3) by adoption of the namelist procedure. This latter procedure frees the user from the usual requirements (and the associated errors) of entering inputs in a predetermined order and in narrow specified fields.

An equal or greater contribution to the solution of the input problem was provided, however, in the organization of the input data. Inputs required for computation are divided into two categories: library data and problem data. Library data is input as required and then is retained for use on subsequent problems. Problem data, on the otherhand, must be input for each problem run.

Problem data is further subdivided between problem-required and problem-option inputs. Problem-required data has been reduced to the absolute minimum number of instructions necessary to activate the model. Problem-required data is composed of less than 10 items and is restricted to such items as the names of the programs and spacecraft to be costed, whether or not common usage subsystems are involved, and the number of spacecraft for which problem data is required.

Problem-optional data is quite voluminous because of the large number of functions performed by the model and the numerous optional methods of accomplishing these functions. Problem options include over 75 different items; however, only a few of these are normally exercised on any given problem. In general, problem options fall into three classes: computational options, library overrides, and cost inputs. Computational options include instructions to compute such items as cost effectiveness, inflation, reconditioning cost, and funding requirements. Library overrides were incorporated to permit temporary variations in libraries such as modification of design or performance data for a baseline spacecraft. In addition to the computational options and library overrides, it is possible to input certain aggregate measures of cost such as research and development cost for a specific spacecraft.

Most of the inputs required for use in a problem will be contained within libraries. There is a significant advantage to this approach to the input problem: once the values of parameters are entered into libraries, the values will be available for use in future problems. The necessity for re-inputting this data for each problem run is eliminated. On the otherhand, the alteration of infrequently changing data can be accomplished expeditiously by incorporating the static data into libraries rather than building it into the program.

Library data is divided into two major groups: general library data and specific library data. Each of these groups in turn is subdivided into subsystem data, module, and spacecraft data.

The general library was established as a means of retaining large groups of data that are relatively independent of the design and performance characteristics of the spacecraft being costed. Consequently, this type of data is input infrequently and is input only as a result of periodic updating or to reflect special costing situations. In general, the following categories of information are contained in the general library:

1. Mission control center parameters
2. Policy and structural coefficients used in the Center Planning submodel
3. Learning curve slopes

4. Spares factors

5. Funding milestones and shaping parameters.

Specific library data applies to some specified design or mission configuration. This type of information is entered the first time a new design is to be costed and is then retained and made available for use in each subsequent problem in which that particular design is called for. Specific library data for the spacecraft includes program milestones, the names of the modules used by the spacecraft, and spacecraft-related design and performance parameters. These parameters are used in the cost estimating relationships and include such data as spacecraft crew complement, weights, and number of flights.

Module level data includes a list and count of subsystems installed in the module, refurbishment parameters (if reuse of the module is being considered), program milestones, cost through puts, and design and performance parameters. Design and performance parameters currently used in the CER's include such information as weights, dimensions, volumes, mission duration, thrust, and attitude change rates.

Subsystem level library data is generally similar in nature to the library data listed for modules and spacecraft.

6.1 COST ESTIMATING RELATIONSHIP LIBRARY

Most cost generation accomplished by means of the model is a result of the use of cost estimating relationships. The cost estimating relationship (CER) is an equation which represents the relationship of the cost of a particular spacecraft hardware element or activity to design, performance, and/or mission parameters.

In the Spacecraft Cost Model, all cost estimating relationships are contained within a library rather than made an integral part of the computer program. This feature, which was pioneered by General Dynamics in a companion study for NASA/MSFC, provides enormous advantages over any previous cost model concept. By use of the library concept, CER's are always available for use and yet may be improved or altered without the requirement of modifying the program.

Each CER in the library is described on one to five cards. The description identifies the CER and contains a Fortran statement of the equation. Each CER is identified with respect to four factors:

1. Computation level (subsystem, module, etc.)
2. Subsystem type (structure, propulsion, etc.)
3. Cost category (manufacturing, flight test, etc.)
4. Technology (current, nuclear, etc.)

The Fortran statement of the equation indicates the variables used in the equation, and the operations to be performed on the variables. The operations include addition, subtraction, multiplication, division, exponentiation (including negative and fractional exponents), and conversion to natural logrithms. During the operation of the model, the computer program calls for a particular CER when it is required, decodes the CER, executes the equations described by the Fortran statement, and stores the cost yielded by the relationship. Application of the library concept to CER's not only permits updating of an individual CER in minutes but also provides the capacity for using virtually an unlimited number of CER's. Up to 99 different CER's may be stored for an individual cost category. This storage feature not only makes it possible to consider all foreseeable technologies but also provides a capability to select CER's based on the availability of input data. By using this concept, it would be possible to select a complex and presumably highly accurate CER when the design of a spacecraft under consideration is well-defined or to use a very gross estimating relationship when the spacecraft to be costed is sketchily defined.

Another major advantage of the use of a cost estimating relationship library is that use of the library allowed model development to proceed concurrently with and separately from the development of CER's. This parallel development effort enabled MSC to obtain a working cost model considerably earlier than would have otherwise been possible. Accordingly, it was decided to give the Cost Analysis Study contractor the responsibility for developing most of the estimating relationships currently being used in the model.

Because of specialized knowledge and prior experience, General Dynamics, however, was charged with development of estimating relationships for the certain advanced technologies. These technologies include nuclear isotope electrical power systems, nuclear reactor electric power systems, nuclear and liquid pump-fed propulsion systems, and large service modules. In the remainder of this section, those relationships developed by General Dynamics are described. (The relationships developed during the Cost Analysis Study are discussed in the final reports of that study.)

6.2 NUCLEAR REACTOR ELECTRICAL POWER SUBSYSTEM RELATIONSHIP

The relationships were developed from and evaluated against data obtained from General Electric, Westinghouse, North American Aviation, and from various Congressional Hearings. The data base included thermoelectric and Rankine cycle systems ranging in power output from .5 to 300 kilowatts-electric. Because of the limited availability of detailed cost information, only two relationships were developed: design and development, and manufacturing.

The following variables were considered in the development of these relationships:

Kilowatts-electric

Number of active power conversion units

Total number of power conversion units

Shield weight

Boom and cable weight

Total subsystem weight

Kilowatts-thermal

Separation distance

Radiation area

Power conversion system weight

By means of multivariate regression analysis, these variables were combined into a number of prototype estimating relationships.

These prototypes were developed in a variety of functional forms: linear, exponential, semi-logarithmic, and mixtures of these forms. The two relationships finally chosen are displayed below. Both relationships perform with acceptable accuracy over the range of data considered. Use of the development cost relationship does tend to understate costs at very low power levels (two kilowatts electric) but, at all other performance levels, estimates produced may be expected to be within 10 percent of the actual. The manufacturing relationship is extremely accurate at all performance levels.

1. Design and development includes the cost of engineering, test, prototype hardware, and tooling cost incurred in reactor development:

$$\text{Cost} = 1459660\ (\text{PKIL})^{.541}(\text{EPW-PSW})^{-.411}$$

2. Manufacturing cost is the first unit cost of a complete subsystem:

$$\text{Cost} = 2275 + 477.6(\text{UNTN}) + 33.37(\text{PKIL})$$

where

Cost is estimated cost in 1000's of dollars

PKIL is rated system power output in kilowatts-electric

EPW is total weight of the subsystem including reactor, power conversion system, shielding and radiator

PSW is shield weight

UNTN is total number of power conversion units in subsystem including redundant units

6.3 RADIOISOTOPE ELECTRICAL POWER SUBSYSTEM

The relationships for this subsystem were developed from data extracted from reports by North American Aviation. Because radioisotope systems do not fall into either the cost or the performance domains applicable to manned spacecraft, all data used are estimates. The data used reflect a total of eight different subsystem designs. The designs include both Rankine and Brayton cycle power conversion systems. Design power output varied from 1.4 to 4 kilowatts-electric.

Three relationships were developed: design and development, boilerplate hardware, and manufacturing. Portions of these relationships were developed with some rigour through statistical techniques, i.e., multivariate regression analysis. However, the portions dealing with isotope fuel costs were not amenable to statistical analysis. Unfortunately, for some type of isotopes, fuel costs may be the only significant component of subsystem costs. Estimation of isotope fuel production cost is difficult because cost data are scarce and not reliable for some fuel types. There is, also, a strong possibility that isotope costs for future programs may not reflect true production costs; these costs may, instead, be the result of inter-Government agency administrative decisions. The treatment of isotope costs in the model reflects the above uncertainties by permitting parametric analysis. The treatment is conservative but not unrealistic.

1. For nuclear isotope electric subsystems, design and development costs include all costs of development except those for facilities and fuel:

$$\text{Cost} = 1175(\text{RTMP})^{.823}(\text{TURB})^{.446}$$

2. Boilerplate hardware accounts for the cost of isotopes used in prototype development and also for deliverable units in which isotope reuse is required:

$$\text{Cost} = (\text{EPEV})(\text{FUEL})$$

3. Manufacturing accounts for all production costs in isotope systems at unit one except for fuel costs where isotope reuse is required:

$$\text{Cost} = 166.3(\text{PSW})^{-.159}(\text{TURB})^{.422} + (\text{EPEV})(\text{FUW})$$

where

Cost is estimated cost in 1000's of dollars

PSW is shield weight

TURB is operating temperature (turbine inlet temperature for dynamic systems)

EPEV is system thermal watt rating

RTMP is the number of redundant power conversion units

FUEL is prototype fuel cost factor (see Table 6-1)

FUW is deliverable subsystem fuel cost factor. (See Table 6-1)

6.4 NUCLEAR PROPULSION SUBSYSTEMS

Nuclear propulsion estimating relationships were based on data obtained from studies of Nerva- and Phoebus-type engines. The studies were performed by Aerojet General Corporation and North American Aviation; under consideration were engines ranging in performance from 50,000 pounds thrust to 700,000 pounds thrust.

On the basis of the limited exploitation of this particular engine technology and institutional restrictions, there is a

Table 6-1

NUCLEAR ISOTOPE ELECTRICAL POWER
SYSTEM FUEL COST FACTORS

A. Low Cost or Short Lived Isotopes

Isotope Type	Prototype Fuel Cost Factor # of Power Conversion Systems per Subsystem 1 - 2	 3 - 4	 5 - N	Deliverable Subsystem Cost Factor
Cobalt 60	.98	.363	.627	.033
Strontium 90	.114	.209	.361	.019
Cesium 137	.126	.231	.399	.021
Cerium 144	.006	.011	.019	.001
Promethiom 147	.558	1.023	1.767	.093
Thulium 170	.060	.110	.190	.010
Polonium 210	.120	.220	.380	.020
Thorium 228	.240	.440	.760	.040
Curium 242	.900	1.650	2.850	.150

B. High Cost Isotopes

Isotope	Prototype Fuel Cost Factor	Deliverable Subsystem Cost Factor
Uranium 232	1.4	0
Plutonium 238	4.8	0
Curium 244	2.0	0

"High Cost Isotope" system costs factors assume four prototype fuel blocks that are reused for flight systems.

Cost Factors based on data appearing in Atomics International Report - A1-65-MEMO-62, dated April 1, 1965.

scarcity of cost data in any form pertaining to nuclear engines. Actual cost experience on nuclear engines is almost non-existent and reliable estimates are difficult to obtain. Most of the data used in developing these relationships is based on estimates. It was possible, to some extent, to supplement these estimates with cost data on liquid chemical engines which are technically related in a number of respects to nuclear engines; cost data on liquid chemical engines is more abundant. These data relationships were developed for design and development, tooling, inplant testing, boilerplate hardware, and manufacturing cost.

Nuclear propulsion design and development cost element includes the non-recurring and sustaining engineering costs of the engine, the cost of detail reactor design, and component test costs. Basic reactor research, such as that performed by the National Laboratories, is not included:

$$\begin{aligned} \text{Cost} = {} & 43082 + 6064.5\ (\text{FMAX/ZSPA})^{.413} \\ & + 15821\ (\text{FMAX})^{.199} \end{aligned}$$

Tooling cost includes non-recurring costs associated with tooling and special test equipment such as instrumentation and valves and other materials used in conducting engine tests:

$$\begin{aligned} \text{Cost} = {} & .000065\ (\text{DELV-RW})^{.491}\ (\text{ZSPA})^{2.054} \\ & + 5400\ (\text{FMAX/1000})^{.431} \\ & + 6\ \text{RCD} \end{aligned}$$

The inplant testing relationship includes the cost of manpower, data reduction, and propellants associated with the test of complete nuclear engine systems.

The boilerplate hardware relationship is used to compute the cost of components and complete engines used by the engine development contractor in his inhouse test program:

$$\text{Cost} = 6(\text{ZNF})^{.52} \; (.000065 \; (\text{DELV-RW})^{.491} \; (\text{ZSPA})^{.2.054} + 540 \; (\text{FMAX}/1000)^{.431} + 6 \; (\text{RCD})$$

The manufacturing cost relationship is used to generate all manufacturing costs including uranium for the first production unit:

$$\text{Cost} = .000065 \; (\text{DELV-RW})^{.491} \; (\text{ZSPA})^{2.054} + 540 \; (\text{FMAX}/1000)^{.431} + 6 \; (\text{RCD})$$

where

Cost is estimated cost in 1000's of dollars

FMAX is vacuum thrust

ZSPA is vacuum specific impulse

DELV is total engine weight

RW is reactor weight

RCD is uranium weight

ZNF is number of engine system tests. (Current estimates of the value for this ZNF range from 50 to 200, depending on reliability requirements and confidence in engine basic design.)

6.5 LIQUID PUMP-FED PROPULSION SYSTEMS

This body of relationships is applicable to pump-fed liquid engines which range in thrust from 15,000 pounds to 1,000,000 pounds and in which both storable and cryogenic propellants are used. The relationships are based on cost and performance data from North American Aviation, Aerojet General, and Pratt and Whitney. Almost every large liquid engine produced in this country is included in this data base. Multivariate regression analysis was applied to the collected data. Candidate relationships were developed through a regression analysis in which a variety of functional forms and 10 design and performance variables were considered. In addition to those variables finally selected for the relationships, such parameters as expansion ratio, restart capability, mass flow, thrust-to-weight ratio, wet engine weight, and propellant density were also considered.

The final estimating relationships were selected on basis of (1) statistical measures, (2) technical judgment, and (3) suitability of the relationship for use in estimating advanced technology engines. The final relationships were developed for the following categories: design and development, tooling, in-plant testing, boilerplate hardware cost, and manufacturing cost.

1. The design and development cost relationship estimates engine contractors variable and nonvariable engineering costs; the

engineering directly associated with engine testing is excluded:

$$\text{Cost} = 1.32\ (\text{FMAX})^{.391}\ (\text{ZSPA})^{.824}$$

2. The tooling relationships account for the cost of instrumentation, valves, and other special test equipment used in engine testing.

$$\text{Cost} = 246.9\ (\text{DELV})^{.451} + 30.5\ (\text{FMAX})^{.394}$$

3. The in-plant testing relationships are used to estimate the costs of both engineering and non-engineering personnel and propellants directly associated with the engine subcontractor's test program:

$$\text{Cost} = 16.15\ (\text{FMAX})^{.474}\ (\text{ZSPA})^{.324} + 1370 + .0167\ (\text{FMAX})\ (\text{STAR})$$

4. The cost of all prototype units used by the engine subcontractor in his inplant test program is estimated with the boilerplate and mockup relationship. In using this equation, it is assumed that 50 equivalent units are consumed during the test program:

$$\text{Cost} = 1543.4\ (\text{DELV})^{.451} + 190.7\ (\text{FMAX})^{.394}$$

5. The manufacturing cost estimating relationship is used to generate all subcontractor production costs attributable to the first production unit:

$$\text{Cost} = 30.87\ (\text{DELV})^{.451} + 3.82\ (\text{FMAX})^{.394}$$

where

Cost is estimated cost in 1000's of dollars

FMAX is vacuum thrust

ZSPA is vacuum specific impulse

DELV is engine dry weight

STAR is propellant adjustment factor

6.6 LARGE SERVICE MODULE STRUCTURE

These relationships are particularly suited to costing structures for large service modules that utilize either liquid pump-fed or nuclear propulsion systems. The data base used in developing these relationships includes designs varying in gross weight from 15,000 pounds to well over 1,000,000 pounds. This base includes almost every large stage or launch vehicle developed in this country. Sufficient data were available to use multivariate regression analysis. Candidate relationships were developed through regression analysis; out of a total of ten variables considered, five were ultimately rejected. The rejected variables were number of engines per module, structure weight, materials factors, relative position, and gross weight. The five acceptable variables are discussed below:

1. Structure design and development cost includes all engineering charges, both recurring and nonrecurring,

associated with the structure and with the integration of other subsystems into the structure:

$$\text{Cost} = 545.5\ (\text{WTGE})^{.524} + 332.8\ (\text{VLUM})^{.569}$$

2. The tooling relationship is used to compute the cost of manufacturing aids and other equipment utilized in the fabrication and final assembly of the module:

$$\text{Cost} = 12.7\ (\text{PLTW})^{.588} + 31.35\ (\text{TMF})^{.488}$$

3. Included within the in-plant testing relationship are all nonhardware costs pertaining to hot and cold static tests:

$$\text{Cost} = 6663.6\ (\text{PLTW})^{.107}$$

4. The boilerplate and mockup relationship is used to generate the cost of prototypes used in structure development. In using the relationship, it is assumed that a total of five equivalent structures are required for this purpose:

$$\text{Cost} = 1047.5\ (\text{WTGE})^{.066}\ (\text{VLUM})^{.315}$$

5. The manufacturing relationship is used to estimate the cost of the first production unit:

$$\text{Cost} = 209.5\ (\text{WTGE})^{.066}\ (\text{VLUM})^{.315}$$

where

Cost is estimated cost in 1000's of dollars

WTGE is module empty weight

VLUM is module right cylindrical volume

PLTW is expanded propellant weight

TMF is total module vacuum thrust

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7.0 PROGRAM DESCRIPTION

The Manned Spacecraft Systems Cost Model (GD/FW Procedure G36) is programmed in FORTRAN IV and MAP languages. The model can be run under standard IBM IBSYS version 12 or 13 on the IBM 7090/7040 and 7094/7044 Direct Couple Computers and on the IBM 7090 and 7094. In documents designated as Appendices I and II to this report, the following explanatory material is presented: flow charts, operating instructions, program and subroutine descriptions, magnetic tape assignment information, input aids, output sample and description, model restrictions, error key, and run time estimating procedure.

The model is programmed in sections for the convenience of the user. There are thirteen overlay sections or links (i.e., core loadings):

MAIN LINK - The main link remains in core throughout the entire run and controls execution of the other links. In addition to the control program, the main link contains subroutines used by higher order links.

LINK 1 - This link is used to transfer libraries from the system input unit to an intermediary input.

LINKS 2-6 - These links are used to read problem data from the system input unit, select the required library data, check the problem and library data for errors, and print the requested data.

LINKS 7-9 - These links are used (1) to schedule R&D and operational flights, module ground tests, and module purchasing and refurbishing; and (2) to compute research and development, recurring, and facility costs. Cost estimating relationships are used when required.

LINK 10 - This link is used to store the cost data on a type-B library tape if so specified. The link is also used to select previously generated data from a type-B library tape. Costs are, if required, inflated and written on an intermediary tape for use in the remaining links.

LINK 11 - This link is used to generate the summary reports.

LINK 12 - This link is used to generate the funding reports.

LINK 13 - This link is used to generate the center planning report.

Multiple spacecraft configurations, module arrangements, and subsystem combinations can be specified for each problem.

Library and problem data for all parameters and most indicators are entered in namelist form to allow flexibility of data format and data order to suit the convenience of the user.

8.0 CONTINGENCY PLANNING MODEL

The cost estimating relationships contained in models (such as the Spacecraft Cost Model) are formulated from historical data which normally represent a wide spectrum of programs. Some of these programs have been accelerated and others "stretched-out" during the program lifetime. The effects of acceleration or "stretch-out" on program cost are difficult to isolate and are, therefore, included in the cost data used to derive the cost estimating relationships. If the long range planner wishes to postulate contingencies, such as program acceleration or stretch-outs, it is often difficult to assess the cost impact of these contingencies.

A procedure to explore the effects of contingencies on launch vehicle costs had been develcped for NASA-MSFC. Early in the study MSC asked that this still-experimental procedure be modified so that its feasibility as a predictor of spacecraft contingency costs might be explored. This modified procedure, the Contingency Planning Model, operates independently of the rest of the Spacecraft Cost Model.

In its final form the Contingency Planning Model assesses the influences of eight major contingencies:

1. <u>Technological Stretch-out</u>: The state of a subsystem, stage, or configuration of a specified spacecraft the progress of which has been deterred through technological difficulties

and which cannot continue at a normal development and/or operating pace.

2. Budget Constraint: An annual budget ceiling placed upon some part or phase of a program budget.

3. Cost Sharing: A contingency that arises due to two or more spacecraft systems utilizing common subsystems or facilities; such common usage makes it desirable to share the costs in some proportionate manner among the programs involved.

4. Cancellation: The contingency resulting from the cancellation of part or all of a spacecraft program; this condition is expressed in terms of the costs involved and the residual costs which are accrued to that cancellation.

5. Technological Recovery: The condition which results from the cancellation of a subsystem or subsystems within a spacecraft program and the replacement of the cancelled system by a similar system which is not necessarily of the same technological complexity.

6. Acceleration: A contingency associated with changing a previously defined schedule by compressing it to cover a smaller time interval.

7. Parallel Systems: A contingency under which consideration is given to the cost involved when two systems are initiated to achieve the same function with respect to the spacecraft; this consideration is subject to the prior understanding that one of the competing systems will eventually be cancelled in favor of the other.

8. Fixed Costs: The condition encountered when consideration is given to the incremental cost required to achieve additional operational capability within a program or when consideration is given to major changes in the program orientation.

These options may be used singly or in combination in order to synthesize a given situation.

Another element of the Contingency Planning Model is the Spacecraft Cost Model Simulator which provides a means of generating a tape to be used as input for the Contingency Planning Model. The simulator has provisions for three types of cost data to be input: (1) a constant cost in all third order categories between a given set of milestones; (2) a constant amount, but varying among categories, between a given set of milestones; and (3) actual cost data, category by category, on a quarterly basis.

Any or all of the sectors of the Contingency Planning Model may then be applied to this basic tape in order to formulate the desired results.

Additional details concerning the Contingency Planning Model may be found in the Contingency Planning Model Programmer and User's Manual (published in November 1965) and in General Dynamics/Fort Worth report number FZM-4247 (published in June 1965).

9.0 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.

9.1 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 9-1. The costs and model inputs

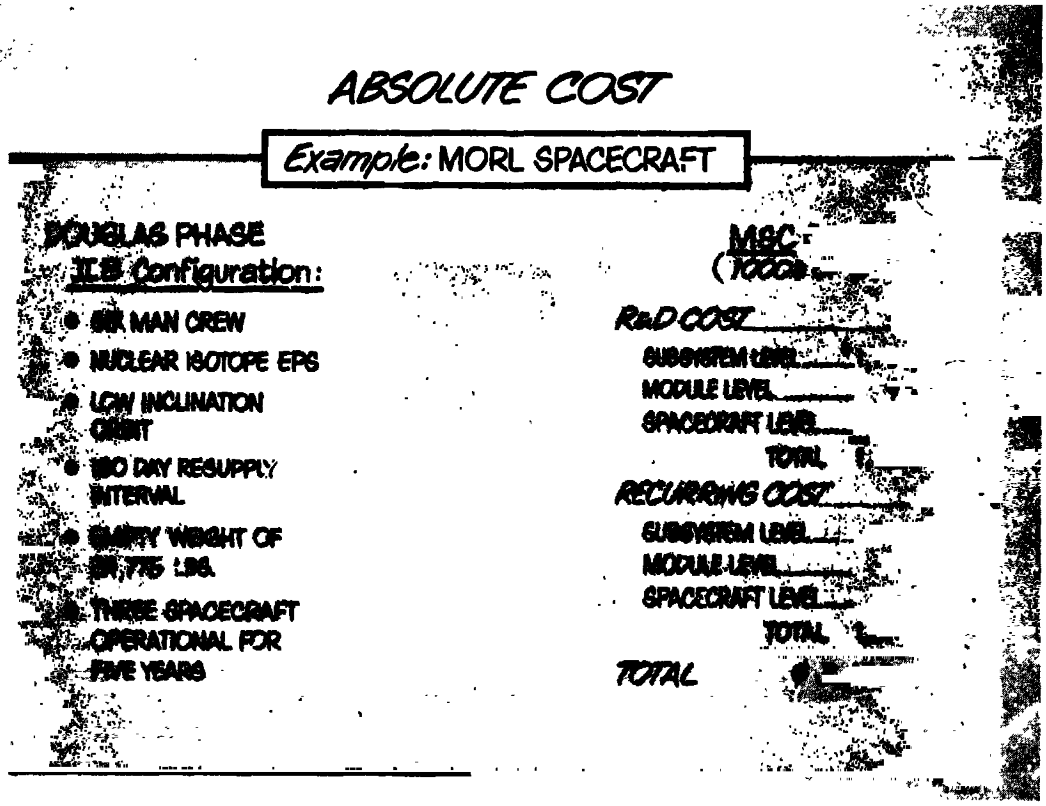

Figure 9-1

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 9-2 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.).

PROGRAM 1 SPACECRAFT 1 MORL IIB

SUMMARY COSTS (TOTALS * 1000)

	TOTAL	MODULE 1 MORL IIB
I. RESEARCH AND DEVELOPMENT	1739464	1234523
A. SUBSYSTEM LEVEL COSTS	1137079	1137079
1. STRUCTURE	343539	343538
A1. DESIGN AND DEVELOP. ENGR.	276336	276336
A3. BOILERPLATE AND MOCKUPS	15794	15794
A4. MANUFACTURING	51409	51409
3. ENVIRONMENTAL CONTROL	210287	210287
A1. DESIGN AND DEVELOP. ENGR.	129351	129351
A2. TOOLING	2498	2498
A3. BOILERPLATE AND MOCKUPS	13918	13913
A4. MANUFACTURING	64620	64620
4. CREW SYSTEMS	27434	27434
A1. DESIGN AND DEVELOP. ENGR.	19540	19549
A2. TOOLING	512	512
A3. BOILERPLATE AND MOCKUPS	2689	2689
A4. MANUFACTURING	4685	4685
5. STABILIZATION	215264	215264
A1. DESIGN AND DEVELOP. ENGR.	146837	146837
A2. TOOLING	2185	2185
A3. BOILERPLATE AND MOCKUPS	37771	37771
A4. MANUFACTURING	28471	28471
6. REACTION CONTROL	43829	43828
A1. DESIGN AND DEVELOP. ENGR.	23149	23148
A2. TOOLING	1812	1312
A3. BOILERPLATE AND MOCKUPS	4855	4855
A4. MANUFACTURING	14013	14013
8. ELECTRICAL POWER	231729	231729
A1. DESIGN AND DEVELOP. ENGR.	31905	31905
A3. BOILERPLATE AND MOCKUPS	195360	195360
A4. MANUFACTURING	4464	4464
9. COMMUNICATIONS	45738	45738
A1. DESIGN AND DEVELOP. ENGR.	20753	20753
A2. TOOLING	211	211
A3. BOILERPLATE AND MOCKUPS	9315	9315
A4. MANUFACTURING	15459	15459
10 INSTRUMENTATION	19263	19263
A1. DESIGN AND DEVELOP. ENGR.	12427	12427
A2. TOOLING	183	193
A4. MANUFACTURING	6653	6653

Figure 9-2

9.2 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 9-3) 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 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

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	PROGRAM 1	SPACECRAFT 1	MMM-CL
	SUMMARY COSTS	(TOTALS * 1000)	
	TOTAL	MODULE 1 MMM-CL	
I. RESEARCH AND DEVELOPMENT	6375705	4699119	
A. SUBSYSTEM LEVEL COSTS	4468074	4468074	
1. STRUCTURE	2823053	2823053	
A1. DESIGN AND DEVELOP. ENGR.	2547143	2547143	
A3. BOILERPLATE AND MOCKUPS	15663	15663	
A4. MANUFACTURING	260247	260247	
3. ENVIRONMENTAL CONTROL	824143	824143	
A1. DESIGN AND DEVELOP. ENGR.	677798	677798	
A2. TOOLING	4183	4183	
A3. BOILERPLATE AND MOCKUPS	17342	17342	
A4. MANUFACTURING	124820	124820	
4. CREW SYSTEMS	46166	46166	
A1. DESIGN AND DEVELOP. ENGR.	30280	30280	
A2. TOOLING	593	593	
A3. BOILERPLATE AND MOCKUPS	3115	3115	
A4. MANUFACTURING	12178	12178	
5. STABILIZATION	80480	80480	
A1. DESIGN AND DEVELOP. ENGR.	38690	38690	
A2. TOOLING	2657	2657	
A3. BOILERPLATE AND MOCKUPS	10416	10416	
A4. MANUFACTURING	28717	28717	
7. NAVIGATION AND GUIDANCE	200360	200360	
A1. DESIGN AND DEVELOP. ENGR.	91615	91615	
A2. TOOLING	700	700	
A3. BOILERPLATE AND MOCKUPS	31416	31416	
A4. MANUFACTURING	76629	76629	
8. ELECTRICAL POWER	397171	397171	
A1. DESIGN AND DEVELOP. ENGR.	363628	363628	
A4. MANUFACTURING	33543	33543	
9. COMMUNICATIONS	96702	96702	
A1. DESIGN AND DEVELOP. ENGR.	36297	36297	
A2. TOOLING	270	270	
A3. BOILERPLATE AND MOCKUPS	11922	11922	
A4. MANUFACTURING	48213	48213	
B. MODULE LEVEL COSTS	231044	231044	

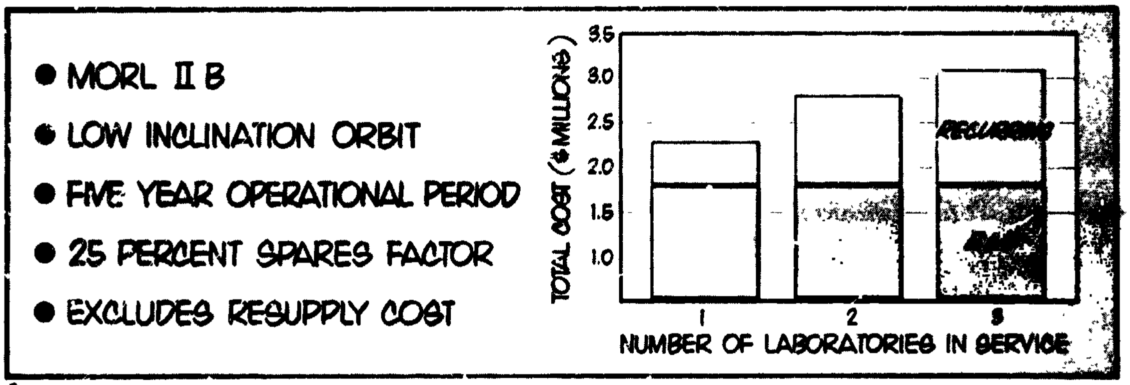
Figure 9-3

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 9-4. 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 in total cost is attributable to (1) higher subsystem level costs which reflect increasing manufacturing and sustaining engineering costs, and (2) the increasing spacecraft level cost which is due to greater mission control requirements.

COST SENSITIVITY

Example: VARYING SPACE STATION QUANTITIES



	ONE LAB	TWO LABS	THREE LABS
Spacecraft Level	$ 852,870	$ 1,070,157	$ 1,287,441
Module Level	101,391	105,338	109,285
Subsystem Level	1,421,538	1,612,175	1,725,624
TOTAL (1000's OF $)	$ 2,375,799	$ 2,787,670	$ 3,122,350

Figure 9-4

9.3 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 economics resulting from using the "building block approach" to performing a given mission

3. Evaluation of specified mission modes.

An example of the latter application is shown in the next figure. Presented in Figure 9-5 are the results of model estimates of the

MISSION ANALYSIS

Example: MARS MISSION

MARS FLYBY	MSC COST (1000's OF $)
• 1975 DEPARTURE	R&D ________ $ 6,353,473
• 700 DAY MISSION	RECURRING ____ 869,532
• 4-MAN CREW	TOTAL $ 7,223,005
• COMMAND/SERVICE & MISSION MODULES	
• GROSS WEIGHT OF 153,470 LBS.	

MARS LANDING	MSC COST (1000's OF $)
• 1982 DEPARTURE	R&D ________ $18,311,233
• 420 DAY MISSION	RECURRING ____ 2,664,298
• 8-MAN CREW	TOTAL $20,975,531
• MISSION, EXCURSION EARTH ENTRY & PROPULSION MODULES	
• GROSS WEIGHT OF 2,404,037 LBS.	

TOTAL MARS MISSION MSC COST

$ 28,198,536

Figure 9-5

NAS [illegible] DATE [illegible]/66 [illegible]

PROGRAM 1 MARS [illegible]

SUMMARY COSTS (TOTALS [illegible])

		SPCFT 1 MMM-CL	SPCFT 2	SPCFT 3	SPCFT 4	SPCFT 5
TOTAL COST	20975531	7541593	[illegible]	1865[illegible]	[illegible]	[illegible]
I. SUBSYSTEM LEVEL COSTS	16549265	5473715	[illegible]	1149715	[illegible]	[illegible]
A. RESEARCH AND DEVELOPMENT	14422975	4459074	[illegible]	1311549	[illegible]	[illegible]
B. RECURRING COSTS	2275290	1305641	[illegible]	[illegible]	[illegible]	[illegible]
C. FACILITIES	0	0	0	0	0	0
II. MODULE LEVEL COSTS	1017098	234991	301003	154633	245963	80561
A. RESEARCH AND DEVELOPMENT	972892	231044	293109	150556	230152	67332
B. RECURRING COSTS	44206	3947	7894	3947	15749	12630
C. FACILITIES	0	0	0	0	0	0
III. SPACECRAFT LEVEL COSTS	3309168	1832846	495208	521[illegible]	[illegible]	[illegible]
A. RESEARCH AND DEVELOPMENT	2915366	1676536	441365	397415	0	[illegible]
B. RECURRING COSTS	393802	156300	53842	12[illegible]	19803	[illegible]
C. FACILITIES	0	0	0	0	0	0

Figure 9-6

cost of one approach to performing a manned Mars mission: a Mars flyby which is followed by a Mars landing expedition. Figure 9-6 (reproduction of output of the model) depicts major spacecraft elements and their costs for the landing expedition.

9.4 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 on 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.

9.5 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 9-7. 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 semiannual basis for the program mix shown in the example.

Figure 9-7

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10.0 RECOMMENDATIONS FOR FUTURE STUDY

Five months of checkout have verified the fact that the model structure is fundamentally sound. However, preliminary investigations by General Dynamics indicate that additional work on most of the model's estimating relationships seems to be warranted. Although the current relationships are the best available, additional effort could profitably be spent on refining the relationships through the process of further filtering of the data from which the relationships were developed. The following steps should be taken:

1. Continue analysis of the division between variable and non-variable costs. Because runout cost projections used in developing the estimating relationships are heavily weighted in favor of variable costs, the basic assumptions relating to runout projections should be re-examined, especially the assumed relationship between sustaining engineering cost and production quantity. The current relationships based on these runout projections have disturbing implications when abnormally large or small production quantities are considered.

2. Further analyze module and spacecraft level costs and, in particular, GSE costs. GSE costs may account for 12 to 20 percent of total spacecraft costs; these costs are

presently generated by two single variable relationships. It seems desirable to place this highly influential cost element on a broader analytical basis.

3. Evaluate all CER's with respect to the implications of advanced technologies. Currently, some CER's appear to either understate or overstate the effects of large advances in the state of the art. Further study, based mainly on technical evaluation, should improve the responsiveness of the relationships.

Although there is convincing evidence that operation of the program is satisfactory, use of the model would be enhanced by making minor alterations to provide additional gross spreading functions and to incorporate a print/plot submodel. One such spreading function is currently available for R&D costs. The additional spreading functions would simplify use of the model under conditions in which detail funding distributions are not required in the calculation of recurring and facilities cost.

The print/plot submodel would provide a graphic output of model costs and would make interpretation of model output more convenient. Provisions were made in the model structure to accommodate both of these changes with a minimum of reprogramming.