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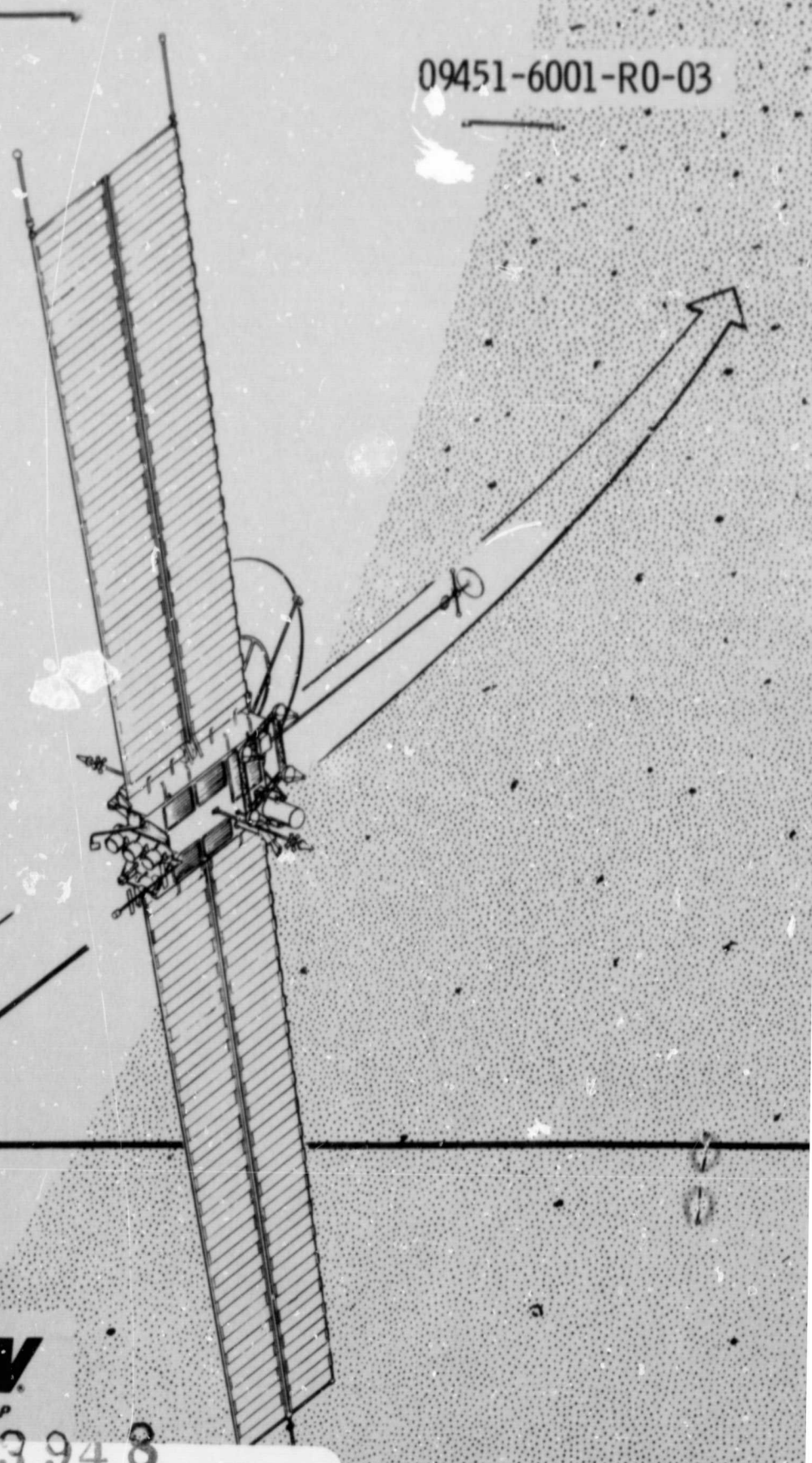
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STUDY OF A SOLAR ELECTRIC MULTI-MISSION SPACECRAFT



VOLUME II

FINAL TECHNICAL REPORT
PROGRAM DEVELOPMENT PLAN

TRW SYSTEMS GROUP

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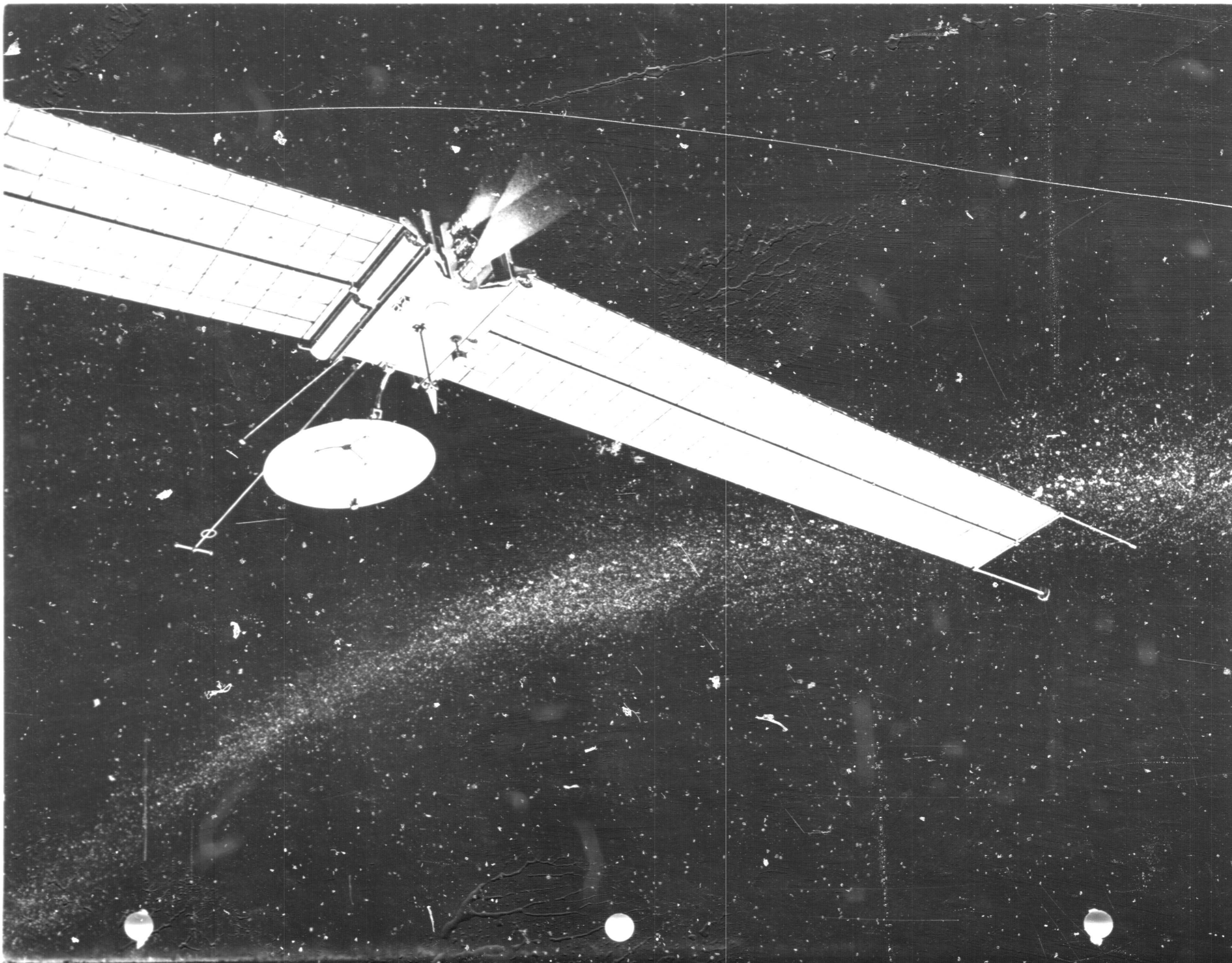
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One Space Park
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ABSTRACT

This document describes a study of a multi-mission solar electric spacecraft and shows that a modest size (6.5 kw, 580 kg dry weight) spacecraft with variable propellant loading (70 to 310 kg of mercury) can be used interchangeably for asteroid probe, targeted asteroid flyby, Jupiter probe, and out-of-the-ecliptic missions (to 35 degrees). The science experiment complement is changed, and in the out-of-the-ecliptic mission thrusters and power conditioning units are added for redundancy. The varying energy requirements of these missions are met by changing the propellant loading and by using the Atlas-Centaur for the asteroid belt probe and the Titan IIIC for the other missions. The payload capacity in every case is several times that of comparable ballistic probes.

In addition to the program cost savings inherent in a multi-use spacecraft, program cost has been minimized by selecting a design point such that a small amount of payload weight is sacrificed in exchange for a large reduction in spacecraft gross weight and power requirement, and hence spacecraft cost. This can be done by using the launch vehicle to deliver a higher injection energy than that which corresponds to the weight-optimal staging condition. This lighter spacecraft, having a shortened propulsion phase and carrying a greatly reduced propellant weight, also has the advantage of employing a simpler mission profile.

A typical two-flight launch program would cost $64 million for the spacecraft and would require 3 years from start to first launch. The specific ion engine to be used (2.25 kw peak power, throttleable over a 3:1 range) should be developed and life tests started before the start of the 3-year program. Costs of this predevelopment are included in the $64 million, however. Current progress in life testing of the 1-kw SERT II thrusters is extremely promising and it is believed that wearout failure modes are now understood and have been designed out of that unit.

Projecting from the results of this study, solar-electric propulsion will be particularly useful and cost-effective in a large number of demanding interplanetary missions other than those considered here. The more energetic the mission the more cost-effective, in general, will be the use of electric propulsion. Examples are flyby and orbiter missions to the outer planets, comet intercept, Mercury orbiter, close-approach solar probe, stationary solar monitor, and magnetotail exploration missions. The electric thruster technology and low thrust flight experience are also needed in preparation for subsequent nuclear electric manned missions. The program described in this study represents a low-cost approach to get this development underway while at the same time providing an effective and cost-saving return of space science data from early missions.

CONTENTS

		Page
1.	PROGRAM PLANS AND COST ESTIMATES	1
	1.1 Introduction	1
2.	RESULTS	4
	2.1 Baseline Plans	4
	2.2 Cost Summary	10
	2.3 Application of Results	10
3.	BASELINE DEVELOPMENT PLAN	12
	3.1 Project Management and Systems Engineering	12
	3.2 Product Integrity	12
	3.3 Subsystem Development	13
	3.4 Support Equipment Development	25
	3.5 Spacecraft Development	28
	3.6 New Technology Requirements	30
	3.7 Facilities	36
4.	PROGRAM COSTS	38
	4.1 Estimating Method	38
	4.2 Program Cost Data	39
5.	PROGRAM COST REDUCTION	41

1. PROGRAM PLANS AND COST ESTIMATES

1.1 INTRODUCTION

The primary purpose of the planning and cost estimating portion of this study is to gather data which are necessary to evaluate the SEMM spacecraft design. Costly or risky design approaches were eliminated; the ultimate design was then costed, and broad development and management plans were prepared.

The data define development effort, schedules, facilities required, and costs and are presented so that they can be combined with launch vehicle and mission support data to compare chemical and solar electric missions. The data also make it possible to compare the SEMM spacecraft with other spacecraft designs and provide input for NASA resource planning.

A baseline program plan using a conventional approach was prepared, and then alternate plans were developed by modifying the baseline plan. Corresponding cost estimates were made and the alternatives studied to find where cost advantages lay. The work was performed in the following manner:

- Ground rules and assumptions were made that apply to all aspects of SEMM spacecraft planning and cost estimating.
- A work breakdown structure was prepared to show how spacecraft development is related to other work in the program. Elements usually furnished by the government were identified. Spacecraft development was divided into customary areas of effort for ease of planning and cost estimating.
- The work breakdown was the basis for a preliminary flow diagram that arranges the work in sequential and parallel steps, and groups these in logical phases.
- The duration of tasks in the flow diagram was estimated and phased to form a master schedule.

Planners and subsystem engineers were given instructions that included ground rules, master schedule, flow diagram, implementation planning sheets, new technology sheet, and detail scheduling sheet.

The detail technical plan data collected was integrated and refined to form the baseline program plan. This and the design data were used as the basis for the cost estimates.

During the initial design of the SEMM spacecraft. Candidate configurations were judged according to general characteristics that affect development functions and hence cost. These characteristics were ranked according to their cumulative scores. Typical characteristics are given below:

Increase Costs	Decrease Costs
Complex	Simple
Fragile	Sturdy
Awkward size	Convenient size
Hazardous to personnel	Nonhazardous
Self-destructive test (irreversible test)	Reversible and repetitive test capability
Inaccessible layout	Accessible
Critical assembly sequence	Simple "bolt together" subassemblies
Exotic or new processes and materials	Proven off-shelf processes and materials
Transport difficult	Easy handling and transport
Inspection difficult	Inspection easy
Manufacture difficult	Standard manufacture
Test setup new and complex	Conventional test setup

Early configurations were created by making logical arrangements of basic features or building blocks. Detailed design of the building blocks was not necessary at this point.

Building blocks of the spacecraft design chosen without detailed analysis of alternatives included:

- Simple cube or modified cube structure

- Fold-out solar array configuration (GE) identical for all configurations
- Modular electric propulsion concept
- Parabolic antenna identical for all configurations
- Canopus sensor identical for all configurations
- Housekeeping subsystems identical for all configurations

When the factors influencing cost were first applied to candidate configurations, no significant differences were found. These factors applied more to the yet undefined internal details of the building blocks than to their arrangement. Therefore a simple method of ranking candidate designs was adopted and is illustrated in Figure 1-1. Each configuration was judged as to relative difficulty in each of five main phases of a typical project, i.e., development, manufacturing, spacecraft assembly-integration-test, launch, and mission operations.

No differences are apparent during development since the main development problems are found at the subsystem level or below. At the total spacecraft system level, development costs would differ only because of differing numbers of solar arrays. Ranking of the configurations during manufacturing, assembly, integration, and test also was influenced only by the number of solar arrays. No differences in difficulty of operation were apparent in launch and mission operations.

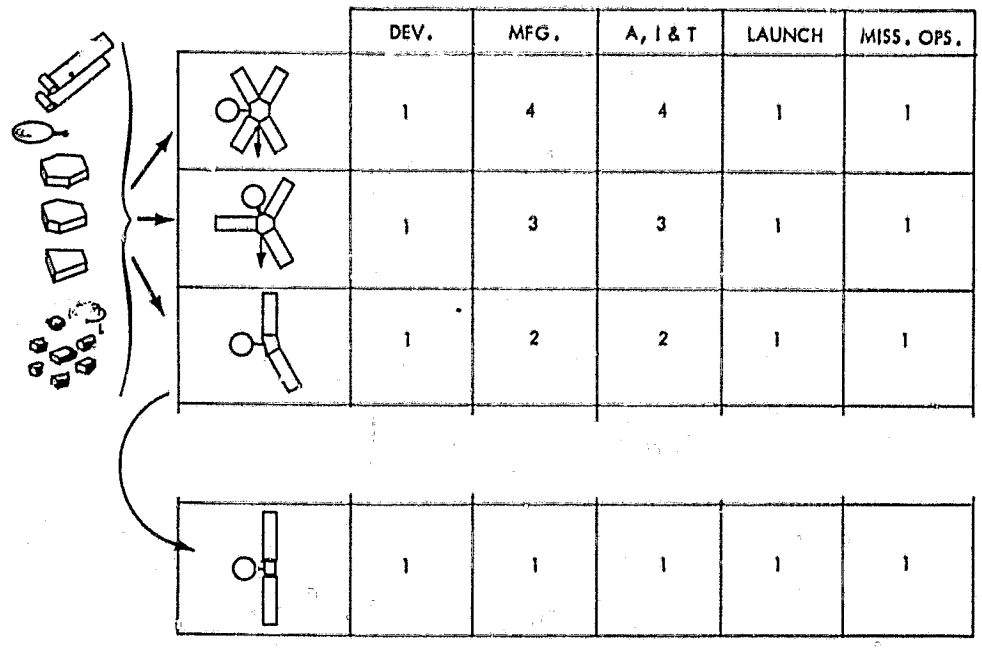


Figure 1-1. Candidate Configuration Evaluation

2. RESULTS

2.1 BASELINE PLAN

The ground rules and assumptions from which the baseline plan was derived are listed in Table 2-1. The work breakdown structure shown in Figure 2-1 outlines the overall program and indicates those elements which are normally furnished by the government. It relates the work studied to parts of the overall program beyond our cognizance. The study pertains only to the spacecraft system, including some elements to be furnished by the government. All such elements are noted as GFE on the figure.

Figure 2-2, the summary flow chart of the program, breaks down the operations required for implementation of the spacecraft and arranges them in sequential and parallel order. It also shows interfaces with the other parts of the program, such as launch vehicle systems and science payload development which are grouped within dashed-line borders, as are the major phases of spacecraft development.

Figure 2-3, the master schedule for the program, time phases the operations arranged in the flow diagram. Scheduling relationships between the spacecraft, science payload, launch vehicle, mission operations, and tracking and data acquisitions are also shown.

The baseline plan is highlighted in Table 2-2. The black box subsystem development is conventional because only existing designs are used, except for the propulsion subsystem and its predevelopment phase of 12 months. We have great confidence in the spacecraft schedule of 36 months to first launch. It is adjusted to the pacing subsystem (since propulsion has an additional 12 months), and allows cost effective scheduling of the nonpacing subsystems. The spacecraft assembly and test is scheduled based on two system test sets. The second flight spacecraft is to be assembled and tested in sequence with the first and is available for launch 12 months later. The schedule permits time sharing of major test articles. For example, the same test model serves for thermal and structural tests and the engineering model units are used in the engineering model spacecraft after completion of unit tests. Development work

leading to lifetime qualification test of the electric propulsion subsystem is started one year before the main project to minimize risk and hence cost.

Table 2-1. SEMMS Program Planning Ground Rules

- The baseline program includes the activities required to design and develop the SEMM spacecraft and extends through the launch and operation of the spacecraft.
- Alternate program plans consider the effects of one additional spacecraft, variations in configuration introduced by two other missions, and an additional booster.
- The plan identifies both contracted and government-furnished elements that are required for the program. This is to assure a clear understanding of the cost estimates.
- Maximum use of existing government-owned facilities is assumed.
- Maximum application of proven design, equipment, and techniques is assumed.
- The program schedule is defined by estimating each segment of the program. Duration of the program is based on arbitrary overlap of segments for contingency and on the use of two system test sets.
- Ground and flight test hardware required for the program will include engineering model units (as required), engineering model spacecraft (made up of these engineering model units), units for qualification test, structural model, thermal model, acceptance tested units for prototype spacecraft, and flight spacecraft, and selected spare units.

No new major facilities are required, because the spacecraft body is similar in size to earlier spacecraft and because the solar arrays are tested separately from the spacecraft. This is current practice for large spacecraft antennas and appendages. A large spherical thermal vacuum chamber is required for about 18 months of continuous propulsion subsystem tests.

Table 2-2. SEMM Spacecraft Program Characteristics

- Development of all black box subsystems is conventional
- Schedule yields high confidence
  - Accommodates pacing subsystem
  - Others nonpacing
  - Permits use of two sets of GSE
  - Second spacecraft completed in sequence
  - Common test articles for major tests
  - Sequential use of engineering models
- Long lead and new technology items start before main project at minimum cost
- No new major facilities required

New technology items identified during the study are listed in Table 2-3. Long-life tape recorder development is included in the SEMM spacecraft schedule. Large solar array development is assumed to be a continuation of present work.

Table 2-3. New Technology Items

	Predevelopment Period (Months)
• Long-life tape recorder	12
• Feed system	10
• Switching gear	10
• Power conditioner	15
• Low conductance isolator	12
• Thruster development and life test	12
• Continue large solar array development	-

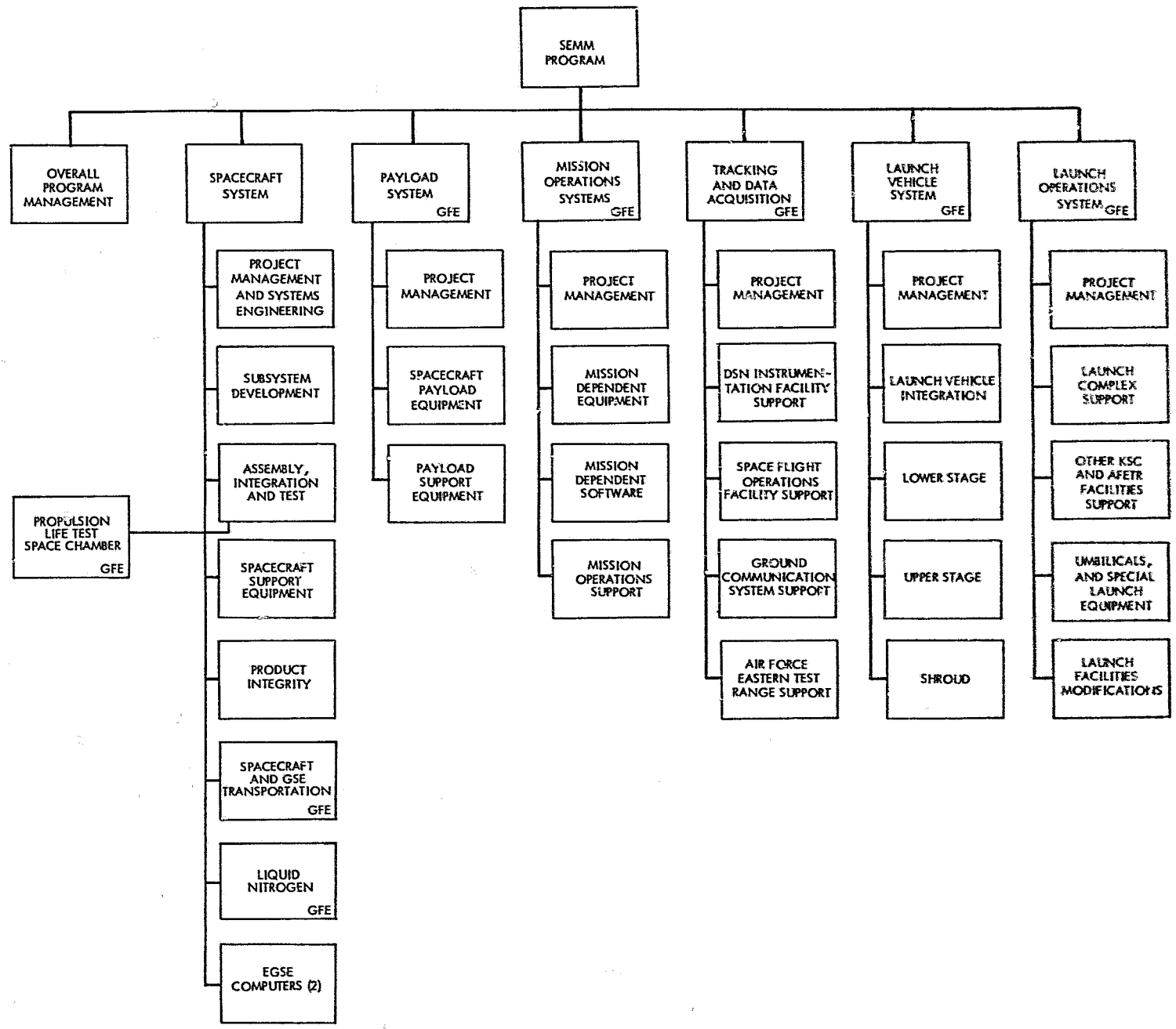
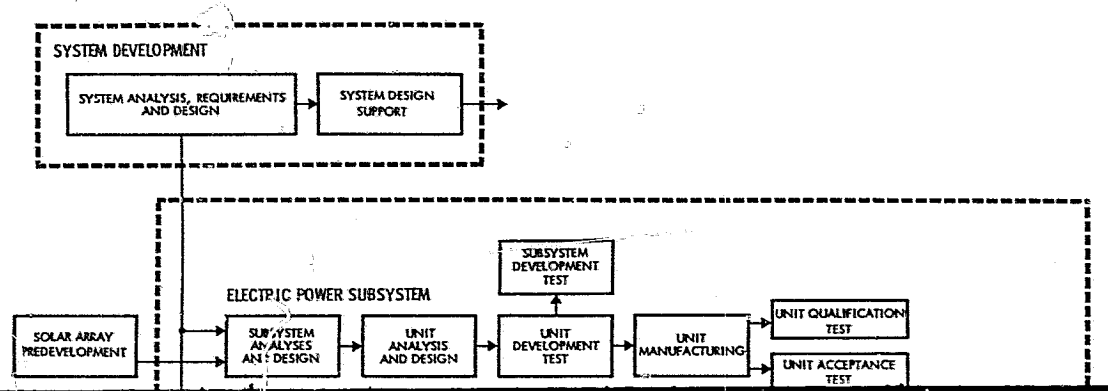


Figure 2-1. Overall SEMM Program Work Breakdown Structure

FOLDOUT FRAME 1



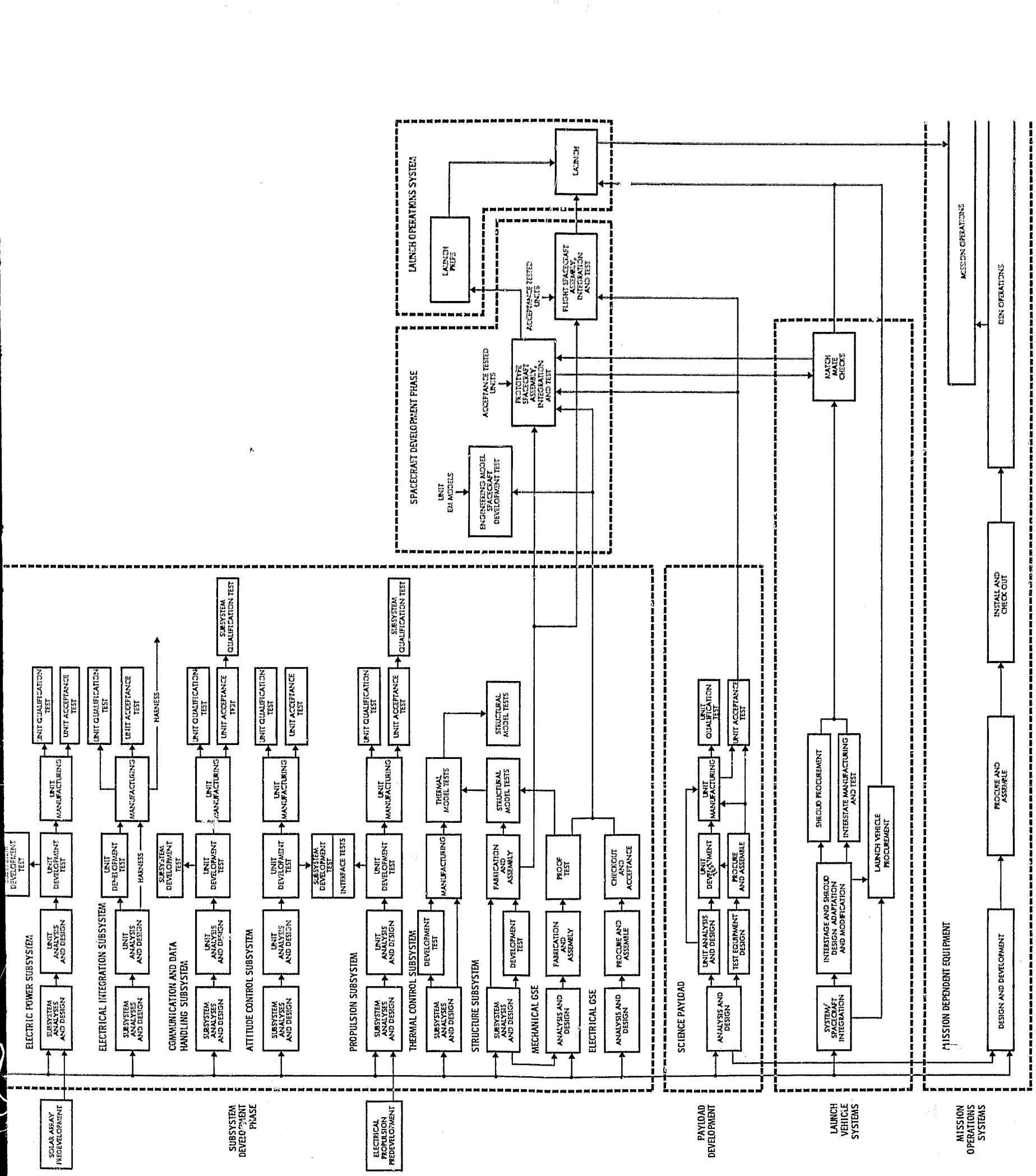
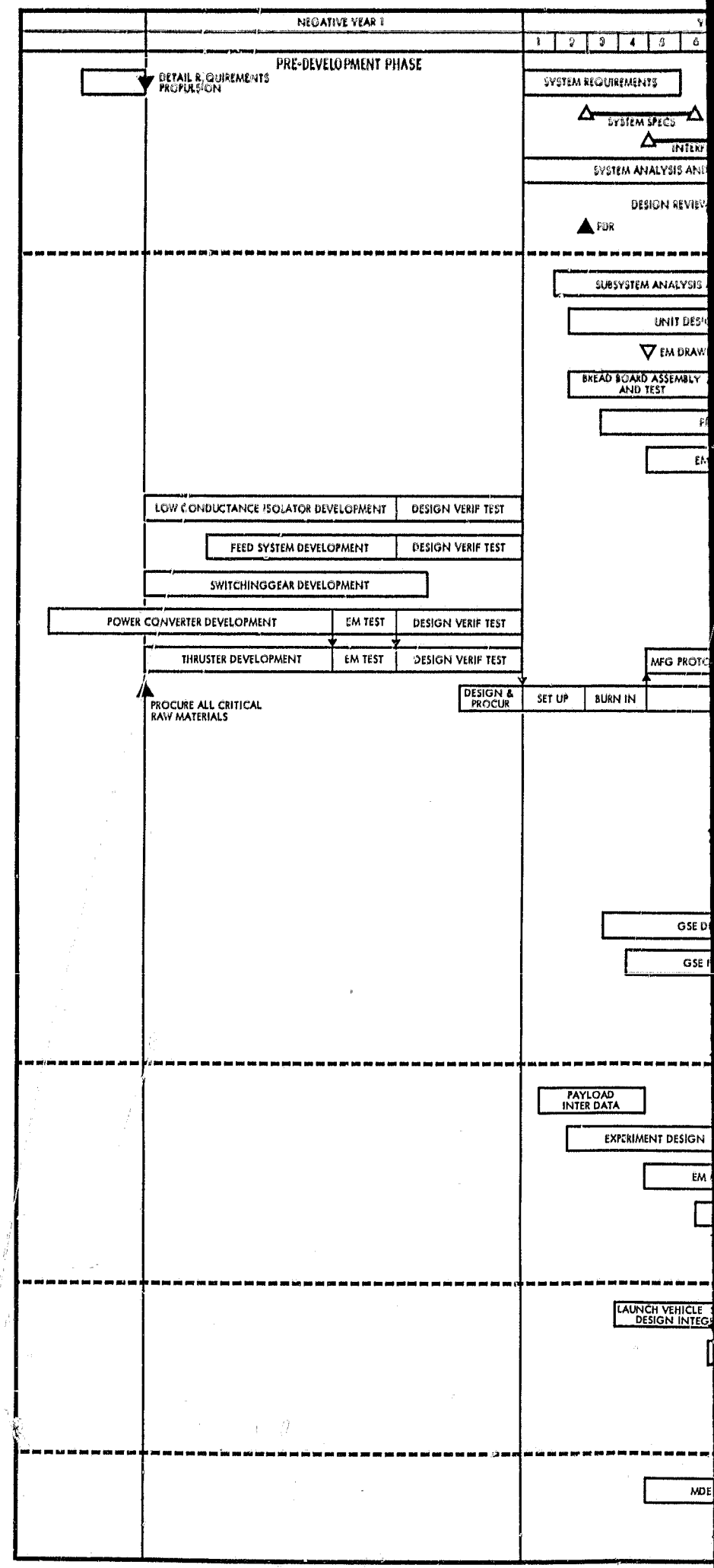


Figure 2-2. Summary Program Flow

FOLDOUT FRAME 2



FOLDOUT FRAME 1

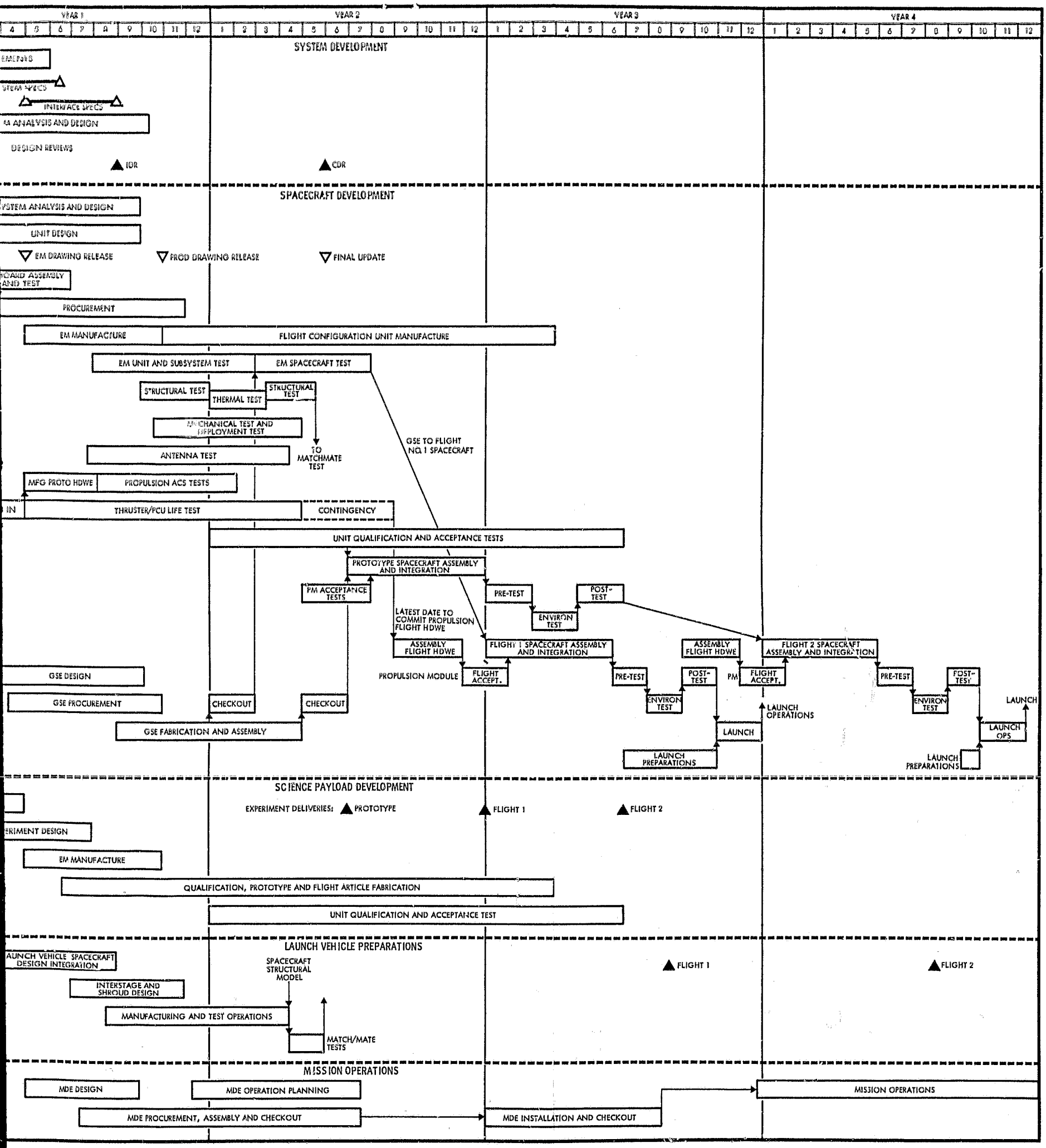
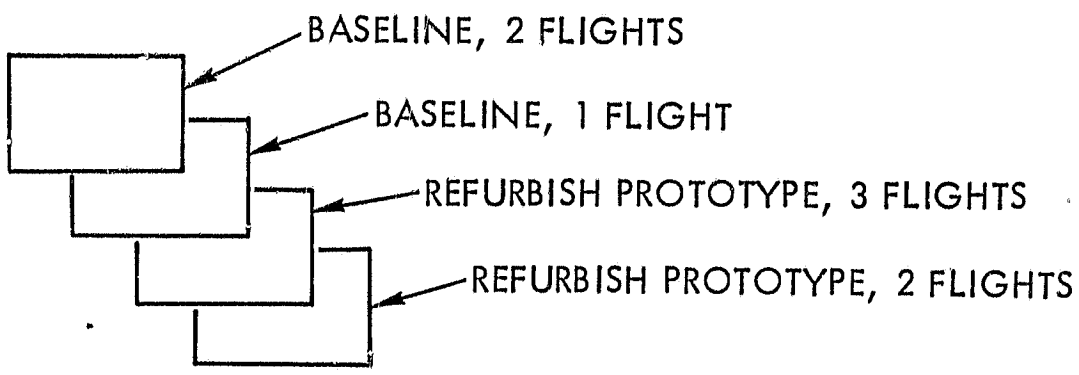


Figure 2-3. Master Schedule

FOLDOUT FRAME 2

2.2 COST SUMMARY

Figure 2-4 categorizes cost data according to major elements of the spacecraft system. The baseline cost is estimated for two flights and for one flight. A plan for refurbishment and flight of the prototype spacecraft includes cost estimates for three flights and for two flights. The data appear in the following order on the figure:



The estimates are total costs in 1969 dollars and include overhead, general and administrative costs, and fee.

Estimates were also made for additional quantities of spacecraft. If three spacecraft are considered, the unit cost drops to 46 percent of the baseline plan and 40 percent of a minimum cost plan. Reuse of test hardware saves approximately 11 percent from the baseline plan.

2.3 APPLICATION OF RESULTS

The schedule for the baseline program is conventional and includes contingency factors.

An alternate shorter schedule starts predevelopment of electric propulsion only two months before the main project. Therefore propulsion development is concurrent with other subsystem work but does not alter the spacecraft schedule. The cost of this alternative is about the same as that of the baseline program; however, the schedule risk is greater.

Reuse of test hardware or reduction of the number of system test sets extends the schedule but total cost and risk remain unchanged.

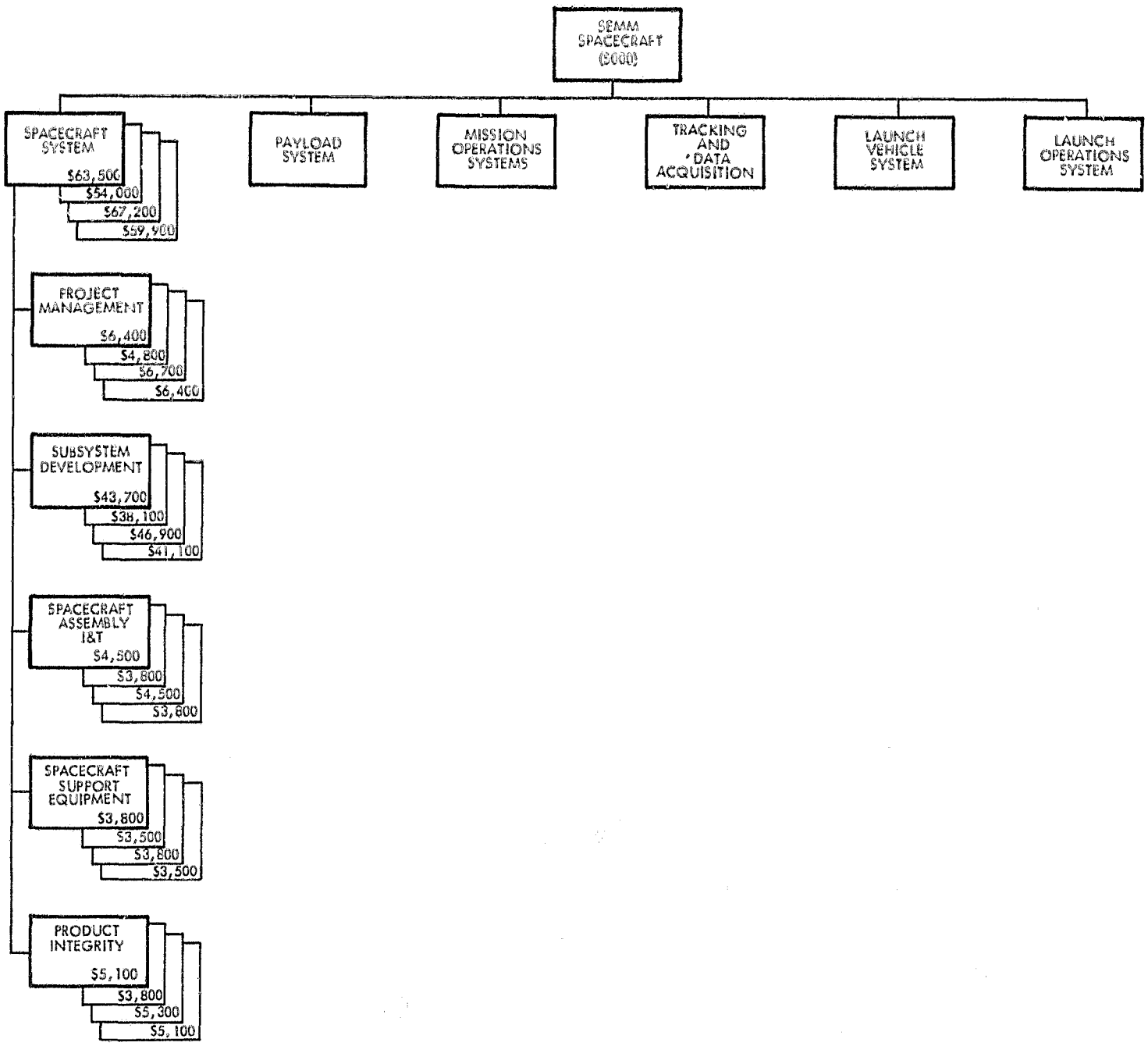


Figure 2-4. Cost Estimate

3. BASELINE DEVELOPMENT PLAN

This section defines the baseline plan and correlates with the baseline cost estimate (see Figure 2-1). Each subsection describes the third-tier segments of the work breakdown structure.

3.1 PROJECT MANAGEMENT AND SYSTEMS ENGINEERING

Management includes the project manager and his staff, project planning and control, system engineering, mission analysis, magnetic control, and experimenter liaison. The level of effort and emphasis of these activities is consistent with current NASA projects, and a manager in each of these areas is assured for the life of the program.

Project planning and control includes the support operations of material coordination, contract property management, project documentation, cost control, and schedule control.

System engineering and mission analysis include the mission-oriented functions of launch vehicle interface analysis, launch requirement analysis, trajectory analysis, system test planning, and system design, specification and analysis.

Magnetic control includes magnetic test specifications and procedures, magnetic evaluation and testing of components, magnetic test planning and site preparation.

Experimenter liaison encompasses documentation of experiment interface data, design specifications and data for experimeter use, definition of test requirements, and maintenance of the experimenter data book.

3.2 PRODUCT INTEGRITY

This activity includes the quality assurance subproject; reliability work element, parts, materials, and processes work element; safety engineering and configuration control.

The quality assurance subproject includes quality engineering activities, quality assurance management and administration, and vendor quality assurance surveillance and management. Also included are quality assurance test observation engineering and inspection associated with subsystem development. Unit qualification and acceptance test quality assurance function are included as part of this element.

Reliability activities include design review support; life test support; unit, subsystem, and system reliability analysis; test survey, specifications and procedures review; vendor surveillance; failure reporting; and reliability management.

The parts, materials, and processes work element includes failure analysis, design review support, parts specification, material specification, support of parts application, evaluation of parts and materials for magnetic properties, magnetic part inspection, and modification.

The configuration control includes document preparation and release, baseline data listing, verification data listing, and configuration management.

3.3 SUBSYSTEM DEVELOPMENT

The subsystem development planning sheets (Tables 3-1 through 3-8) express for each element of the subsystem (i.e., units and subsystem functions) its degree of development and the typical activities that are required to provide the hardware. The column headings across the top of the sheet are activities needed to develop the subsystem and its hardware. The line headings list units that make up the subsystem and space is provided for subsystem or assembly level activities. Notation on the sheet outlines planning data indicating design derivations, design status, whether or not specification and drawing exists; notes on how the design would be adapted to the SEMM spacecraft, manufacturing notes (procurement problems, status of planning, processes, tooling, test fixtures, and test sets). The number of test articles are listed and the types of tests planned for each article are noted. The abbreviations used are:

BB - Breadboard or equivalent
EM - Engineering model or equivalent
Q - Qualification test unit
P - Prototype spacecraft unit or units
F - Flight and spare units

Table 3-1. Thermal Control Subsystem, Activity Matrix

THERMAL CONTROL	NO. PER SPACECRAFT	DESIGN: DESIGN DEVIATIONS	DESIGN: DESIGN STATUS	DESIGN: SPECIFICATIONS EXIST?	DESIGN: DRAWINGS EXIST?	DESIGN: HOW IS DESIGN ADAPTED TO SEMMS?	MANUFACTURING: PROCUREMENT	MANUFACTURING: PLANNING	MANUFACTURING: PROCESSES	MANUFACTURING: TOOLING	MANUFACTURING: TEST FIXTURES	MANUFACTURING: TEST SET	GROUND & FLIGHT TEST ARTICLES	NUMBER REQUIRED	TESTING: DEVELOPMENT TESTING: MODULE OR COMPONENT	TESTING: DEVELOPMENT TESTING: UNIT OR ASSEMBLY	TESTING: DEVELOPMENT TESTING: SUBSYSTEM	TESTING: DEVELOPMENT TESTING: SPACECRAFT	TESTING: DEVELOPMENT TESTING: CRITICAL TEST REQUIREMENTS	TESTING: DESIGN VERIFICATION: COMPONENT	TESTING: DESIGN VERIFICATION: ASSEMBLY	TESTING: DESIGN VERIFICATION: SPACECRAFT	TESTING: QUALIF TESTING: UNIT	TESTING: QUALIF TESTING: ASSEMBLY	TESTING: QUALIF TESTING: SPACECRAFT	TESTING: ACCEPTANCE TESTING: COMPONENT	TESTING: ACCEPTANCE TESTING: UNIT	TESTING: ACCEPTANCE TESTING: ASSEMBLY	TESTING: ACCEPTANCE TESTING: SPACECRAFT
SUBSYSTEM LEVEL ACTIVITIES																													
Equipment/Propulsion Module Analysis		New	New	No	No																								
External Experiments Analysis		New	New	No	No		New →					Exists	Experi. Mods.	A/R		X								X					
Thermal Model Test		New	New	No	No		New →					Exits	S/C Therm. Mod.	1				X							X				X
UNIT LEVEL ACTIVITIES																													
Louvers 3 types	1 2 2	OGO	Modified	Update	Update	Limited	Adapt →						Q (typ. assy) Louver A Louver B Louver C	1 5 9 9				 1 2 2			X			1 2 2		1 1 1	2 4 4
Insulation	1 set	Pioneer F&G	Modified	New	New	New	New →						Thermal Mod Q P F	1 set 1 set 3 sets				X 						X 				X
Thermostatic Heaters (thermostatic action at low temperatures – new)	1 set	OGO	Modified	Update	Update	Modified	Long Lead						Therm. Mod Q P F	1 1 1 3				X 				X			X X X		X X X	X

Table 3-2. Structure Subsystem, Activity Matrix

		DESIGN					MANUFACTURING								TESTING															
															DEVELOPMENT TESTING					DESIGN VERIFICATION			QUALIF TESTING			ACCEPTANCE TESTING				
STRUCTURE	NO. PER SPACECRAFT	DESIGN DEVIATIONS	DESIGN STATUS	SPECIFICATIONS EXIST?	DRAWINGS EXIST?	HOW IS DESIGN ADAPTED TO SEMMS?	PROCUREMENT	PLANNING	PROCESSES	TOOLING	TEST FIXTURES	TEST SET	GROUND & FLIGHT TEST ARTICLES	NUMBER REQUIRED	MODULE OR COMPONENT	UNIT OR ASSEMBLY	SUBSYSTEM	SPACECRAFT	CRITICAL TEST REQUIREMENTS	COMPONENT	ASSEMBLY	SPACECRAFT	UNIT	ASSEMBLY	SPACECRAFT	COMPONENT	UNIT	ASSEMBLY	SPACECRAFT
SUBSYSTEM LEVEL ACTIVITIES																														
Assem. of Structure	1		New	No	No								Struct. Mod.	1							X								
													Q																
													P	1										X					
													F	2															X
UNIT LEVEL ACTIVITIES Panels - Beryllium face sheet over honeycomb filler.	2 set	New	New	No	No	New - full develop. effort	Relative long lead	New	Adapt	New	New		Components	1	X	X			Micrometeroid impact tests, machining, insert install.											
													Q																
													P											X				
													F																X
Solar Array - (Substrates, structure, deployment mechanism)	2 wings	GE Developed	Current Dev.	?	No	Size adaptation	No long lead	New	New	New	New		Strut. Mod.	1					Vibration shock deployment damping factor		X								
													Q																
													P											X				
													F																X
Appendages (including hinges and latches)	1 set	OGO, Pioneer	New	No	No	New - nominal dev. effort	No long lead	New	Adapt	New	New		Struc., Mod.	1 ea.					Deployment, damping, torque - theta		X								
													Q																
													P											X				
													F																X
Tank & Tank Support Structure (Including boron filament support struts)	1	New	Conv. tank & new support	No	No	New - full develop. in support structure	Relative long lead	New	Adapt	New	New		Struct. Mod.	1					Static & dynamic load, damping		X								
													Q																
													P											X				
													F																X
Antenna Structure	1	Pioneer F&G	Current	Adapt	Adapt	Size adaptation, 9' dia. Pioneer to 8' dia. SEMMS	No long lead	Adapt	Adapt	New	New		Struct. Mod.	1		X			Static load, deployment & damping		X								
													Q																
													P											X				
													F																X

Table 3-3. Communications Subsystem, Activity Matrix

COMMUNICATIONS	NO. PER SPACECRAFT	DESIGN: DESIGN DEVIATIONS	DESIGN: DESIGN STATUS	DESIGN: SPECIFICATIONS EXIST?	DESIGN: DRAWINGS EXIST?	DESIGN: HOW IS DESIGN ADAPTED TO SEMMS?	MANUFACTURING: PROCUREMENT	MANUFACTURING: PLANNING	MANUFACTURING: PROCESSES	MANUFACTURING: TOOLING	MANUFACTURING: TEST FIXTURES	MANUFACTURING: TEST SET	GROUND & FLIGHT TEST ARTICLES	NUMBER REQUIRED	TESTING: DEVELOPMENT TESTING: MODULE OR COMPONENT	TESTING: DEVELOPMENT TESTING: UNIT OR ASSEMBLY	TESTING: DEVELOPMENT TESTING: SUBSYSTEM	TESTING: DEVELOPMENT TESTING: SPACECRAFT	TESTING: DEVELOPMENT TESTING: CRITICAL TEST REQUIREMENTS	TESTING: DESIGN VERIFICATION: COMPONENT	TESTING: DESIGN VERIFICATION: ASSEMBLY	TESTING: DESIGN VERIFICATION: SPACECRAFT	TESTING: QUALIF TESTING: UNIT	TESTING: QUALIF TESTING: ASSEMBLY	TESTING: QUALIF TESTING: SPACECRAFT	TESTING: ACCEPTANCE TESTING: COMPONENT	TESTING: ACCEPTANCE TESTING: UNIT	TESTING: ACCEPTANCE TESTING: ASSEMBLY	TESTING: ACCEPTANCE TESTING: SPACECRAFT
SUBSYSTEM LEVEL ACTIVITIES		Similar to Mariner 1969	New	No	No								EM S/S				X	X	Performance at nominal drive levels - and over driven						X			X
UNIT LEVEL ACTIVITIES: TWT and Power Supply	2	Saturn SIV-B	Unmodified	Yes	Yes	No adaptation required	Off Shelf	← Buy Item →					BB																
													EM	1															
													Q	1										X					
													P	2				X							X			X	
													F	5													X		X
UNIT LEVEL ACTIVITIES: Receiver and Ranging Unit	2	Mariner 1969	Modified	Yes	Yes	Minor changes to improve reliability	Off Shelf	← Exists Same as on Mariner '69 →					BB																
													EM	1		X	X	X	No critical tests										
													Q	1										X					
													P	2											X			X	
													F	5													X		X
UNIT LEVEL ACTIVITIES: Exciter	2	Mariner 1969	Unmodified	Yes	Yes	No adaptation required	Off Shelf	← Exists Same as on Mariner '69 →					BB																
													EM	1				X											
													Q	1										X					
													P	2											X			X	
													F	5													X		X
UNIT LEVEL ACTIVITIES: RF Switch	1	Mariner 1969	Modified	No	No	Adapted to SEMMS Characteristics	Off Shelf Comp.	New	Std.	New	New		BB																
													EM	1		X	X	X	No critical tests										
													Q	1										X					
													P	1											X			X	
													F	5													X		X
Antenna Section Activities of Comm. Subsystem	f																		Radiation Pattern, Isolation, VSWR, Function and Gain on Simul. Spacecraft										
													EM S/S			X	X													
UNIT LEVEL ACTIVITIES: Low Gain Antenna	2	Conventional Design	New	No	No	Usual development, additional work due to large solar array	No long lead	No	Exist	New	New		BB																
													EM	1		X	X													
													Q	1										X					
													P	2											X			X	
													F	5													X		X
UNIT LEVEL ACTIVITIES: High Gain Antenna	1	Pioneer F&G	New	No	No	Conventional development similar to Pioneer F&G	No long lead	No	Exist	New	New		BB																
													EM	1		X	X													
													Q																
													P	1											X			X	
													F	3													X		X

Table 3-4. Propulsion Subsystem, Activity Matrix

PROPULSION	NO. PER SPACECRAFT	DESIGN: DESIGN DEVIATIONS	DESIGN: DESIGN STATUS	DESIGN: SPECIFICATIONS EXIST?	DESIGN: DRAWINGS EXIST?	DESIGN: HOW IS DESIGN ADAPTED TO SEMMS?	MANUFACTURING: PROCUREMENT	MANUFACTURING: PLANNING	MANUFACTURING: PROCESSES	MANUFACTURING: TOOLING	MANUFACTURING: TEST FIXTURES	MANUFACTURING: TEST SET	GROUND & FLIGHT TEST ARTICLES	NUMBER REQUIRED	TESTING: DEVELOPMENT TESTING: MODULE OR COMPONENT	UNIT OR ASSEMBLY	SUBSYSTEM	SPACECRAFT	CRITICAL TEST REQUIREMENTS	TESTING: DESIGN VERIFICATION: COMPONENT	ASSEMBLY	SPACECRAFT	TESTING: QUALIF TESTING: UNIT	ASSEMBLY	SPACECRAFT	TESTING: ACCEPTANCE TESTING: COMPONENT	UNIT	ASSEMBLY	SPACECRAFT
SUBSYSTEM LEVEL ACTIVITIES																			Subsystem Qual. Tests Using Proto S/C Units					X[5]					
UNIT LEVEL ACTIVITIES: Propellant Storage Tank	1	Current Design	Modification	Yes	No	Limited Effort	Off Shelf	Exists	Standard	Exists	Exists		EM	3					Cycle & Burst Life Test	X	X								
													Q	3	X	X	X						X	X					
													P	1(1)											X		X	X	
													F	2(2)													X	X	X
Fill Valve	1	Current Design	No Change	Yes	Yes	Limited Effort	Off Shelf	Exists	Standard	Exists	Exists		EM						Life Test										
													Q	2									X	X					
													P	1(1)											X		X	X	
													F	2(2)													X	X	X
Charging Valve	1	Current Design	No Change	Yes	Yes	Limited Effort	Off Shelf	Exists	Standard	Exists	Exists		EM	3			X		Life Test										
													Q	2									X	X					
													P	1(1)											X		X	X	
													F	2(2)													X	X	X
Shutoff Valve	1	Current Design	Modification	Yes	Yes	Limited Effort	Off Shelf	Exists	Standard	Exists	Exists		EM	3	X	X	X		Life Test	X	X								
													Q	2									X	X					
													P	1(1)											X		X	X	
													F	2(2)													X	X	X
Thruster Assembly	3	Scale Existing Designs in Power and ISP	New	No	No	New Design, Full Development Effort	Problems	New	Standard	New	New		BB	2					Life Test										
													EM	3	X	X	X			X										
													Q	6									X	X					
													P	3(1)											X		X	X	
													F	6(2)													X	X	X
Feed System	1	Current Design	Modification	No	No	Updated Design Effort	Long Lead	New	Standard	New	New	New	BB	5	X	X			Life Test										
													EM	3	X	X	X			X	X									
													Q	6									X	X					
													P	1(1)											X		X	X	
													F	2(2)													X	X	X
Power Conditioner	3	Update Current Design	Modification	No	No	Updated Standard	No Detail	New	Standard	New	New	New	BB	2	X	X			Life Test										
													EM	1	X	X	X			X	X									
													Q	6									X	X					
													P	2(1)											X		X	X	
													F	4(2)													X	X	X

Table 3-4. Propulsion Subsystem, Activity Matrix (Continued)

	PROPULSION (Continued)	NO. PER SPACECRAFT	DESIGN: DESIGN DEVIATIONS	DESIGN: DESIGN STATUS	DESIGN: SPECIFICATIONS EXIST?	DESIGN: DRAWINGS EXIST?	DESIGN: HOW IS DESIGN ADAPTED TO SEMMS?	MANUFACTURING: PROCUREMENT	MANUFACTURING: PLANNING	MANUFACTURING: PROCESSES	MANUFACTURING: TOOLING	MANUFACTURING: TEST FIXTURES	MANUFACTURING: TEST SET	GROUND & FLIGHT TEST ARTICLES	NUMBER REQUIRED	TESTING: DEVELOPMENT TESTING: MODULE OR COMPONENT	TESTING: DEVELOPMENT TESTING: UNIT OR ASSEMBLY	TESTING: DEVELOPMENT TESTING: SUBSYSTEM	TESTING: DEVELOPMENT TESTING: SPACECRAFT	TESTING: DEVELOPMENT TESTING: CRITICAL TEST REQUIREMENTS	TESTING: DESIGN VERIFICATION: COMPONENT	TESTING: DESIGN VERIFICATION: ASSEMBLY	TESTING: DESIGN VERIFICATION: SPACECRAFT	TESTING: QUALIF TESTING: UNIT	TESTING: QUALIF TESTING: ASSEMBLY	TESTING: QUALIF TESTING: SPACECRAFT	TESTING: ACCEPTANCE TESTING: COMPONENT	TESTING: ACCEPTANCE TESTING: UNIT	TESTING: ACCEPTANCE TESTING: ASSEMBLY	TESTING: ACCEPTANCE TESTING: SPACECRAFT
	SUBSYSTEM LEVEL ACTIVITIES																			Subsystem Qual. Tests Using Proto S/C Units					X					
UNIT LEVEL ACTIVITIES	Switch Gear	3	New	New	No	No	New Design, Full Development Effort	↑	New	Standard	New	New	New	BB	3	X	X				X	X								
														EM	6	X	X		X	Life Test	X	X								
														Q	2									X	X					
														P	1(1)										X	X		X	X	
														F	2(2)													X	X	X
	Single Axis Gimbal	3	Current Design	Modification	No	No	Modified Design, Limited Effort Required	Long Lead Problems	New	Standard	New	New	New	BB	2	X														
														EM	3	X	X				X	X								
														Q	2									X						
														P	3(1)										X	X	X	X	X	
														F	6(2)													X	X	X
	Translator Actuator	1	Current Design	Modification	No	No	Modified Design, Limited Effort Required		New	Standard	New	New	New	BB	2	X														
														EM	2	X	X				X	X								
														Q	2									X						
														P	1(1)										X	X		X	X	
														F	2(2)													X	X	X
	Translator Platform and Drive Assembly	1	New	New	No	No	Full Design Effort	No Detail	New	Standard	New	New		BB	3	X														
														EM	2	X	X				X	X								
														Q	-									X						
														P	1										X	X	X			
														F	2(2)														X	X

Table 3-5. Data Handling Subsystem, Activity Matrix

	DATA HANDLING	NO. PER SPACECRAFT	DESIGN: DESIGN DEVIATIONS	DESIGN: DESIGN STATUS	DESIGN: SPECIFICATIONS EXIST?	DESIGN: DRAWINGS EXIST?	DESIGN: HOW IS DESIGN ADAPTED TO EMMS?	MANUFACTURING: PROCUREMENT	MANUFACTURING: PLANNING	MANUFACTURING: PROCESSES	MANUFACTURING: TOOLING	MANUFACTURING: TEST FIXTURES	MANUFACTURING: TEST SET	TESTING: GROUND & FLIGHT TEST ARTICLES	TESTING: NUMBER REQUIRED	TESTING: DEVELOPMENT TESTING: MODULE OR COMPONENT	TESTING: DEVELOPMENT TESTING: UNIT OR ASSEMBLY	TESTING: DEVELOPMENT TESTING: SUBSYSTEM	TESTING: DEVELOPMENT TESTING: SPACECRAFT	TESTING: DEVELOPMENT TESTING: CRITICAL TEST REQUIREMENTS	TESTING: DESIGN VERIFICATION: COMPONENT	TESTING: DESIGN VERIFICATION: ASSEMBLY	TESTING: DESIGN VERIFICATION: SPACECRAFT	TESTING: QUALIF TESTING: UNIT	TESTING: QUALIF TESTING: ASSEMBLY	TESTING: QUALIF TESTING: SPACECRAFT	TESTING: ACCEPTANCE TESTING: COMPONENT	TESTING: ACCEPTANCE TESTING: UNIT	TESTING: ACCEPTANCE TESTING: ASSEMBLY	TESTING: ACCEPTANCE TESTING: SPACECRAFT
	SUBSYSTEM LEVEL ACTIVITIES			New	No	No													X	Performance Power, Input Sens, Gain, Losses, Distortion, Stability, etc.										
UNIT LEVEL ACTIVITIES	Core Storage Unit	1	OGO/Vela	Unmodified	Yes	Yes	None Required	No Long Lead	Existing	Existing	Existing	Existing	Existing	BB																
														EM	1				X	No Critical Tests										
														Q	1									X						
														P	1											X				
														F	3													X		X
	Tape Recorder	2	Conventional (New Longevity)	New	New	New	New	No Long Lead	New	New	New	New	New	BB	1	X	X			See New Technology Sheet										
														EM	1	X	X		X											
														Q	1									X						
														P	2											X				
														F	5													X		X
	PCM Encoder	2	Standard Design Only Larger Capacity	New	New	New	New	No Long Lead	New	New	New	New	New	BB																
														EM						No Critical Tests										
														Q																
														P																
														F																
	Command Unit (Detector and Decoder)	2	Mariner 1969	Unmodified	Yes	Yes	None Required	No Long Lead	← Exists Same as Mariner 1969 →					BB																
														EM	1	X	X		X	No Critical Tests										
														Q	1									X						
														P	2											X				
														F	5													X		X
	Central Computer and Sequencer	1	Mariner 1969	Update	Yes	No	Adapted to EMMS Requirements	No Long Lead	New	Standard	New		New	BB																
														EM	1	X	X		X	No Critical Tests										
														Q	1									X						
														P	1											X				
														F	3													X		X

Table 3-6. Electrical Integration Subsystem, Activity Matrix

ELECTRICAL INTEGRATION	NO. PER SPACECRAFT	DESIGN: DESIGN DEVIATIONS	DESIGN: DESIGN STATUS	DESIGN: SPECIFICATIONS EXIST?	DESIGN: DRAWINGS EXIST?	DESIGN: HOW IS DESIGN ADAPTED TO SEMMS?	MANUFACTURING: PROCUREMENT	MANUFACTURING: PLANNING	MANUFACTURING: PROCESSES	MANUFACTURING: TOOLING	MANUFACTURING: TEST FIXTURES	MANUFACTURING: TEST SET	MANUFACTURING: GROUND & FLIGHT TEST ARTICLES	MANUFACTURING: NUMBER REQUIRED	DEVELOPMENT TESTING: MODULE OR COMPONENT	DEVELOPMENT TESTING: UNIT OR ASSEMBLY	DEVELOPMENT TESTING: SUBSYSTEM	DEVELOPMENT TESTING: SPACECRAFT	DEVELOPMENT TESTING: CRITICAL TEST REQUIREMENTS	DESIGN VERIFICATION: COMPONENT	DESIGN VERIFICATION: ASSEMBLY	DESIGN VERIFICATION: SPACECRAFT	QUALIF TESTING: UNIT	QUALIF TESTING: ASSEMBLY	QUALIF TESTING: SPACECRAFT	ACCEPTANCE TESTING: COMPONENT	ACCEPTANCE TESTING: UNIT	ACCEPTANCE TESTING: ASSEMBLY	ACCEPTANCE TESTING: SPACECRAFT
SUBSYSTEM LEVEL ACTIVITIES			New	No	No													X	Check Out Using EM Spacecraft										
UNIT LEVEL ACTIVITIES: Command Distribution Unit	1	Prog. 777 and 169	Modified	Update	Update & New	Conventional Design, Larger Capacity - More Dense	No Long Lead	Adapt	Exists	Adapt Existing	Adapt	Adapt	BB						No Critical Tests										
													EM	1			X	X											
													Q	1									X						
													P	1											X		X		
													F	3													X		X
Spacecraft Harness	1 set	Conventional Design	New	New	New	New	No Long Lead	New	Exists	Exists	New	Exists	BB						No Critical Tests										
													EM	1			X	X											
													Q																
													P	1											X				
													F	2															X
													BB or Equiv																
													EM or Equiv																
													Flight Conf																
													BB or Equiv																
													EM or Equiv																
													Flight Conf																

Table 3-7. Electric Power Subsystem, Activity Matrix

ELECTRIC POWER	NO. PER SPACECRAFT	DESIGN: DESIGN DEVIATIONS	DESIGN: DESIGN STATUS	DESIGN: SPECIFICATIONS EXIST?	DESIGN: DRAWINGS EXIST?	DESIGN: HOW IS DESIGN ADAPTED TO SEMMS?	MANUFACTURING: PROCUREMENT	MANUFACTURING: PLANNING	MANUFACTURING: PROCESSES	MANUFACTURING: TOOLING	MANUFACTURING: TEST FIXTURES	MANUFACTURING: TEST SET	TESTING: GROUND & FLIGHT TEST ARTICLES	TESTING: NUMBER REQUIRED	TESTING: DEVELOPMENT TESTING: MODULE OR COMPONENT	TESTING: DEVELOPMENT TESTING: UNIT OR ASSEMBLY	TESTING: DEVELOPMENT TESTING: SUBSYSTEM	TESTING: DEVELOPMENT TESTING: SPACECRAFT	TESTING: DEVELOPMENT TESTING: CRITICAL TEST REQUIREMENTS	TESTING: DESIGN VERIFICATION: COMPONENT	TESTING: DESIGN VERIFICATION: ASSEMBLY	TESTING: DESIGN VERIFICATION: SPACECRAFT	TESTING: QUALIF TESTING: UNIT	TESTING: QUALIF TESTING: ASSEMBLY	TESTING: QUALIF TESTING: SPACECRAFT	TESTING: ACCEPTANCE TESTING: COMPONENT	TESTING: ACCEPTANCE TESTING: UNIT	TESTING: ACCEPTANCE TESTING: ASSEMBLY	TESTING: ACCEPTANCE TESTING: SPACECRAFT
SUBSYSTEM LEVEL ACTIVITIES																						X							
UNIT LEVEL ACTIVITIES																													
Solar Array Panel (2 Panels = 1 Wing, two wings per s/c	4 Panels	GE Rollup	Modified	New	New	Modified Design, Nominal Analysis and Design Effort	Long Lead	N/A	N/A	N/A	New	New	BB																
													EM	1	X	X	X	X	Acoustic, Vibration, Thermal Deployment									
													Q	1										X	X				
													P	1										X			X	X	
													F	8													X	X	
Battery and Charger	1	Mariner Mars '69	No Change	Update	Update	Updated Limited Effort	Off Shelf	N/A	N/A	N/A	New	New	BB																
													EM	20			X	X	Elec. Capacity, Thermal Vibration, Life Test	X	X							
													Q	1										X					
													P	1											X		X		
													F	3													X		X
2.4 kHz Inverter	1	Mariner Mars '69	No Change	As Is	As is	No Additional Effort	Off Shelf	New	Existing	New	New	New	BB																
													EM	1		X		A	Thermal, Electrical Performance									
													Q	1										X					
													P	1											X		X		
													F	3													X		X
Bulk Boost Regulator	1	New (Like Project 777)	New	New	New	Full Analysis and Design Effort	New	New	New	New	New	New	BB	1	X	X			Vibration, Thermal, Electrical Performance									
													EM	2		X	X	X		X	X								
													Q	1										X					
													P	1											X		X		
													F	3													X		X
2ϕ 1.2 kHz Inverter	1	New	New	New	New	Full Analysis and Design Effort	No Long Lead	New	New	New	New	New	BB	1	X	X			Thermal, Vibration, & Electrical Function									
													EM	1		X	X	X		X	X								
													Q	1										X					
													P	1											X		X		
													F	3													X		X
Power Source Logic	1	Pioneer F&G	New	New	New	Full Analysis and Design Effort	No Long Lead	New	New	New	New	New	BB	1	X	X			Thermal, Vibration & Electrical Function									
													EM	2		X	X	X		X	X								
													Q	1										X					
													P	1											X		X		
													F	3													X		X

Table 3-8. Attitude Control Subsystem, Activity Matrix

ATTITUDE CONTROL (Continued)	NO. PER SPACECRAFT	DESIGN: DESIGN DEVIATIONS	DESIGN: DESIGN STATUS	DESIGN: SPECIFICATIONS EXIST?	DESIGN: DRAWINGS EXIST?	DESIGN: HOW IS DESIGN ADAPTED TO SEMMS?	MANUFACTURING: PROCUREMENT	MANUFACTURING: PLANNING	MANUFACTURING: PROCESSES	MANUFACTURING: TOOLING	MANUFACTURING: TEST FIXTURES	MANUFACTURING: TEST SET	GROUND & FLIGHT TEST ARTICLES	NUMBER REQUIRED	TESTING: DEVELOPMENT TESTING: MODULE OR COMPONENT	TESTING: DEVELOPMENT TESTING: UNIT OR ASSEMBLY	TESTING: DEVELOPMENT TESTING: SUBSYSTEM	TESTING: DEVELOPMENT TESTING: SPACECRAFT	TESTING: DEVELOPMENT TESTING: CRITICAL TEST REQUIREMENTS	TESTING: DESIGN VERIFICATION: COMPONENT	TESTING: DESIGN VERIFICATION: ASSEMBLY	TESTING: DESIGN VERIFICATION: SPACECRAFT	TESTING: QUALIF TESTING: UNIT	TESTING: QUALIF TESTING: ASSEMBLY	TESTING: QUALIF TESTING: SPACECRAFT	TESTING: ACCEPTANCE TESTING: COMPONENT	TESTING: ACCEPTANCE TESTING: UNIT	TESTING: ACCEPTANCE TESTING: ASSEMBLY	TESTING: ACCEPTANCE TESTING: SPACECRAFT
SUBSYSTEM LEVEL ACTIVITIES																													
Pneumatics Section Level Activities													EM						Assemble EM Units for Assy. Dev. Tests. Use Proto S/C Units for Ass. Quad. Tests		X								
UNIT LEVEL ACTIVITIES																													
Nitrogen Tanks	2	All Current Projects	No Change	Yes	Yes		Procure as on Existing Projects						BB																
													EM	1		X	X												
													Q	1										X					
													P	2												X	X		X
													F	5													X		X
Regulators and Relief Valves	2	All Current Projects	No Changes	Yes	Yes		Procure as on Existing Projects						BB																
													EM	1		X	X												
													Q	1										X					
													P	2												X	X		X
													F	5													X		X
Solenoid Valves	12	All Current Projects	No Changes	Yes	Yes		Procure as on Existing Projects						BB																
													EM	8		X	X												
													Q	1										X					
													P	12												X	X		X
													F	27													X		X
Lines and Fittings	1 set	All Current Projects	New	No	No		No Long Lead	New	Exists	New	New	New	BB																
													EM	1	X	X	X												
													Q																
													P	1												X	X		X
													F	4													X		X
Fill Valves	2	All Current Projects	No Change	Yes	Yes		Procure as on Existing Projects						BB																
													EM	1		X	X												
													Q	1										X					
													P	2												X	X		X
													F	5													X		X
High Pressure Transducer	2	All Current Projects	No Change	Yes	Yes		Procure as on Existing Projects						BB																
													EM	1		X	X												
													Q	1										X					
													P	2												X	X		X
													F	5													X		X
Temperature Transducers	2	All Current Projects	No Change	Yes	Yes		Procure as on Existing Projects						BB																
													EM	1		X	X												
													Q	1										X					
													P	2												X	X		X
													F	5													X		X
Nozzles	12	VELA	New Develop-ment	No	No	Modified to Include Rapid Heating	No Long Lead	New	New	New	New	New	BB																
													EM	16	X	X	X												
													Q	1										X					
													P	12												X	X		X
													F	27													X		X

Table 3-8. Attitude Control Subsystem, Activity Matrix (Continued)

ATTITUDE CONTROL	NO. PER SPACECRAFT	DESIGN: DESIGN DEVIATIONS	DESIGN: DESIGN STATUS	DESIGN: SPECIFICATIONS EXIST?	DESIGN: DRAWINGS EXIST?	DESIGN: HOW IS DESIGN ADAPTED TO SEMMS?	MANUFACTURING: PROCUREMENT	MANUFACTURING: PLANNING	MANUFACTURING: PROCESSES	MANUFACTURING: TOOLING	MANUFACTURING: TEST FIXTURES	MANUFACTURING: TEST SET	GROUND & FLIGHT TEST ARTICLES	NUMBER REQUIRED	TESTING: DEVELOPMENT TESTING: MODULE OR COMPONENT	TESTING: DEVELOPMENT TESTING: UNIT OR ASSEMBLY	TESTING: DEVELOPMENT TESTING: SUBSYSTEM	TESTING: DEVELOPMENT TESTING: SPACECRAFT	TESTING: DEVELOPMENT TESTING: CRITICAL TEST REQUIREMENTS	TESTING: DESIGN VERIFICATION: COMPONENT	TESTING: DESIGN VERIFICATION: ASSEMBLY	TESTING: DESIGN VERIFICATION: SPACECRAFT	TESTING: QUALIF TESTING: UNIT	TESTING: QUALIF TESTING: ASSEMBLY	TESTING: QUALIF TESTING: SPACECRAFT	TESTING: ACCEPTANCE TESTING: COMPONENT	TESTING: ACCEPTANCE TESTING: UNIT	TESTING: ACCEPTANCE TESTING: ASSEMBLY	TESTING: ACCEPTANCE TESTING: SPACECRAFT
SUBSYSTEM LEVEL ACTIVITIES																	X	X	Combined Test With Propulsion Subsystem									
Electronics Section Level Activities																													
UNIT LEVEL ACTIVITIES																													
Star Tracker	1	Mariner '69	No Change	Yes	Yes	No Additional Effort	No Long Lead	← Existing Same as for Mariner '69 →					BB																
													EM	1		X	X	X											
													Q	1									X						
													P	1										X			X		
													F	3													X		X
Star Tracker Gimbal Drive	1	Project 777	Current Development	No	No	Modify From Single Axis to Double Axis	No Long Lead	New	Exists	New	New	New	BB																
													EM	1		X	X	X											
													Q	1									X						
													P	1										X			X		
													F	3													X		X
Star Tracker Gimbal Drive Electronics	1	Standard Technology	New	No	No	Conventional Concept New Module Design	No Long Lead	New	Exists	New	New	New	BB	1	X	X													
													EM	1		X	X	X											
													Q	1									X						
													P	1										X			X		
													F	3													X		X
Sun Sensor Assembly (Course & Fine)	1	Standard Technology	New	No	No	New Design Normal Effort	No Long Lead	New	New	New	New	New	BB	1	X	X													
													EM	1		X	X	X											
													Q	1									X						
													P	1										X			X		
													F	3													X		X
Rate Gyro Assembly	1	Project 949	Current Development	No	No	Minor Modificarion (DC to AC)	No Long Lead	Exists	Exists	Exists	Exists	New	BB																
													EM	1		X	X	X											
													Q	1									X						
													P	1										X			X		
													F	3													X		X
Control Electronics Assembly	1	Project 169	Current Development	No	No	Minor Modification	No Long Lead	Exists	Exists	Exists	Exists	Exists	BB																
													EM	1		X	X	X											
													Q	1									X						
													P	1										X			X		
													F	3													X		X
Bi-Axial Antenna Drive	1	Project 777	Current Development	No	No	Minor Mods. to Reduce Number of Active Sections	No Long Lead	Exists	Exists	Exists	Exists	New	BB																
													EM	1		X	X	X											
													Q	1									X						
													P	1										X			X		
													F	3													X		X
Antenna Drive Electronics	1	Project 777	Current Development	No	No	Minor Modification	No Long Lead	Exists	Exists	Exists	Exists	New	BB																
													EM	1		X	X	X											
													Q	1									X						
													P	1										X			X		
													F	3													X		X

Table 3-8. Attitude Control Subsystem, Activity Matrix (Continued)

ATTITUDE CONTROL (Continued)	NO. PER SPACECRAFT	DESIGN: DESIGN DEVIATIONS	DESIGN: DESIGN STATUS	DESIGN: SPECIFICATIONS EXIST?	DESIGN: DRAWINGS EXIST?	DESIGN: HOW IS DESIGN ADAPTED TO SEMMAS?	MANUFACTURING: PROCUREMENT	MANUFACTURING: PLANNING	MANUFACTURING: PROCESSES	MANUFACTURING: TOOLING	MANUFACTURING: TEST FIXTURES	MANUFACTURING: TEST SET	GROUND & FLIGHT TEST ARTICLES	NUMBER REQUIRED	TESTING: DEVELOPMENT TESTING: MODULE OR COMPONENT	DEVELOPMENT TESTING: UNIT OR ASSEMBLY	DEVELOPMENT TESTING: SUBSYSTEM	DEVELOPMENT TESTING: SPACECRAFT	DEVELOPMENT TESTING: CRITICAL TEST REQUIREMENTS	DESIGN VERIFICATION: COMPONENT	DESIGN VERIFICATION: ASSEMBLY	DESIGN VERIFICATION: SPACECRAFT	QUALIF TESTING: UNIT	QUALIF TESTING: ASSEMBLY	QUALIF TESTING: SPACECRAFT	ACCEPTANCE TESTING: COMPONENT	ACCEPTANCE TESTING: UNIT	ACCEPTANCE TESTING: ASSEMBLY	ACCEPTANCE TESTING: SPACECRAFT
SUBSYSTEM LEVEL ACTIVITIES																													
UNIT LEVEL ACTIVITIES																													
Pressure Switches	12	All Current Projects	No Change	Yes	Yes		Procure as on Existing Projects						BB																
													EM	8	X	X	X						X						
													Q	1												X			
													P	32													X		X
													F	27													X		

Unit development tests begin with breadboard testing for circuit verification. Engineering models are used on SEMM spacecraft primarily for magnetic cleanliness testing and electromagnetic compatibility as well as for test set validation and performance testing.

The major subsystem development tests include the propulsion, structural, thermal, and a combined attitude control and propulsion module test. The propulsion tests include assembled engineering model testing, qualification test firing, and life testing. The structural tests include dynamic and static load tests, mass properties tests, appendage deployment verification, separation, launch vehicle compatibility and fit checks, and mechanical ground support handling and use verification. The thermal subsystem tests verify the thermal control design under thermal-vacuum conditions simulating the worst case conditions for the mission. The combined attitude control and propulsion system tests check the performance and dynamic response of the translator and single axis gimbal to control system operation.

Unit qualification and acceptance test are conventional for the electrical units. Qualification tests include shock, vibration, acoustics, thermal vacuum exposures with pre- and post-environment performance tests, EMC test, and magnetic properties test. Acceptance tests include vibration and thermal vacuum exposures with pre- and post-environmental performance tests and magnetic cleanliness tests. The qualification and acceptance test levels are based on the extremes of Atlas-Centaur and Titan IIIC environments.

3.4 SUPPORT EQUIPMENT DEVELOPMENT

The electrical ground support equipment planned for use on the SEMM spacecraft assembly, integration, and test consists of the consoles and racks listed in Table 3-9. Two of these system test sets are required for the baseline plan. The computer is assumed to be government furnished. Figure 3-1 shows the general arrangement at a spacecraft test station.

The mechanical ground support equipment planned is listed in Table 3-10. It is typical of such spacecraft as OGO and the project 949.

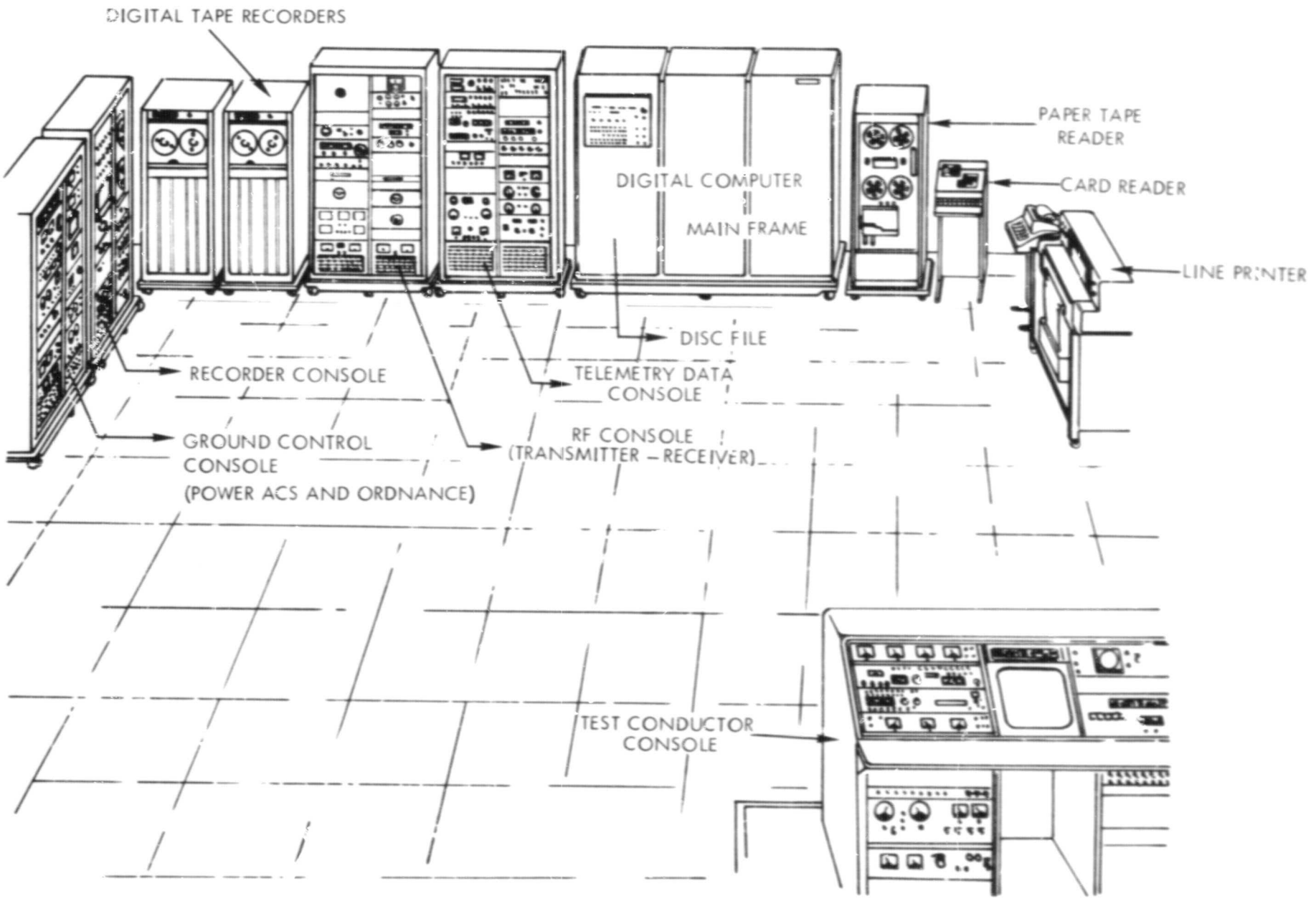


Figure 3-1. Spacecraft Test Station

Table 3-9. Electrical Ground Support Equipment

RF Console
- Narrowband receiver
- Low power transmitter (exciter)
- RF amplifier
- Ramp generator
- Command generator

Digital Computer
- Main frame
- Paper tape punch
- Card reader
- Disc file
- Typewriter
- Line printer

Recorder Console
- 7-track
- Mixed direct and FM
- Tape transport servo

Telemetry Data Console
- Demodulator synchromizer
- Computer buffer
- Word select
- Status display
- D-A converters
- Remote console driver/buffer

Test Conductor Console
- Remote display and callup
- Remote CRT

Ground Power Console
- Solar array simulator
- Spacecraft power supply

EGSE Peripheral
- Ordnance/ACS test
- ACS-simulator
- Engine simulator
- Hardline monitor
- Sensor stimulators
- Xenon array tester

Figure 3-2 shows application of some of the equipment during assembly and test operations. Note that the propulsion module and the equipment section can be treated as separate subassemblies allowing concurrent buildup and test. Two deployment test aids are shown. The antenna (parabola not shown for clarity) boom support is similar to that used on OGO where the torque for deployment is measured. The solar array deployment on a horizontal belt can incorporate the same deployment force measurement feature for deployment on both prototype and flight articles without removal from the spacecraft body.

Table 3-10. Mechanical Ground Support Equipment

- Work stand
- Rotation and vertical erection dolly
- Transporter (vertical)
- Solar array holding and installation fixture
- Solar array (micrometeoroid) deployment fixture
- Thruster assembly holding and installation fixture
- Thruster assembly alignment fixture
- High-gain antenna holding and installation fixture
- High-gain antenna alignment fixture
- Louver protective holder (three or four kinds)
- +X axis boom fixture
- Vibration test fixture
- Space simulation fixture
- Lifting slings
- Solar array storage containers
- Spacecraft shipping container
- Propellant loading/pressurization cart

3.5 SPACECRAFT DEVELOPMENT

The spacecraft development testing begins with the assembly of the engineering model spacecraft. The spacecraft assembled from units made available as subsystem engineering model test are complete, is an electrically complete spacecraft (less redundant units and solar array). It is used for initial system compatibility and performance tests and to verify the system test set prior to use on the prototype and flight spacecraft.

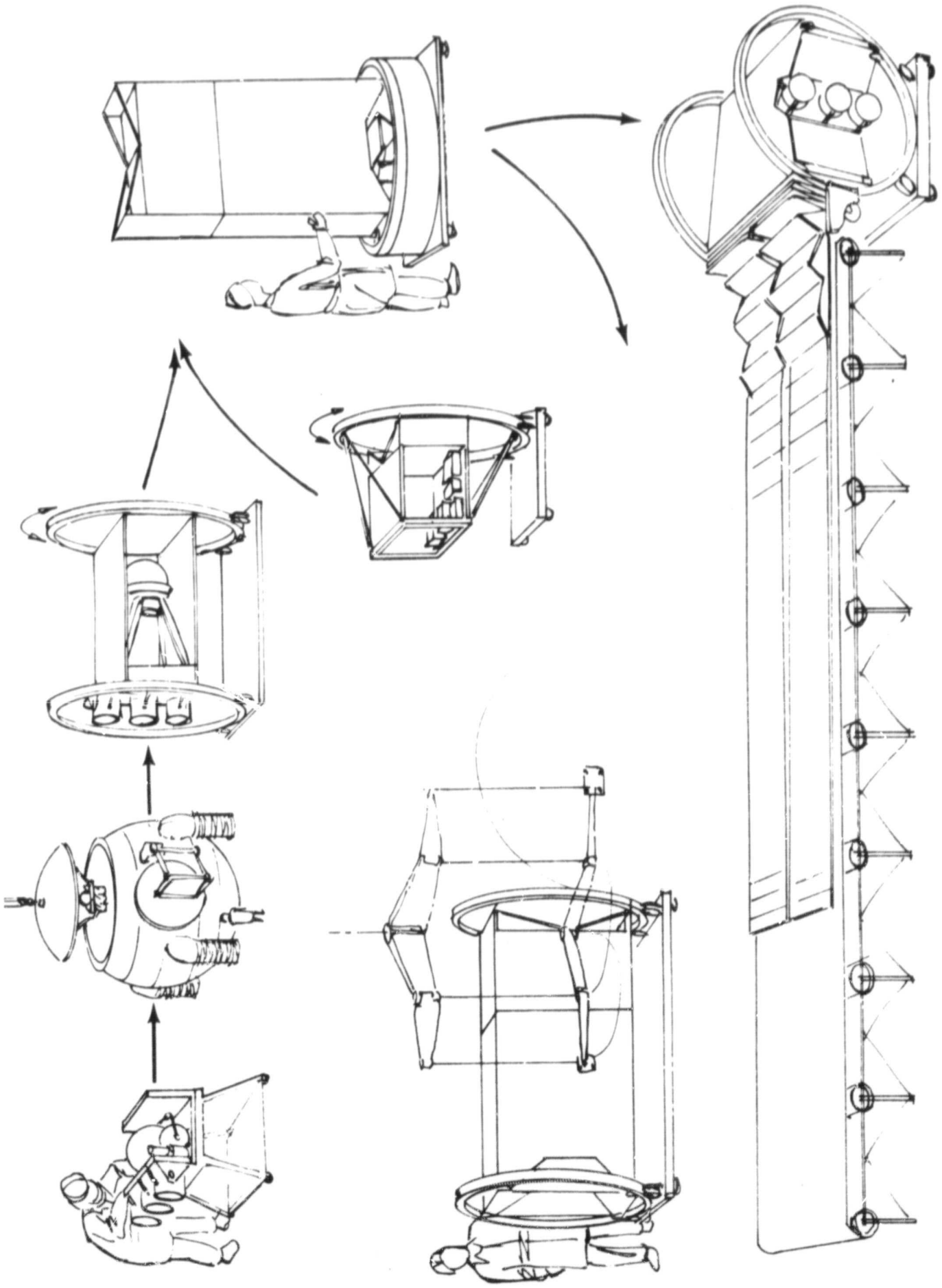


Figure 3-2. MGSE Application—Assembly and Test Operations

Testing of the engineering model spacecraft is supplanted by assembly and integration of the prototype spacecraft. The engineering model is retained as a support instrument for investigation of problems as they may arise during prototype spacecraft work. Assembly and integration operations are outlined for the SEMM spacecraft in Figure 3-3, and subsequent qualification and acceptance test operations are shown in Figure 3-4. The assembly of the electric propulsion system module is completed and a hot firing test in a vacuum chamber is made prior to installation on the spacecraft. All subsystems can be integrated and checked on the spacecraft prior to engine installation (less solar array). The remaining work includes integration of the experiments and system level tests. Of the system testing, most is conventional in nature and typical of current spacecraft designed for the SEMM spacecraft launch vehicles and for deep space exploration. Tables 3-11, 3-12, and 3-13 outline certain system compatibility tests considered typical for the SEMM spacecraft.

3.6 NEW TECHNOLOGY REQUIREMENTS

The new technology items listed previously in Table 2-3 fall into three categories: propulsion, solar array, and a long life tape recorder. The propulsion subsystem development is discussed in Section 8.2.9 of Volume IB.

The solar array development work, already underway by General Electric, is considered as a new technology item. Further work to prepare for the SEMM spacecraft application would include specific design of the modular elements, investigation of manufacturing processes, and integration and test operations. SEMM spacecraft interface definition is required to identify necessary thermal and dynamic testing of the modules. Using a full-scale mass and inertially similar model, deployment tests would be performed to check the design.

The requirement for a tape recorder to meet a 3-1/2 year mission life is considered critical. Further complexity is introduced by the need for two record and four playback speeds. The approach to a solution would include a study of methods of accomplishing multispeed operation with particular emphasis on reliability. The most likely solution would involve the use of two motors, one for record and one for playback.

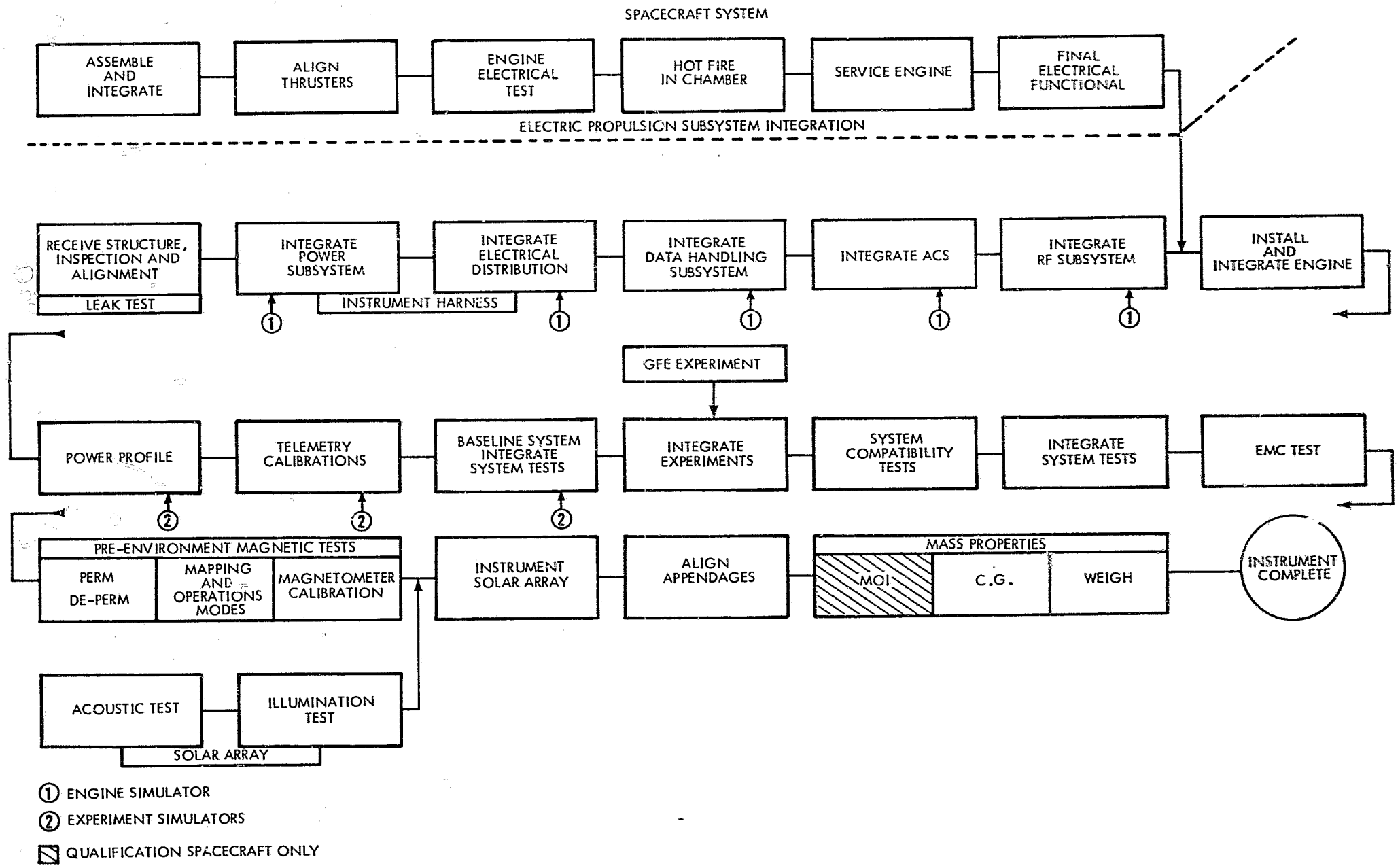


Figure 3-3. SEMM Spacecraft Assembly and Integration Flow

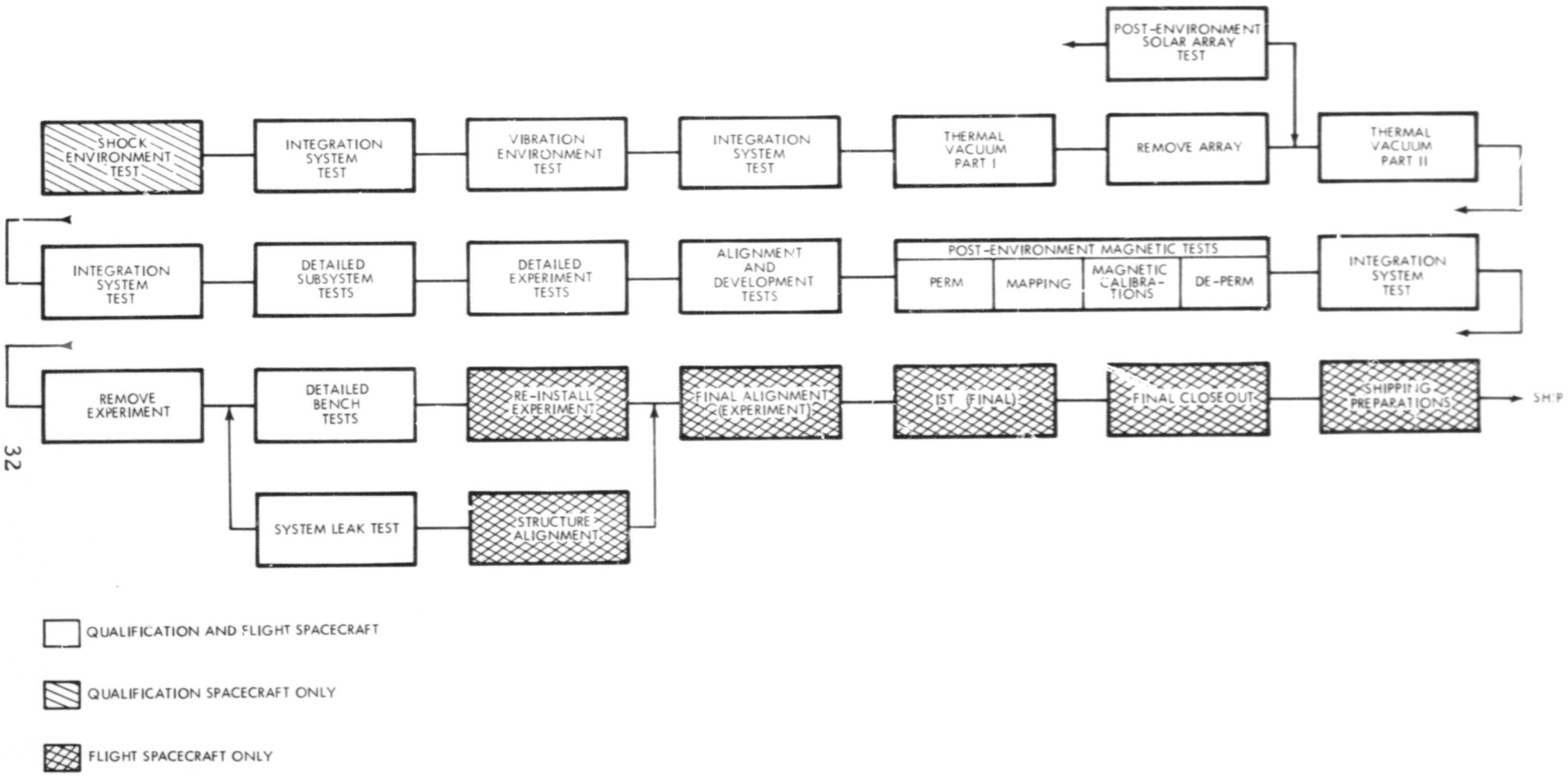


Figure 3-4. SEMM Spacecraft Environmental Qualification and Acceptance Test Flow

Table 3-11. System Compatibility: Magnetic Cleanliness

Design Considerations

Use of nonmagnetic material

Back wire array for self-cancellation of fields generated in array

Last three feet of array length near the magnetometer to include special compensating loop for absolute null at magnetometer

Electromagnetic thrusters arranged to buck out resultant magnetic fields

Tests Required

Magnetometer calibration done in small coils and spacecraft in earth field (similar to OGO)

As is/perm and deperm mapping tests

Stray fields operating modes test

Table 3-12. System Compatibility: (EMC) Electromagnetic Compatibility

Design Considerations

Provide separate shielding for power, grounding and telemetry lines

Provide adequate shielding for radiated noise

Avoid experiments having a susceptibility in 1 GHz range

Utilize isolation filters

Low common bonding impedance paths

EMC analysis for interference design criteria

Tests Required

Box level conducted and radiated EMC tests on engineering model units. Incorporate new design data (if applicable) and repeat in qualification boxes.

Engineering model tests on electric propulsion sybsystem to measure EMC signature

Spacecraft propulsion compatibility established with engine simulator

Experiment-to-experiment and experiment-to-spacecraft baseline compatibility established during spacecraft integration testing (engineering model tests plus prototype)

EMC signature

1) RF susceptibility
2) Audio susceptibility
3) Operating spacecraft modes performance evaluation

Note: Engine simulator generates conducted interference, design based on engine EMC signature.

Table 3-13. DSN Compatibility

Basic design of communications based on Mariner 69 (receiver and ranging unit-exciter)

Possible approaches for RF design compatibility demonstration

- After engineering model spacecraft tests take spacecraft to Goldstone (single channel)
- After engineering model spacecraft tests repackage into portable transponder—deliver to JPL (single channel)
- After unit qualification tests package into portable transponder—deliver to JPL (single channel)
- Develop spacecraft transponder simulator with flight-type hardware (not environmentally tested)—would include PCM encoder and command decoder—deliver to JPL

Software verification

- Use with item four above (depends on complexity of simulator)
- Magnetic tapes derived from actual spacecraft tests

Final compatibility verification with DSN

- Operational readiness training (ORT)
- Command and control verification with real time data processing—all up DSN

Considerable reliability and life testing would be necessary to verify the final design. A 12-month development period is estimated.

The cost of these development tasks are included in the cost estimate.

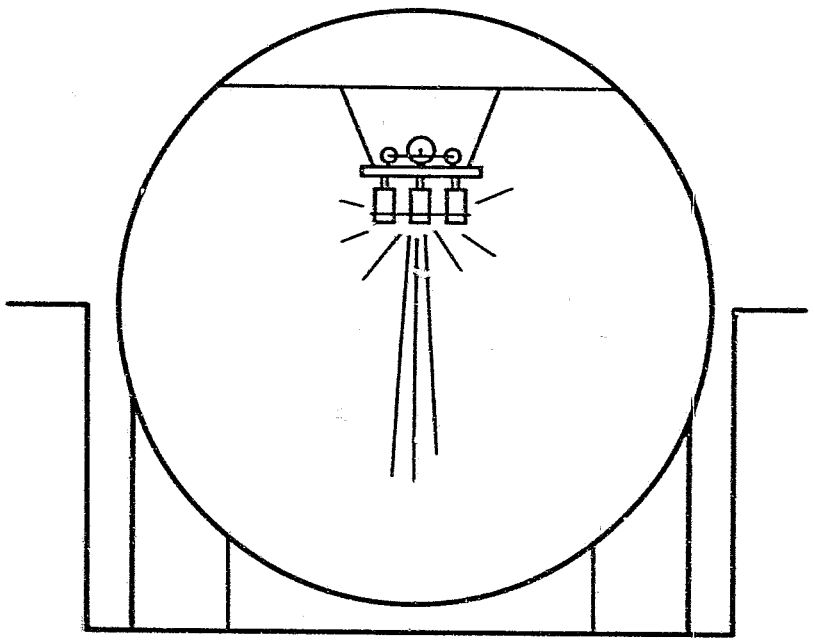
3.7 FACILITIES

The facilities required for fabrication, assembly, integration and test of the SEMM units, subsystems, and spacecraft are in existence. They are available at TRW Systems, Space Park site with the exception of the vacuum chamber for performance of the propulsion subsystem life test. Although the TRW 30-foot diameter sphere vacuum chamber is adequate in size, the long term use required for the life test suggests that a similar government-owned chamber might be suitably designated for the duration of test.

Unit fabrication can be accomplished in a manufacturing facility similar to that found at TRW (M5) where manufacturing and acceptance test can be completed in a single building. Mechanical spacecraft hardware and mechanical operational support equipment could be fabricated and assembled in the multishop and assembly bay building such as M3 at TRW.

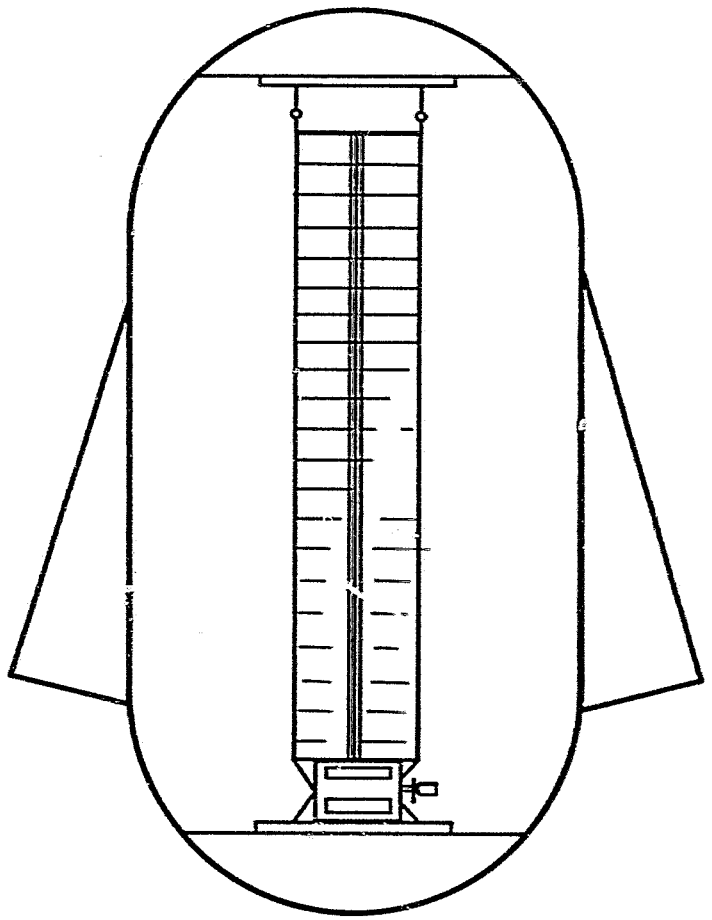
Solar array assembly and checkout, the experimentation laboratory, spacecraft assembly area, stores and support offices could be accommodated in a high bay (40-foot) building such as M-1. This building also provides facilities for electromagnetic testing and for combined acoustic and low frequency vibration testing at the system level.

The space simulation chamber for testing of the thermal model, the prototype spacecraft, and the flight spacecraft could be accommodated in building M-4. The 22-foot diameter by 46-foot high chamber can accommodate the spacecraft and one deployed solar array wing. Figure 3-5 shows propulsion subsystem testing and the spacecraft space simulation test configuration.



30 FT DIA SPHERE

PROPULSION SUBSYSTEM QUALIFICATION



22 FT DIA x 46 FT
CYLINDER

SPACECRAFT AND SOLAR ARRAY
QUALIFICATION AND ACCEPTANCE TEST

Figure 3-5. Facilities

4. PROGRAM COST

4.1 ESTIMATING METHOD

The approach used to prepare cost estimates for the SEMM spacecraft system combined TRW recorded cost experience and "performer" management judgement to assure up to date application of the historical cost data. "Performer" refers to the organization that would accept responsibility for the relevant work. Extensive use was made of the TRW cost data bank to develop comparisons between the SEMM spacecraft cost elements and those of projects recorded in the data bank. Particularly useful data came from projects that resemble the SEMM spacecraft such as OGO with its box structure and multiple appendages, and Pioneer F and G with missions similar to that of the SEMM spacecraft. DOD spacecraft experience was useful for up to date data at the unit level. The solar array estimate was derived from data supplied by General Electric Space Division. Direct estimates were made in some cases where the cost data bank data did not apply or where historical data did not exist.

The sequence of estimating and review is as follows. Each subsystem engineer involved in the design was required to complete "planning data sheets" (see Section 3.3). These contained such information as design status of current programs or new development, existing drawings and specifications, amount of development required for adaptation to the SEMM spacecraft, manufacturing information, and test required. Planning data sheets were prepared to the black box level for each subsystem.

The TRW pricing organization used these data and the technical description of each subsystem as references when extracting data from the data bank. Data was adjusted to the SEMM spacecraft by applying factors for complexity, quantity, and specific cost-sensitive characteristics.

For project level cost elements such as project management, system engineering, and product integrity, the SEMM spacecraft project was compared to projects similar to NASA. Care was taken to insure similarity of definition and content to analogous data.

For spacecraft assembly, integration, test, and launch support estimates by analogy included crew size and the period during which it would be active.

Electrical and mechanical ground support equipment costs were estimated by comparing the type and quantity of equipment specified for the SEMM spacecraft with data from current projects. This is particularly appropriate because of the intention to reapply existing government-owned equipment. Computers for the system test set are assumed to be furnished by the government.

All the data including vendor quotations were reviewed by the pricing organization for compliance with current ratios for TRW projects. A composite result was then prepared for further review with "performer" management and cost adjustments made. A final senior management review assured that the estimates were realistic.

4.2 PROGRAM COST DATA

The cost data shown in Table 4-1 represent the baseline plan and the alternative plan for refurbishment of the prototype spacecraft for flight use. The table shows costs for baseline plan flights of one and two spacecraft and for alternative plan flights of two and three spacecraft.

Each subsystem cost covers design, development, qualification, and manufacturing. Spacecraft integration and launch support costs include spacecraft engineering model development, prototype spacecraft integration and test, and flight spacecraft integration, test, and launch operations. Electrical GSE costs include design, development, test, and delivery of the system test sets. Mechanical GSE costs include design, development, test, and delivery of the equipment required for spacecraft handling, transportation and storage. Unit test costs include the cost of acceptance testing all units (black boxes). Product integrity includes reliability and quality assurance functions at the project level. Quality assurance and inspection at the subsystem level are included in each subsystem cost. Program management includes planning and control, system engineering, and science payload integration. Refurbishment of the prototype spacecraft includes repair and retest of prototype spacecraft hardware and launch operations for the prototype.

Table 4-1. SEMM Spacecraft Cost Summary

($ x 10^6)

	Baseline		Alternate (Refurbish and Fly Prototype Spacecraft)	
Quantity of Flight Spacecraft:	2	1	3	2
Structure subsystem	5.0	4.6	5.0	4.6
Thermal subsystem	1.5	1.2	1.5	1.2
Electrical power subsystem	9.0	6.6	11.2*	8.4*
Electrical distribution subsystem	2.0	1.8	2.0	2.0
Attitude control subsystem	8.0	7.5	8.0	7.5
Communication and data handling subsystem	10.4	9.2	10.4	9.2
Propulsion	6.9	6.5	6.9	6.5
Spacecraft integration/test/launch support	4.5	3.8	4.5	3.8
Electrical GSE (computers are GFE)	2.5	2.5	2.5	2.5
Mechanical GSE	1.3	1.0	1.3	1.0
Unit test (acceptance and qualification)	0.9	0.7	0.9	0.7
Subtotal	52.0	45.4	54.2	47.4
Product integrity	5.1	3.8	5.3	5.1
Program management	6.4	4.8	6.7	6.4
Refurbishment of prototype spacecraft	--	--	1.0	1.0
Total	63.5	54.0	67.2	59.9

*Cost includes addition of 1-1/2 wings to equip qualification unit to flight configuration.

5. PROGRAM COST REDUCTION

Alternate plans were created in an attempt to reduce the cost of the baseline plan. Methods considered were to modify the schedule, reduce the quantity of test hardware required, and relax customary requirements of quality assurance and management operations. Each was evaluated for its effectiveness.

The schedule expressed in the baseline plan is of high confidence. Time sensitive management and supervision costs can be reduced by increasing the overlap of some segments of work. Increasing the overlap of prototype and flight spacecraft work would have this effect but would require an additional system test set. Complete subsystem overlap already exists in the baseline plan so nonpacing subsystems can be managed in the most cost effective manner. Some reduction in schedule could be realized if integration of the engineering model spacecraft could start earlier; however, since it is assembled from subsystem engineering model units, additional units would be required, and the cost savings due to a shorter schedule would tend to be offset by the cost of these. Since the baseline schedule was derived from similar spacecraft schedules, it is near optimum from a cost and risk standpoint. Therefore, cost reduction by schedule modification was considered ineffective.

Reducing costs by cutting management operations and quality assurance requirements was discarded because only small benefits are possible.

Reducing test hardware requirements proved to be the most effective way to save money. Table 5-1 outlines the alternatives considered. The reused hardware is circled and arrows show order of use.

Each alternative carries with it some increased risk because the hardware may be degraded. The order of confidence in the various plans is shown in Table 5-1 with the baseline plan ranked first. The second and third plans are ranked ahead of the others because used hardware is not flown. The second ranks ahead because the spares for the flight article are unused. Little difference exists between the second and third plans because in either case used units will be incorporated in the prototype spacecraft and the best available spares will support the flight spacecraft. The fourth plan ranks ahead of the fifth because the latter has the least new hardware available.

Table 5-1. Alternative Plans

Sets of GSE	Set of Qual. Units	Set of Spares	Prototype Spacecraft	Flight Spacecraft			Order of Confidence
2	Q	S	P	F1	F2	F3	1st (Baseline)
1	Q	S	P	1	2	3	
2	Q	S	P	1	2	3	2nd
1	Q	S	P	1	2	3	
2	Q	S	P	1	2	3	3rd
1	Q	S	P	1	2	3	
2	Q	S	P	1	2	3	4th
1	Q	S	P	1	2	3	
2	Q	S	P	1	2	3	5th
1	Q	S	P	1	2	3	

Table 5-2 summarizes cost for each plan for quantities up to eight spacecraft. Data are given in both total cost and unit cost for each quantity. The order of confidence is the same as for the previous table.

Figure 5-1 shows the effect of quantity ordered on the unit cost per spacecraft. The baseline cost is shown by the length of the bars. The shaded areas indicate what can be saved by maximum reuse of hardware. Although the cost savings are significant, the effect of increasing the number of spacecraft ordered is much larger. Three baseline spacecraft orders cost approximately 54 percent apiece less than a single spacecraft order. With maximum reuse of hardware the saving is 60 percent.

The impressive cost savings from buying in quantity are especially relevant to the SEMM spacecraft. The multi-mission concept, permits growth and adaptation of a single design to changing science payload requirements. Therefore, it is possible to buy for three or four missions without necessitating new spacecraft development or requalification.

Figure 5-2 illustrates the use of SEMM for four initial missions. A baseline spacecraft can be used for the first two. Modifications needed for subsequent missions are shown. Qualification of the baseline design can be done for either or both of the launch vehicles considered. If a larger propellant tank is added for the out-of-ecliptic mission and additional thrusters are added, requalification can be done at the subsystem or assembly levels. Further growth could be handled in much the same way.

Table 5-2. Alternate Plans Cost Summary

Definition of Plan	Sets of GSE	Costs ($x10^6$)	Number of Spacecraft 1	2	3	4	5	6	7	8	Order of Confidence
Baseline	2	Total	54.0	63.5	77.5	89.5	99.5	109.5	119.5	129.5	
		Unit	54.0	31.8	25.8	22.4	19.9	18.3	17.1	16.2	1st
Baseline, longer schedule	1	Total	53.2	62.7	76.7	88.7	98.7	108.7	118.7	128.7	
		Unit	53.2	31.4	25.6	22.2	19.7	18.1	17.0	16.1	
Use qual, units for prototype	2	Total	Same as "use qual. units for spares" 2 sets GSE								
		Unit									2nd
Use qual, units for prototype longer schedule	1	Total	Same as "use qual. units for spares" 1 set GSE								
		Unit									
Use qual units for spares	2	Total	52.6	62.1	76.1	88.1	98.1	108.1	118.1	128.1	
		Unit	52.6	31.1	25.2	22.0	19.6	18.0	16.9	16.0	3rd
Use qual units for spares longer schedule	1	Total	51.8	61.3	75.3	87.3	97.3	107.3	117.3	127.3	
		Unit	51.8	30.7	25.3	21.8	19.5	17.9	16.8	15.9	
Refurbish Prototype Use for flight 2	2	Total	54.0	59.9	73.9	85.9	95.9	105.9	115.9	125.9	
		Unit	54.0	30.0	24.6	21.5	19.2	17.7	16.6	15.7	4th
Refurbish Prototype Use for flight 2 longer schedule	1	Total	53.2	59.1	73.1	85.1	95.1	105.1	115.1	125.1	
		Unit	53.2	29.6	24.4	21.3	19.0	17.5	16.4	15.6	
Use qual units for spares and proto.	2	Total	52.6	58.5	65.8	77.8	87.8	97.8	107.8	117.8	
		Unit	52.6	29.3	21.9	12.5	17.6	16.3	15.4	14.7	5th
Use qual units for spares and proto. longer schedule	1	Total	51.8	58.0	65.0	77.0	87.0	97.0	107.0	117.0	
		Unit	51.8	29.0	21.7	19.3	17.4	16.2	15.3	14.6	

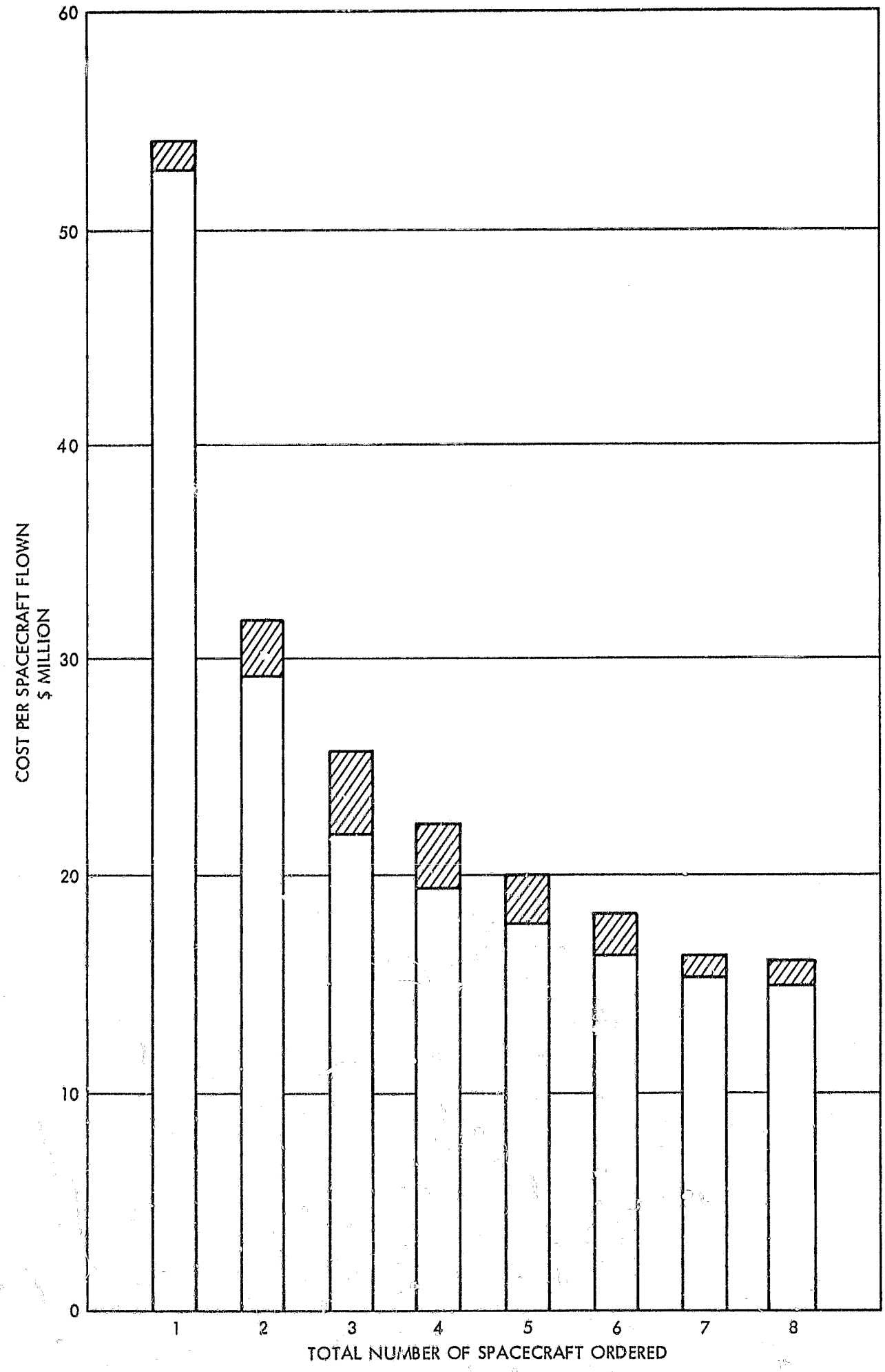


Figure 5-1. Cost Per Spacecraft Flown

MISSIONS	ATLAS BURNER	ATLAS CENTAUR	TITAN IIIC	REMARKS
3.5 AU				BASELINE
3.5 AU + FLYBY				
JUPITER				OFF LOAD MICROMETEOROID DETECTORS CHANGE ADAPTER TO BOOSTER CHANGE SHROUD
OUT-OF-ECLIPTIC				ADD THRUSTERS AND PCU'S LARGER PROPELLANT TANK

GROWTH

Figure 5-2. Mission Sequence