REPORT G975

OPTIMIZED COST/PERFORMANCE DESIGN METHODOLOGY

VOLUME II DATA REVIEW AND ANALYSIS
BOOK 2 - PROGRAM PLANS AND DATA

CONTRACT NAS 2-5022

MCDONNELL DOUGLAS CORPORATION

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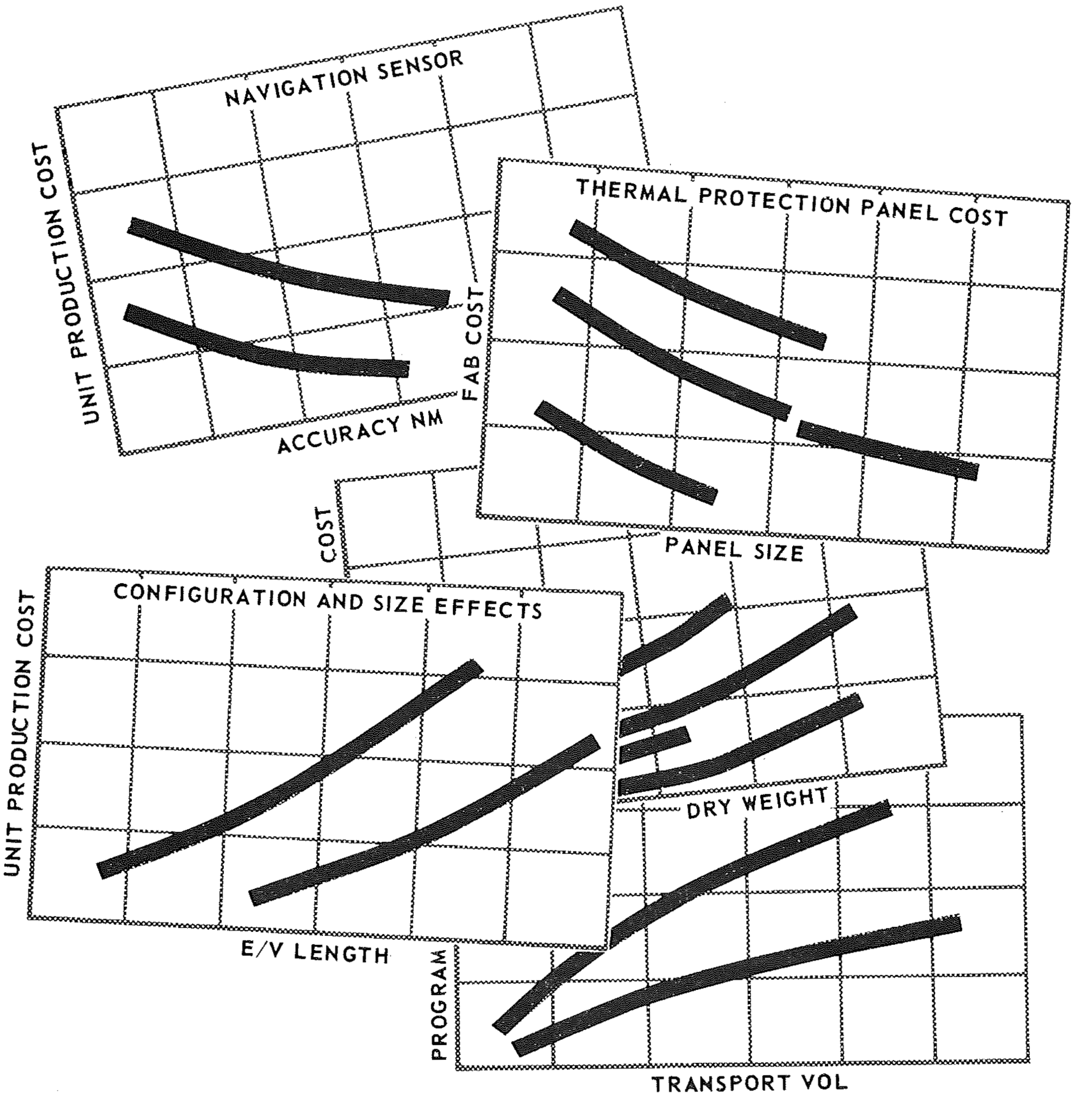

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FOREWORD

This report is submitted to NASA, the Mission Analysis Division of OART, as part of the final reporting on Contract NAS 2-5022, Optimized Cost/Performance Design Methodology of Orbital Transportation Systems. This twelve month study was initiated in July 1968 and was performed in two general phases: a data review and analysis phase and a system evaluation phase. The reporting of the study is organized in three volumes but includes several books in Volumes 2 and 3. Volume 1 is a short summary of the complete study, Volume 2 covers the phase 1 data review and analysis, and Volume 3 covers the phase 2 system evaluation. The Study Manager was L. M. McKay; the major Task Leaders were P. T. Gentle, V. E. Henderson, L. E. Smith, and A. D. Trautman. The NASA Technical Monitor was C. D. Havill.

ABSTRACT

The broad objectives of this study were to gather historical cost and performance data, organize and analyze the data so that cost estimating relationships could be developed, and evaluate several system concepts for space logistics support.

The primary source of historical cost data was the Gemini and Saturn Programs and cost estimating relationships draw extensively on this experience. A range of reuse concepts were evaluated and optimum (least cost) concepts defined for a variety of program options. These include variations in such things as crew size, cargo capacity, program requirements, etc. for either ballistic or lifting body (M2-F2) entry vehicles.

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1. INTRODUCTION - The purpose of the Optimized Cost/Performance Design Methodology study was to provide a method of using cost as a basic design parameter in identifying and defining more economical space transportation systems. This study was performed in six tasks as shown in Figure 1-1. Task 1 involved developing the cost data, organizing the data by categories, and developing cost estimating relationships. Tasks 2 and 3 developed the requirements and the physical and functional characteristics of the alternate spacecraft subsystems and operations. An analytical cost model was formulated in Task 4. Task 5 developed the logic, data, and methods for systematically varying the design and operational specifications of each vehicle configuration. Task 6 took all the data and tools developed in the other tasks and then determined the economically optimum design and operational philosophies, sensitivities to program size, launch rate, and payload size - the problem areas - and technology limitations.

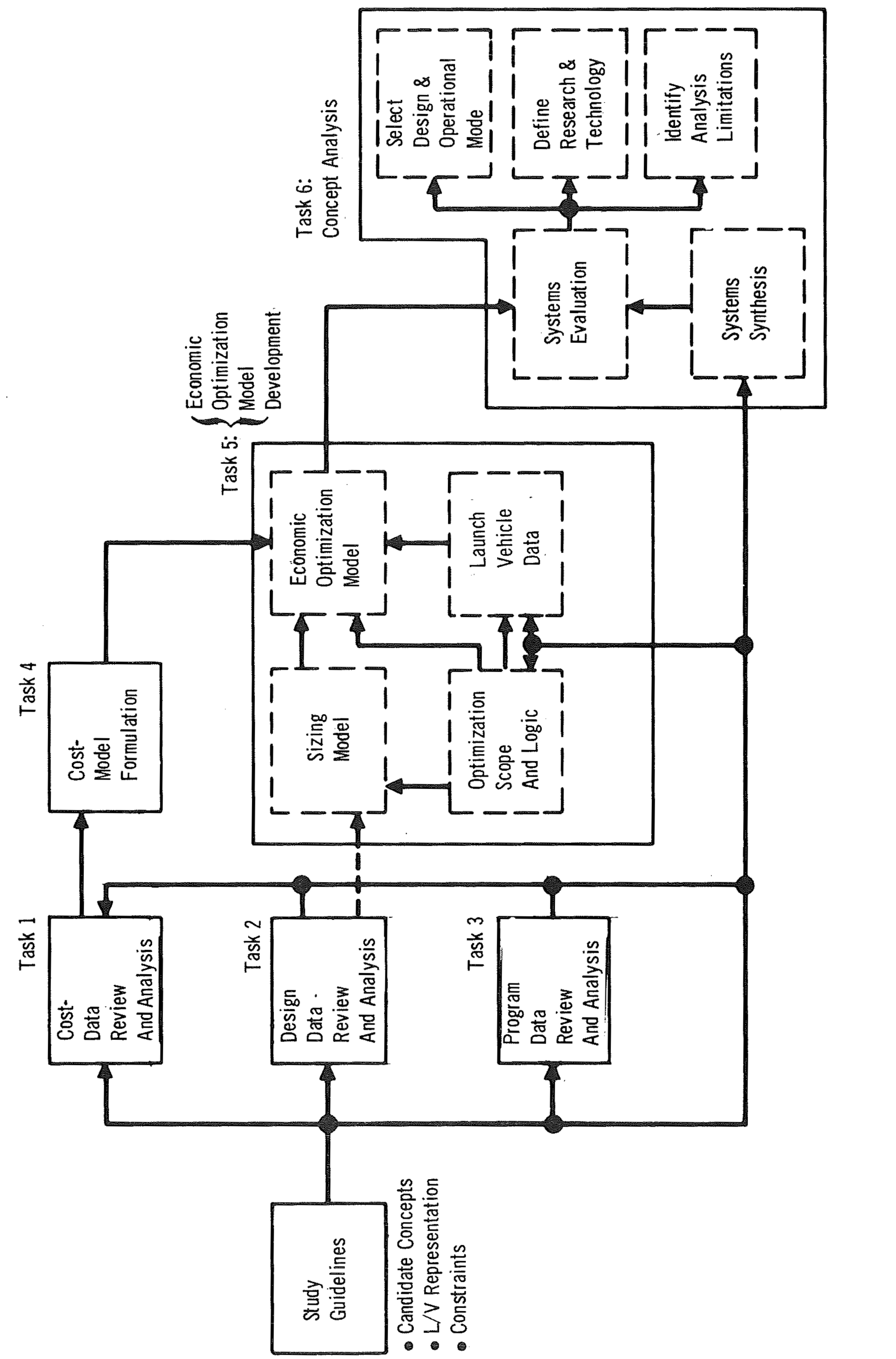
This book reports on the work accomplished in Task 3. The objectives of this task were to:

1. Define the development plans and schedules for the two spacecraft types, by subsystem and vehicle system as a function of the degree of reuseability, and the amount of integral propulsion.

2. Define the operational costs in manhours, dollars, or other resources for the operational activities from pre-launch through launch, on-orbit operations, deorbit, recovery, and recertification for each of the vehicles.

Figure 1-1

STUDY TASK FLOW



2. SUMMARY - This book documents the efforts and results of Task 3, Program Data Review Activities and Analysis. The two major subtasks were development plans and schedules (Section 4) and the operational effects upon costs (Section 5). In each category, a baseline value was determined for one particular configuration. The changes because of requirements of the other configurations were then documented as incremental increases or changes to the baseline values.

The Gemini and Saturn S-IVB programs were used as the historical background from which the baseline development plan and schedules were developed. However, each of these two programs had unique qualities which were considered in developing the baselines. For example, the initial concept of Gemini envisioned using a parawing gliding recovery system for land landing. The design evolved around this concept. The structure was designed for large lateral point-loads from a landing skid system; water recovery was an abort mode only.

However, development snags and delays in the parawing system forced a redesign to water landing with conventional ringsail parachutes for the terminal landing system.

The resulting changes in the schedule and the development plan made the time and hardware quantities greater than would have been required if the final concept had been the only one considered. Such effects were considered in arriving at a baseline value of 35 months for subsystem development and of 45 months for completion of a five-flight test program for a ballistic, modular, all-expendable vehicle (configuration IA).

A similar M2-F2 vehicle would require two months more for subsystem development. It would also require from eight to ten months longer for flight test program completion. Adding integral upper stage propulsion will increase hardware requirements and development time. The time increment for the integral propulsion is nine months for subsystem development for the ballistic vehicle and ten months for the M2-F2 vehicle. Completion of a five-flight test program for the vehicles would take 64 months or from 73 to 75 months, respectively.

Operational aspects considered were launch operations and support, mission operations, AGE and facilities maintenance, recovery site location and recovery costs, and recertification or refurbishment. The launch operations, launch

support, and mission operations activites were defined by manhours for each launch as a function of vehicle configuration and size, operations philosophy, and size of the total program (number of launches or learning). Recovery site analysis involved the statistical probability of return to specified locations.

Because recertification is controversial with no experience to serve as a basis for estimating, this analysis assumes a middle-of-the-road position (compared with previous studies) for both the manhours, material costs, and flow time for each configuration. The analysis considered size, configuration, and philosophy in determining equations for estimating the cost of each cycle and the selected learning rates. The initial baseline value is about four months; this is reduced to about two months at the fiftieth unit through the cycle.

Investigation of AGE and facilities was limited by the time and manpower available. Major effort was devoted to evaluating the effects of on-board checkout on equipment and facilities and upon testing time during launch operations and recertification.

As part of the analyses of Task 6, a spectrum of reuse and integral launch concepts were defined for total system evaluation. The progression of the reuse categories from fully expendable to fully reusable, as shown in Table 2-1, apply to both the ballistic (Configuration I) and the lifting body (Configuration II) configurations. For the ballistic vehicle, a 60 deg. cone angle was used for categories A and B, 40 deg cone angle for the other categories. For the lifting body configuration, the NASA M2-F2 shape was used. The boosters were treated parametrically.

Table 2-1
Reuse Category Summary

Category / Component	Expendable	Partially Reusable				Reusable
	A	B	C	D	E	F
Entry Vehicle	E	R	R	R	R	R
Maneuver Propulsion/ Cargo Module	E	E	R	R	R	R
Upper Stage Engines	E	E	E	R	R	R
Upper Stage Tanks	E	E	E	E	R	R
First Stage	E	E	E	E	E	R

E - Expendable   R - Reusable   ▯ Integral

The following sections discuss ground rules and assumptions (Section 3), development plans and schedules (Section 4), operations and support (Section 5), and support equipment (Section 6). Within the operations and support section is discussed prelaunch and launch operations, on-orbit operations, recovery site selection, recovery forces and costs, recertification, and turn-around time.

3. GROUND RULES AND ASSUMPTIONS - In executing the analyses discussed, ground rules were established and assumptions were made to bound the scope of the analyses for the time and manpower available. The guidelines followed or ground rules assumed are as follows:

1. Historical Gemini and Saturn S-IVB data represent the trends to be expected in future spacecraft programs.
2. The actual Gemini and Saturn S-IVB development history can be used to formulate realistic development plans for new spacecraft systems.
3. Where there is no historical data available, recent studies will serve as the data base.
4. The Saturn S-IVB development history is representative of the development required for a spacecraft having integral upper stage propulsion.
5. The nominal wait time in orbit prior to return will be a maximum of 24 hours.
6. The spacecraft will be in a quiescent storage mode while docked to the space station; it will draw all of its support power and gases from the space station.
7. The exact composition of any given subsystem has little effect upon the total development time for qualification of all subsystems.
8. The historical development schedule of the J-2 engine is representative of an integral upper stage propulsion system engine schedule.
9. All baseline subsystem concepts utilize existing technology. No technology advancement is required.
10. Vertical or horizontal land landing technology is developed by other preceeding programs.
11. The development program is defined to include the first five flights - unmanned and manned combined.

12. The lateral range (or cross-range) capability (-3σ) of the ballistic vehicle will be 150 na mi, and of the M2-F2, 600 na mi.

13. The study will consider only 300 na mi orbits inclined at 50 deg, 70 deg, and 90 deg.

14. Recovery sites will be existing sites within the continental U. S. unless a new, ideally located site is specified.

4. DEVELOPMENT PLANS AND SCHEDULES - Based upon the McDonnell Douglas experience with the Gemini and Saturn S-IVB programs, a baseline development plan and schedule was prepared. This indicated that a ballistic vehicle, either expendable or reusable (Configurations IA, IB, or IC), could be developed and flight qualified in 45 months from go-ahead through completion of the fifth flight. The subsystems could be developed within 35 months. The comparable M2-F2 vehicle would require two months longer for subsystem development and up to eight months longer for vehicle development and qualification.

The inclusion of upper stage propulsion within the spacecraft stretches the development plan and schedule by including the parallel development effort of the upper stage systems. Thus, the baseline development time is increased to 54 months for the subsystems of the ballistic vehicle or to 57 months for the M2-F2 vehicles. This also leads to a qualified flight vehicle (five flights) in sixty-four months (ballistic) or up to seventy-three months (M2-F2)

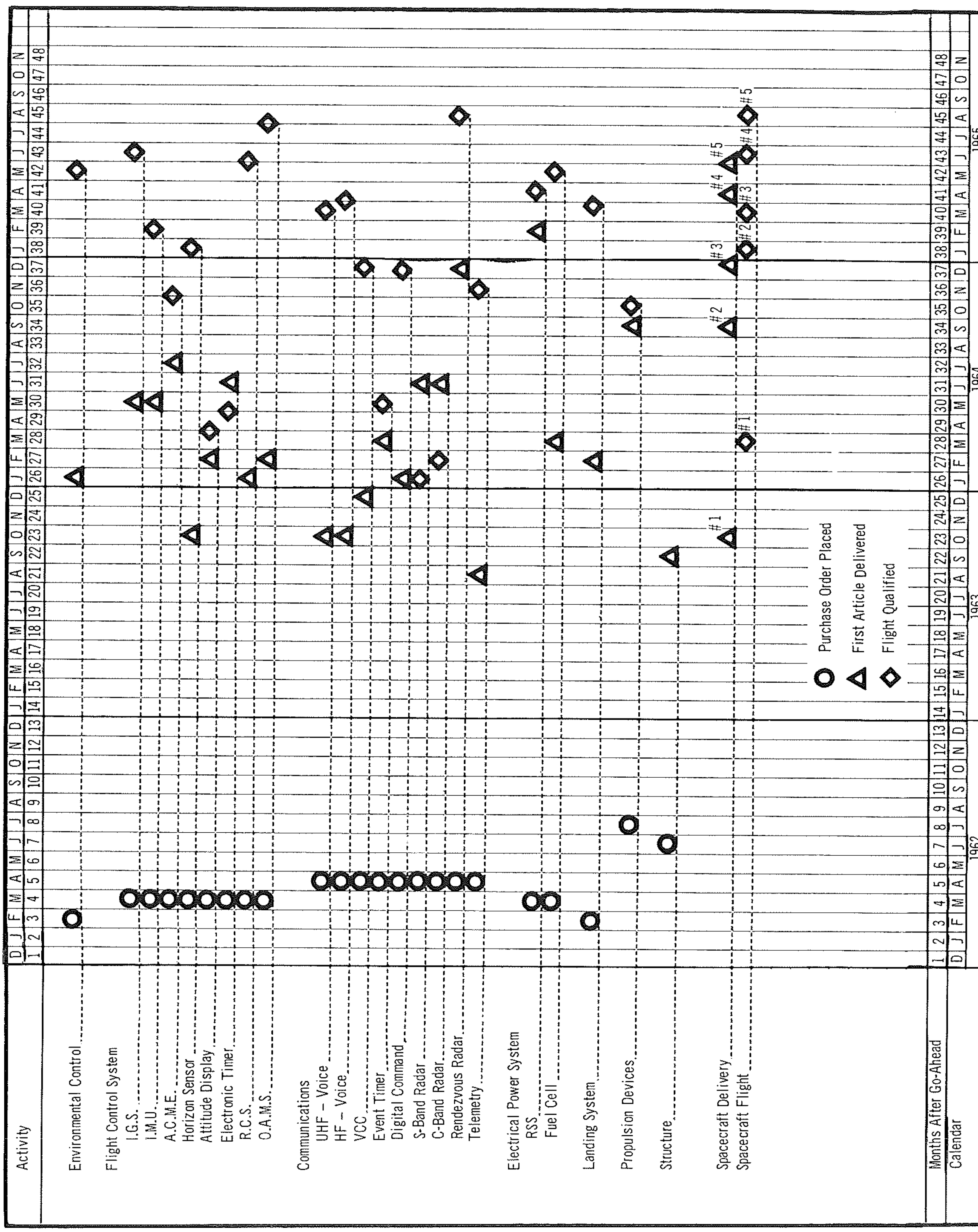
Major development hardware requirements for each schedule were defined. The baseline schedule for configurations IA, IB, IIA, and IIB required five boilerplate vehicles, three static test entry vehicles, three test adapters, a thermal qualification vehicle, and eleven mock-ups or test articles. The additional hardware to complete the test and qualification program for the other configurations was treated as a perturbation of this baseline.

4.1 Gemini and S-IVB Subsystem Development - The Gemini program made extensive use of subcontracts, but had little government furnished equipment (GFE). In contrast, the bulk of the S-IVB system was either done in-house or was GFE (i.e. the engines and valves). The available S-IVB data has limited application to this particular analysis, and the remaining discussion will concentrate upon the history of the Gemini subsystem development which is shown in Figure 4-1.

Within five months after go-ahead, all subcontracts for major subsystems had been placed except those for propulsive devices. This last subsystem was contracted eight months after go-ahead. In Figure 4-1, the structure has been included for completeness, although it was done by McDonnell

Figure 4–1

GEMINI SUBSYSTEMS



and it was difficult to separate structural development from the integration task. The relationship between development and qualification for the structural subsystem is shown more clearly in section 4-2.

The critical pacing items in the Gemini program were propulsion, rendezvous radar, and the landing system. Each had unique problems which were more a result of the advanced technology involved than in the subsystem or subcontractor deficiencies. The best known problems were in the land landing system which had to be completely redesigned for water landings when weight and schedule slippage forced a redirection of the program. As a result, the landing system required almost 41 months to reach qualification. Development could have been considerably shorter if it had started with the final design concept.

4.2 Gemini System Development - The Gemini system development followed the pattern that evolved during the Mercury program. Much of the development and test philosophy resulted from the NASA and McDonnell experiences during that program. The first listing of tests and test articles was published about six weeks after go-ahead. This list was continually updated as the requirements were better understood. Also, the impact of budgetary restrictions was noted by the changes in hardware requirements, and by schedule slippages with assignment of in-process hardware. For the paraglider, however, the slippage forced redesign to utilize conventional parachutes with attendant changes to test hardware and system development schedules.

4.2.1 Background and History - After a letter of intent was received in mid-December 1961, effort was stepped up on developing the test plan and development schedules. The initial document, published near the end of January, 1962, called for six boilerplates, seven static test vehicles, four static adapters, and six major test articles.

In the fall of 1962, NASA budgetary problems forced economies which caused two of the static test vehicles to be cancelled. Also, as the paraglider program slipped further, the flight quality airframe produced to support the qualification of the paraglider was diverted to the production airframe line. This static test article was replaced by a delayed production airframe, and was subsequently used as a crew access and recovery test vehicle - a test article rather than a static test vehicle. The paraglider problems also resulted in deletion of one boilerplate vehicle.

The balance of the planned test program was accomplished generally as originally conceived. Some tests required greater effort than first estimated, and others were completed in less time. By careful schedule planning and continuous updating, by priority assignment, and by control of laboratory staffing levels, the job was completed essentially on schedule in spite of delays and funding restrictions.

For this overall test plan and schedule, about 850 separate test requests were written to define specific tests on the major test hardware and many of the small specimens or samples. Although all of these were not executed, about 750 separate test requests were completed. The initial test schedules were general, consisting of two pages. As the test program became better defined, the test schedule grew to about 14 pages with increased detail and status information. Several of the test articles served dual purposes, such as test of the system and as a training aid for test personnel in the procedures for production (SST) test. These were also utilized to trouble-shoot problems during the later portion of the flight program.

4.2.2 Major Test Hardware - The major test hardware (the boilerplates, the static test vehicles, the test articles, and the mock-ups) quantities of the Gemini program were the base for the hardware requirements used in this study. Tables 4-1 through 4-4 list these planned Gemini articles individually with a brief description of experienced usage.

The most expensive testing of the Gemini program was the Thermal Qualification testing performed on the test article identified as S/C 3A. This was used to simulate missions in the test chambers. The vehicle had to be flight quality although it would never be flown, and was probably subjected to more testing than any other piece of test hardware.

The Electronic Systems Test Unit (ESTU) was little more than a mock-up structurally, although electronically it was a flight quality system. Its purpose was to help identify component incompatibility and to help minimize electromotive interference between the many electrical and electronic components.

Table 4-1

Gemini Test Articles

Boilerplates

Unit No.	Vehicle Description	Test Use
1.	Welded steel mockup of reentry vehicle, shipped to test site 31 July 62	Parachute development at El Centro, destroyed 30 July 1963.
2.	Welded steel Mockup of the pressurized cabin volume. Complete ECS system installed.	Manned functional evaluation of the crew life support system.
3.	Welded steel shape of the reentry vehicle with hatches in the fixed open position. Delivered to Weber July 1962.	Sled test unit for ejection seat development
3A	Boilerplate shape with production large pressure bulkhead, seat rail torque bed, hatch size, side panels, hatches, and flipper doors. Delivered December 1963.	Functional qual test for complete ejection system including simulated pad aborts and sled runs.
4.	Skin and stringer reentry shape with ballast installation allowing c.g. position within the design envelope.	Used to define the landing dynamics of the vehicle and skid gear. Paraglider (and skid gear) terminated prior to test. Built but no used
5.	Same as B/P No. 1. Shipped to test site 31 August 1962.	Same use as B/P No. 1.

Table 4-2

Gemini Test Articles

Static Re-entry Vehicle

Unit No.	Vehicle Description	Test Use
1	Production re-entry structure	Originally scheduled as a structural test vehicle. Cancelled fall of 1962 as an economy move-structure reassigned as S/C 3A.
2.	Production structure. Equipment included ejection seats, paraglider controls.	Paraglider qualification at NAA. Became S/C 4 to improve a schedule delivery. S/C 4 identified as static 2 was later terminated for this use and was reidentified as static 5.
3.	Production structure with parachute torque box.	Static tests.
4.	Production structure plus dummy (mass and c.g.) equipment.	Structural dynamics test and static tests.
5.	Production structure plus volume and weight simulated equipment.	Flotation stability evaluation (MAC) and egress trainer (NASA)
6.	Proposed - **never** built.	
7.	Boilerplate conical section, production R & R and RCS sections.	Qualification of the parachute recovery system.

Table 4-3

Gemini Test Articles

Static Adapter Vehicles

Unit No.	Vehicle Description	Test Use
Martin No. 1	Production structure	To Martin Co. for structure and structural dynamics tests with Titan. Returned to MAC for structural tests.
Martin No. 2	Production structure	Structural tests. Structural dynamic tests.
Static No. 3	Production structure	Structural tests - equipment mounts and retro rocket supports.
Static No. 4	Production structure	Popgun test and pyrotechnic separation demonstrations.

Table 4-4

Gemini Test Articles

Miscellaneous Test Vehicles

Unit No.	Vehicle Description	Test Use
Thermal Qualification Test Vehicle (S/C 3A)	Complete re-entry and adapter vehicle. All equipment installed. "Canned man" simulators.	Simulated mission in 30 ft chamber. Orbital heating and deep space cold simulated.
Electronic Systems test Unit (ESTU)	Simple structure (wood, aluminum, etc.) with engineering prototype equipment.	Component and electronic system compatibility evaluation.
Compatibility Test Unit (CTU)	Preliminary or pilot run spacecraft structure production prototype equipment and wire bundles.	System compatibility, EMI, AGE compatibility, SST procedure evaluation and personnel training.
Specimen Hatch	Production hatch sill, side panels, hatches, and latch mechanism mounted on a boilerplate box assembly.	Latch rigging, functional tests, leakage tests.
R & R, RCS Pyro Test Unit	Production structure and live pyro devices.	Pyrotechnic demonstrations of the several devices in this module.
R & R, RCS Structural Test Unit	Production structure.	Structural tests of chute and radar support structure.

The Compatibility Test Unit (CTU) continued the compatibility investigations to encompass the entire operating spectrum and the physical location of all components. It also served as the test article to ensure that the AGE and the launch umbilical tower were functionally compatible, and further functioned as the training vehicle both at the factory and at the launch site.

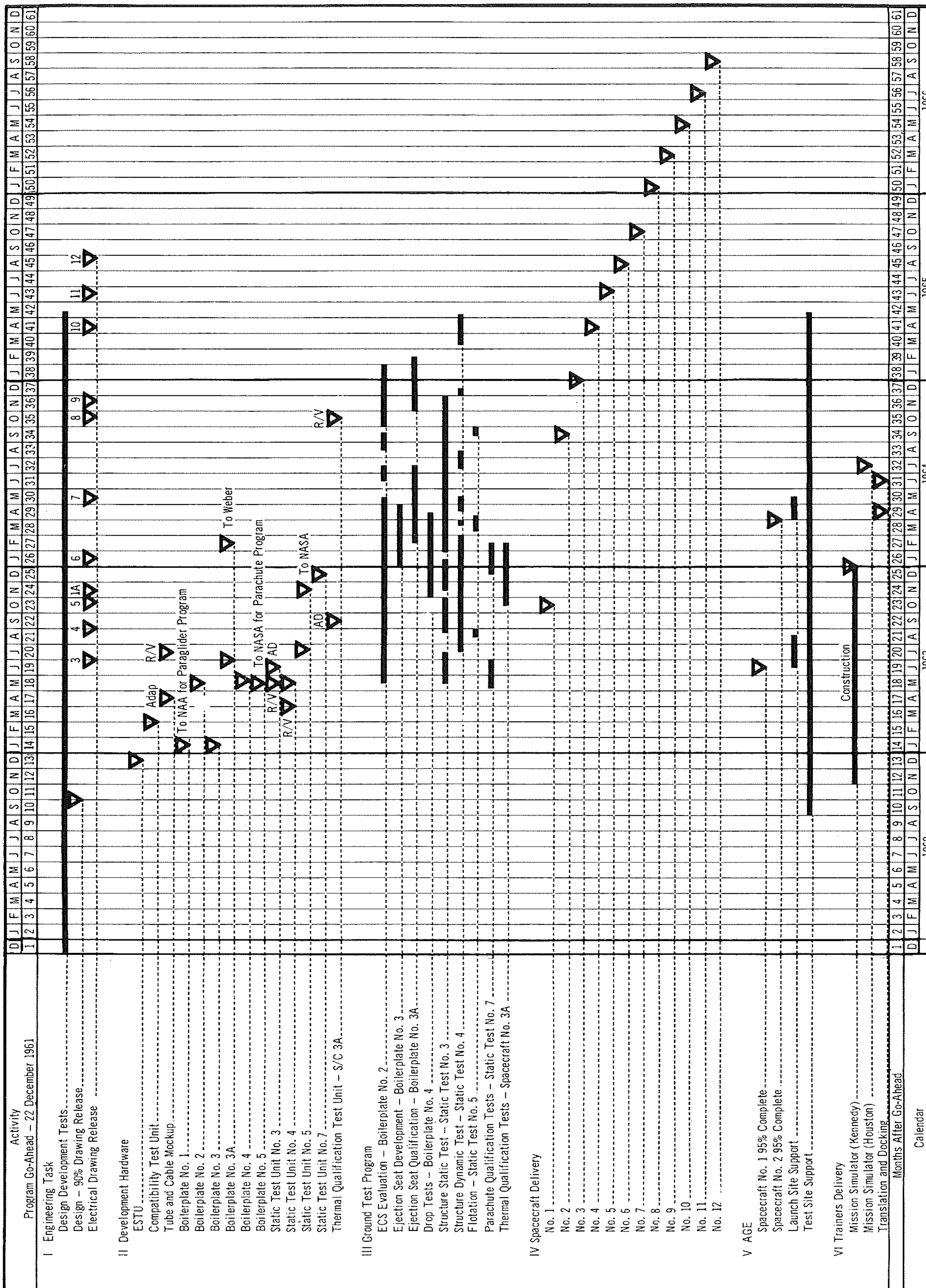
Because there was much concern about the hatch seals, specimen hatch tests were conducted using the specimen hatch test articles. The test results did much to satisfy that the seals were adequate and that the leakage rate was not excessive. It also served as a tool in developing hatch rigging procedure.

4.2.3 Plans and Schedules - Due to the budgetary restrictions and the schedule slippages, the actual schedules and the test hardware to support them were less than originally planned. The actual test program utilized five boilerplates (one additional was built but not used), four static test vehicles, and six test articles. The most significant change was the elimination of three static test vehicles. Some tests were deleted with the sailwing cancellation, but most testing was accomplished by more extensive utilization of each static vehicle. Also, one of the test articles was much too elaborate for the usage it received, and was more like a static test vehicle than a test article.

The final test schedule and development plan for the Gemini program is shown in Figure 4-2.

4.3 Saturn S-IVB Stage Development - The Saturn S-IVB stage development benefited from the development experiences of the Thor and Saturn S-IV programs. This experience provided the management experience so essential to the successful completion of a launch vehicle stage project. The Saturn S-IVB is the third stage of the Saturn V launch vehicle, and has a restartable J-2 engine. The development plans and schedules of this stage most closely resemble the expected development of the integral upper stage propulsion concepts of this study.

Figure 4-2
GEMINI PROGRAM SCHEDULE



4.3.1 Background and History - The history of the S-IVB is closely interwoven with that of the S-IV and much of the testing performed for the S-IV was directly applicable to the S-IVB. For example, the data from S-IV hydrogen tank slosh tests can be applied to the S-IVB, eliminating the need for more liquid hydrogen tank tests. Major tests were:

a. Structural static tests
b. Structural dynamic tests
c. Feed systems tests
d. Propellant utilization system tests
e. Flight control system tests
f. Auxiliary propulsion or RCS tests
g. Electrical tests
h. Data acquisition system tests
i. ECS tests

Since the S-IVB development program was essentially conducted completely within the prime contractors organization, many of these tests which would usually be conducted by a major subcontractor were conducted by Douglas. The only subsystem which could be considered a major subcontract is the J-2 engine which was a GFE item. An attempt has been made to include the critical milestones of the engine development, but this was not a part of the basic historical data in this study.

4.3.2 Major Test Hardware - The major test hardware for this program was not as extensive as that for the Gemini program. It consisted of one battleship tank, three static test tanks, one stage mock-up, and one simulator. Several test articles, mostly of interstage and skirt structure, thrust structure, and mock-ups were also utilized.

The battleship tank is the most important piece of test hardware. It supports the extensive test program leading to qualification of the stage. The primary objective of the battleship test program was to provide the major design parameters of the propulsion installation. The engine mounting, propellant inlet lines, baffling, propellant feed system, etc., were all similar to those on the stage. The second objective was to prove the suitability of the control and monitoring systems.

The test program was divided into two parts: first, cold flow on the test stand for leak checks and propellant loading, and, second, static test firings of the engine to verify the propulsion and integrated systems. Electromagnetic compatibility checks of the stage-installed electrical or electronic systems and equipment were made during these firings.

4.3.3 Plans and Schedules - The cold flow tests on the battleship test stand began with a series of propellant loading exercises and tank pressurization tests to qualify the support facilities and to develop operational procedures. These tests were:

a. Leak and functional checks
b. Oxidizer system checkout
c. Fuel system checkout
d. Cold helium loading system checkout
e. Gaseous hydrogen loading system checkout
f. Ambient helium loading system
g. Loading countdown

After engine installation and leak check, a series of "dry" countdowns led to a "wet" countdown which was terminated just before ignition. Satisfactory completion of these tests was followed by live shakedown firings. Data on pressure drops in the main fuel and oxidizer low-pressure ducts were obtained from early battleship testing. Fuel tank anti-vortex screen operation was observed during depletion tests. Since the fuel tank outlet geometry and vortex screen are essentially the same as on the S-IV, an induced propellant rotation test was not required for the S-IVB. The usual photography as proof of the successful function of anti-vortex screens was not required for the S-IVB.

Fuel tank pressurization system tests were conducted to demonstrate that the gaseous hydrogen bleed from the engine could be properly regulated, and that the diffuser at the tank inlet was effective. This involved tests such as: (1) satisfactory operation with large and small starting ullages, (2) transition from ground to engine bleed pressurization, (3) repressurization from stage helium pressurization system, and (4) proper functioning of the fuel vent system.

Similar tests of the oxidizer tank pressurization system were conducted. The oxidizer tank is pressurized from the stage helium pressurization system. Engine start tests established the start procedure and qualified it for operational use. They also established propellant and pressurant gas consumption. Pressure surges (water hammer effect) in the propellant feed system when the main control valves were closed were also investigated. Since the stage utilized a command control cut-off rather than depletion cut-off, this condition was a critical design situation. These tests also aided in developing safe shut-down sequences. All firings of the battleship test vehicle were monitored for start and shut-down. This provided a wealth of data needed to establish run-to-run and engine-to-engine variations, and to validate the operational sequences.

Development testing of the propellant utilization system was conducted simultaneously with the static firings and flow tests. These tests ensured that the system properly sensed incipient depletion in the propellant tanks, and satisfactorily controlled the mixture ratio supplied to the engine. Various types of system malfunctions were simulated to demonstrate that safe propulsion system operation would continue if propellant utilization system malfunction or failure occurred.

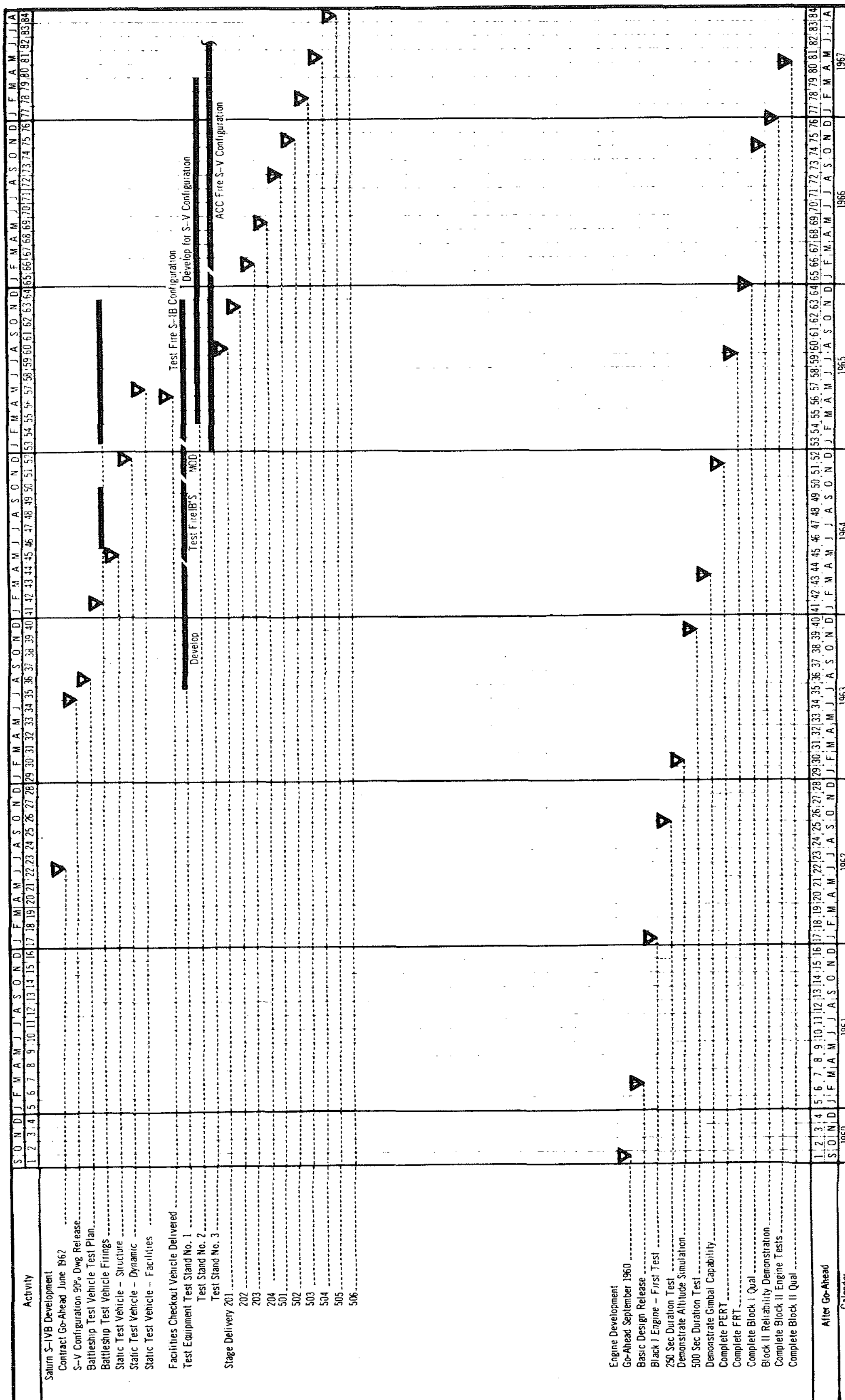
Other tests were conducted on the static test vehicles, including the usual static and dynamic tests, proof and burst tests on tanks, and aft interstage purge and environmental control tests. An all-systems test vehicle was also utilized. This was a flight quality vehicle used for final checkout of all test procedures, for support equipment interfaces, and, eventually, as a dynamics test vehicle for the Saturn V checkout.

Pyrotechnic tests of the stage separation system and the emergency destruct system were conducted to qualify the mild detonating fuse explosive train. Also, qualifying the four retro-rockets included in the aft interstage was the responsibility of Douglas as the stage contractor. The final test schedule and development plan is shown in Figure 4-3.

4.4 Baseline Plans and Schedules - The historical data form the basis for the baseline plans and schedules of this study. The quantities of hardware and the time phasing schedules discussed below represent either the all expendable or the reusable entry module configurations. Other configurations are considered as incremental increases added to the baseline quantities or times.

Figure 4-3

S-IVB DEVELOPMENT



4.4.1 Major Test Hardware - The Gemini program utilized a relatively large amount of test hardware: five boilerplates, four static test entry vehicles, four static adapters, a thermal qualification vehicle, and at least five test articles and six mock-ups. A future development program would not require as many of the more expensive pieces of hardware, but would still need at least the amount itemized in Table 4-5. The table also lists the additional amounts needed for the more advanced concepts.

These various pieces of test hardware will be used to develop and qualify the parachute or landing system; to develop and qualify the ECS system; to demonstrate the integrity of the crew module and launch escape system during abort, water impact and subsequent flotation; and to demonstrate the static and dynamic strength characteristics of the vehicle. If there is a large integral propulsion system such as Main Maneuver or Upper Stage Boost, additional hardware is necessary to develop and qualify the system or systems. The five other propulsion systems (retro, orbit attitude control, entry attitude control, vernier, and landing assist) that may be a part of the vehicle are developed and qualified utilizing test articles or in conjunction with other tests noted above.

The hardware quantities are the minimums that a development program would require. As the actual program to be undertaken becomes near-term, the amount of testing and the quantity of test hardware will be defined by negotiation between the customer and the contractor directly involved in producing the desired vehicle. At such a time, the political and fiscal influence will significantly affect the degree of conservatism with which the development phase will be approached. These values represent a middle-of-the-road approach, neither as conservative as previous programs nor as "sporty" as some think the industry will eventually evolve.

4.4.2 Subsystem Plans and Schedules - In developing the following plans and schedules, certain assumptions were made concerning the nature of the baseline subsystems for the vehicles. The most significant assumption was that these new subsystems were new applications of present technology. This implies that development work is needed to apply the existing technology to the new vehicle requirements, but that there is no need for a major effort to advance the state-of-the-art before the effort can begin. This assumes that all of the R&D work has been done to provide a subsystem which will work

Table 4-5

Hardware Requirements

Baseline (Configurations A and B)

5 Boilerplates

- 2 - Parachutes and/or landing system
- 1 - ECS evaluation
- 1 - Escape system
- 1 - water impact and flotation

3 Static Test Reentry Vehicles

- 1 - Structural Test and Abort
- 1 - Dynamic Response and Flotation
- 1 - Parachute Qualification and Landing

3 Static Cargo/Maneuver Modules

- 1 - Structural Test and Qualification
- 1 - Dynamic Response and Abort
- 1 - Pyro Qualification

1 Thermal Qualification (Static Vehicle Quality Used as Mock-up)

1 Compatibility Test Unit

1 Electronic Systems Test Unit

7 Other major test articles (i.e., specimen hatch, pyro test units, structural test units, etc.)

2 Other major mock-ups (Engineering and Promotional, and tube and cable)

For Integral Propulsion (Configuration C)

1 additional boilerplate (for test and qualification of integral propulsion)

For Integral Upper Stage Propulsion (Configuration D, E and F)

1 Battleship Test Vehicle

1 Additional Boilerplate

2 Additional Test Articles

1 additional Mock-up

in a spacecraft environment. Since land landing is required, all of the basic technology development work to provide a workable system is assumed to have been completed before the start of the particular spacecraft program. The only additional development would be for application of this technology to the new system.

These plans are based upon the MDC experience with the identified subsystem components. The schedule, Figure 4-4, is for a reusable ballistic entry vehicle - configuration IB, which has been assumed as the baseline; however the baseline values are applicable to configuration A and C also. Other configurations are handled as perturbations.

The landing system schedule assumes a sailwing system. This system is the pacing item, requiring 35 months from go-ahead to flight qualification. Allowing a three month contingency for the subsystem contractor, the total time to a flight qualified system is thirty-eight months.

The ECLS system schedule assumes a conventional one-gas system utilizing gaseous storage and lithium hydroxide, basically existing technology, and application.

The guidance and control system is assumed to be essentially existing. Improved accuracy for the landing phase is required which affects both the inertial reference and the control electronics.

When integral upper stage propulsion is added to the spacecraft, this propulsion system becomes the pacing item. The development time for the Saturn S-IVB stage was shown previously. It is assumed that the milestones in that program are typical of those expected for the integral upper stage development. However, a shorter time from go-ahead to initiation of test firing is expected. It is assumed that the time from go-ahead to qualification would be about 54 months for a ballistic vehicle and 57 months for an M2-F2 vehicle.

For the M2-F2 configurations, the landing system development is shorter, about 27 months, and is not the pacing item. Heat protection development requires considerably more effort, and in conjunction with the structural subsystem, it becomes the pacing item at about 37 months. The escape system no longer utilizes a tower, but the development can still be completed

FIGURE 4-4

OCPDM - SUBSYSTEM DEVELOPMENT
CONFIGURATION 1B, REUSABLE BALLISTIC E/V
EXPENDABLE M/M & L/V

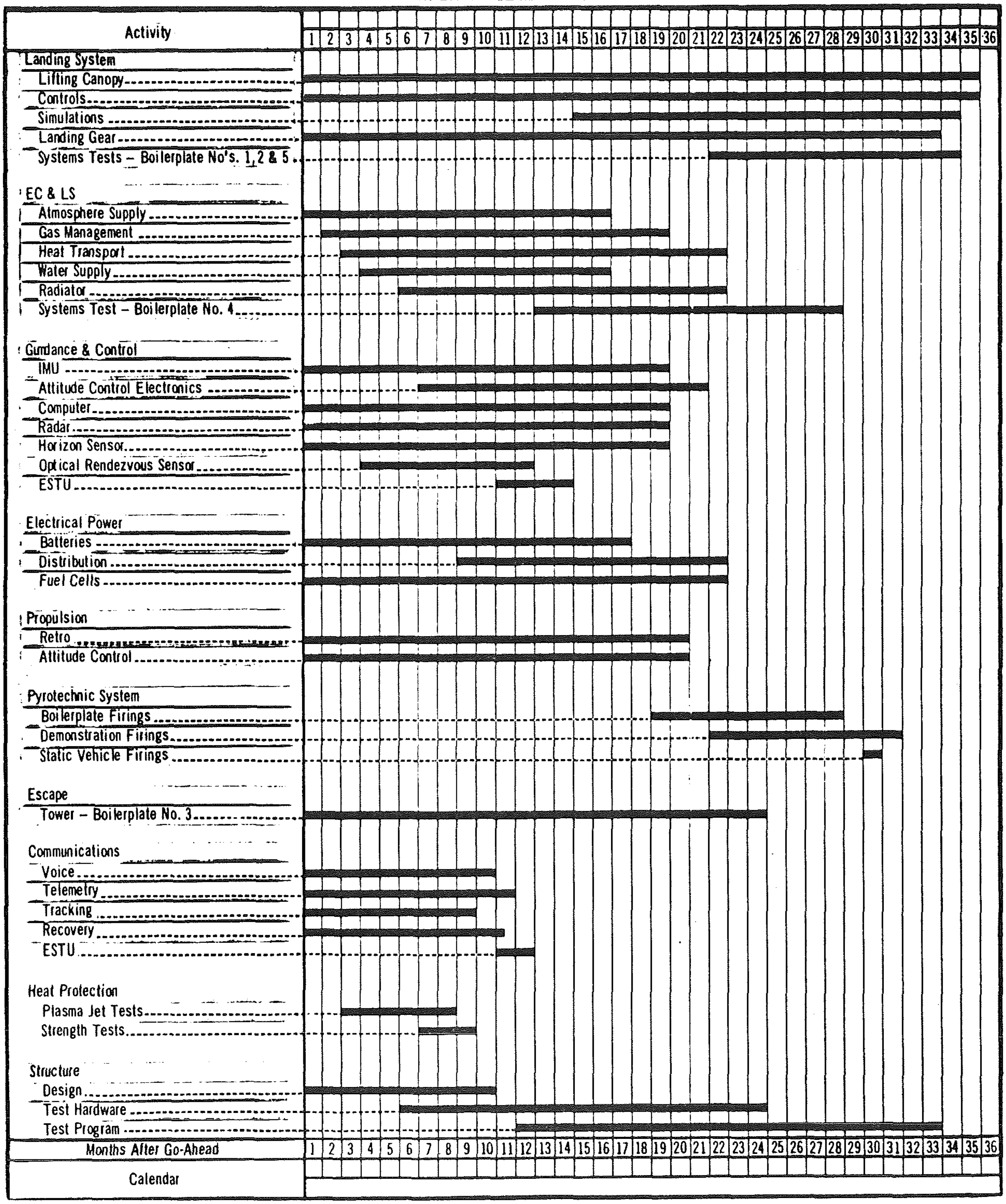


Table 4-6

Subsystem Development Time

Configuration	Subsystem Qualification Complete (Months)	Pacing Subsystem
IA, IB, IC	35	Landing System
ID, IE, IF	54	Upper Stage Propulsion
IIA, IIB, IIC	37	Structure/Thermal Protection
IID, IIE, IIF	57	Upper Stage Propulsion

within 24 months. The remaining subsystems can be developed within the baseline values shown in Figure 4-4. Analysis results are summarized in Table 4-6.

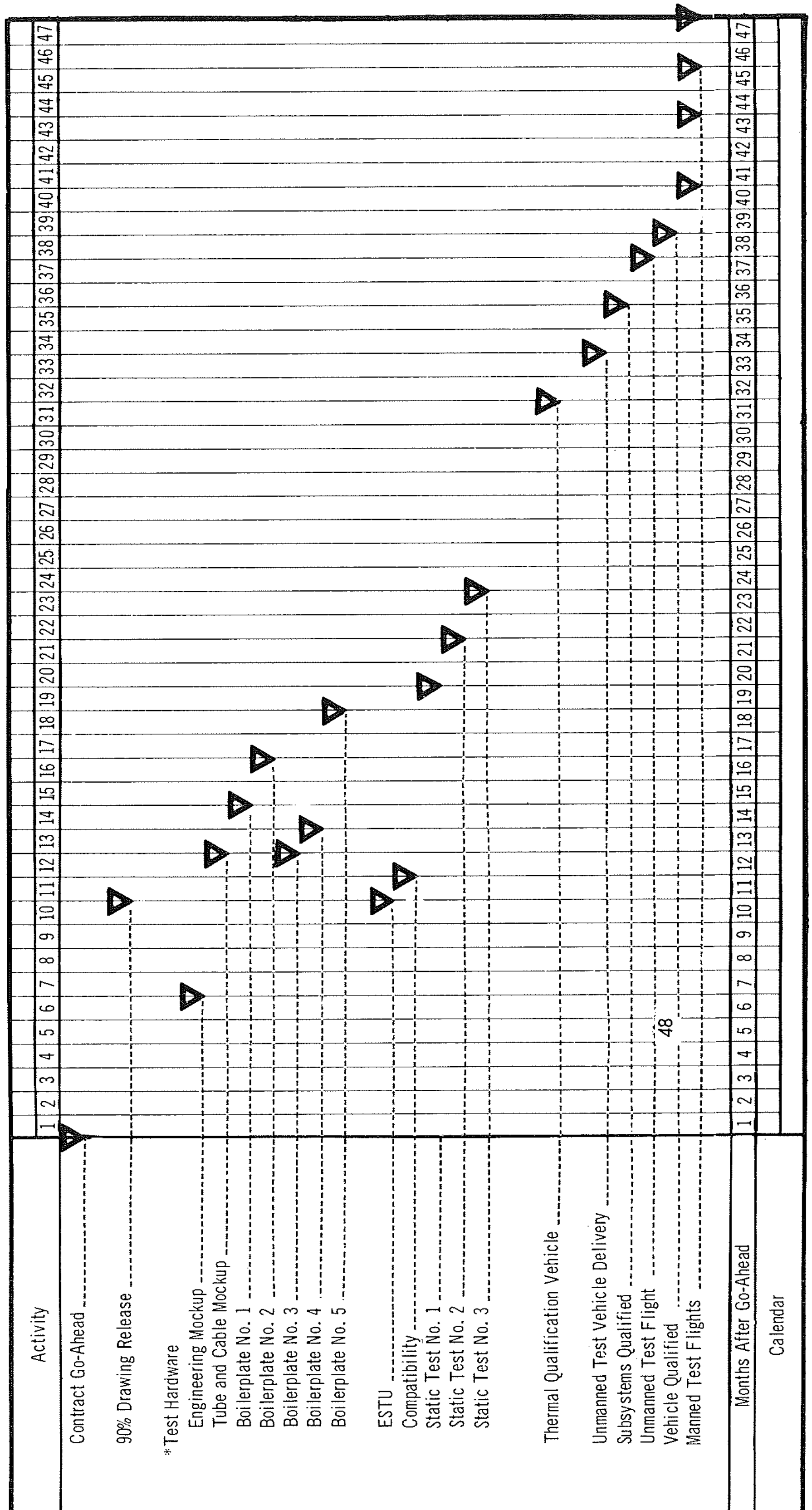
4.4.3 Spacecraft System Development - Figure 4-5 presents the baseline development program for a reusable modular ballistic entry vehicle with expendable mission module, configuration IB. This is also true for configuration IA and IC. Comparing this figure and the previous figure indicates that the first manned flight will occur about four months after the pacing subsystem has reached qualification. The unmanned development flights would occur just after the subsystems are qualified, and a five-flight test program would completely qualify the system.

If the vehicle is an M2-F2, configuration IIA, B, or C, the first manned flight would be delayed until about 43 months after go-ahead. This is due to the longer subsystem qualification program (37 months) and to the longer time periods between launches. Allowing four months between the unmanned flight and the first manned-flight, the manned-flights should begin about 43 months after go-ahead and should be complete ten months later.

Figure 4–5

OCPDM – DEVELOPMENT MILESTONES

CONFIGURATION IB. REUSABLE BALLISTIC E/V. EXPENDABLE M/M & L/V



*See Table 4–5 Page 22 for Definition of Test Hardware Application

The development program for the configurations having integral upper stage propulsion (configuration ID, IE, IF, IID, IIE, and IIF) will have a similar five - flight test program. These will extend 10 months or 14 months after subsystem qualification, depending on whether a ballistic or M2-F2 vehicle is under consideration. Thus, these larger vehicles will have a longer development time extending to about 73 months for an M2-F2. These times are summarized in Table 4-7 and shown in Figure 4-6.

Table 4-7

Development Program Time
(Through first 5 flights)

Configuration	Development Time Months
IA, IB, IC	47
ID, IE, IF	66
IIA, IIB, IIC	53
IID, IIE, IIF	73

Figure 4–6

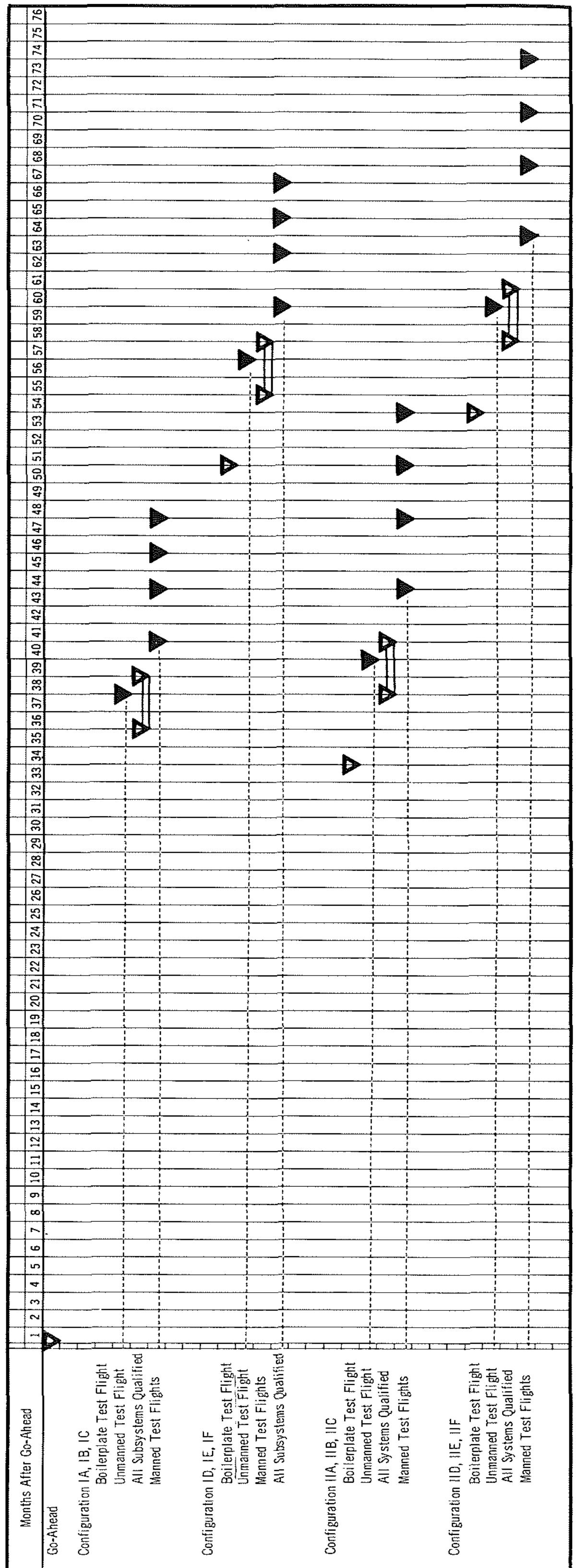


Figure 4–6

FLIGHT TEST DEVELOPMENT SCHEDULE

5. OPERATIONS AND SUPPORT - During Phase I of the study, several Operational and Support Activities were investigated. Those having some influence upon the spacecraft related total cost picture of a logistics mission were (a) prelaunch and launch operations, (b) the launch support and mission operations, (c) recovery site quantities and method of operation, (d) recovery forces, and (e) recertification or refurbishment.

The launch operations analysis resulted in estimating relationships of man-hour costs to vehicle size, configuration, and number of launches. These operations require activities for support and mission control which are functions of program duration and number of launches. Additional cost areas of AGE and Facility Maintenance were also analyzed.

Recovery sites and recovery forces enter into trade-offs with vehicle maneuver capability. To permit these trade-offs to be performed, the costs of operating one or more recovery forces and recovery sites were determined. In addition, a statistical analysis of site location vs return probability was conducted to ensure the data on maneuver capability requirements, discussed in Section 4.5 of Book 1 was realistic rather than ideally parametric.

Recertification or refurbishment analyses were primarily based on previous studies. The result is a set of equations to estimate man-hours and flow time as a function of vehicle size, configuration, and subsystem. Provisions to include or not include testing at the combined systems test level (complete vehicle checkout) and hot-firing of the propulsion systems are contained. These resulting man-hours can be easily converted to a cost to which can be added the materials costs, to produce a total dollar cost for recertification.

5.1 Prelaunch and Launch Operations - The spacecraft launch operations contract for the Gemini program encompassed more activities than just launch operations and launch support. Substantial effort was made in AGE design and modification, training of ground crews, facility checkout and maintenance, and advanced mission planning. This analysis relied heavily upon the work of Reference 5-1, but included nearly 875,000 man-hours charged to these operations not considered there. The adjusted total man-hours expended on the Cape operations was 4,952,251, including 105,569 man-hours of St. Louis launch support effort.

5.1.1 Gemini Cape Activities - The cost code items of the Gemini program directly related to the preparation and launch of the spacecraft grouped into six functionally-oriented categories. These involve industrial area activities within the main buildings; the industrial area activities at remote locations, i.e. pyro buildup; on-pad assembly activities; prelaunch systems testing; final countdown; and miscellaneous activities.

Support-related activities were general support, materials and logistics support, operations support, pre-delivery technical support, subcontractor field support, repair of government owned equipment, and liaison or support engineering; also included were reports and sketches, future mission planning, and the launch support provided by personnel covered by the production contract. Mission control support activities included those for the simulator, control operations and activities, and ground crew training.

The launch operations contract also included AGE-related activities, such as additional AGE design and fabrication, GSE items, AGE spare part procurement, AGE research and development, AGE modification and design, field change notices, and AGE maintenance and validation. There also were a few activities related to validation, maintenance, and activation of facilities.

There are many small value cost codes and cost items in the detailed breakdown of this Gemini Spacecraft Operations contract that have been combined into the general support category. The records from which this data was extracted had 38 item numbers subdivided into a total of 360 cost codes.

The detailed accounting of man-hours covers only Gemini 5 through 12 because early in the program all of the man-hour charges were recorded against one cost number. However, about the time Spacecraft 5 was delivered to the Cape industrial area, new accounting practices were instituted which allowed costs to be tracked by spacecraft.

In support, the activity called "Repair of Government-Owned Equipment" was the only area where a significant hardware cost was associated with the activity. The manhours expended on this activity approximated 179,000 or about 3.6 percent of the total manhours. Associated was a cost of $2,966,895 paid to subcontractors for materials and services. This was about twice the manhour cost.

Another cost item in the Support category is future program planning. This was work performed for NASA which was not related to the Gemini program and consisted of advance planning technical support to the offices within the Kennedy Spaceflight Center. Approximately 289,500 manhours were charged to this, representing 5.8 percent of the total, or 24.5 percent of the support category manhours.

5.1.2 Data Organization - Since the historical data of the Gemini Spacecraft Operations contract was not useful in its basic form, the first problem attacked was the reformating of that data into the Cost Element Structure pattern. This involved rearranging the data of Reference 5-1, adding the costs excluded in that analysis, verifying the job descriptions for each cost code or cost item, and checking to ensure that the resulting total duplicated the totals for the contracts involved as reported in the NASA form 533 reports. There was a 248,000 manhour difference in the values recorded in Reference 5-1 and those determined from the NASA form 533 reports. This is partly explained by the different data sources; the NASA form 533 reports are actual totals while the sources for Reference 5-1 were incomplete, having about 97 percent of the total run-out costs but neglecting divisional overhead, general overhead, and travel. These upward adjustments were made in the broad category of Support since the NASA form 533 reports are not sufficiently detailed to identify the exact cost category to be adjusted. The resultant data, regrouped and adjusted, are presented in Table 5-1. These data constitute the base on which the analysis was performed. The Support Activities include all costs charged against spacecraft number 1 through number 4.

A second reorganization resulted from the guideline assumption that the first five flights of the Gemini program would be considered the development flight test phase. Deeper analysis of the Gemini program data suggested that the first unmanned Gemini flight more closely resembled a structural integrity test than an unmanned test flight. The structure was mostly boilerplate, contained few subsystem components, and no attempt was made to recover the vehicle. Thus, we have assumed that Gemini 2 was the first unit, and that Gemini 6 was the last vehicle in the flight test program. This agrees with the actual Gemini program which considered Gemini 7 through Gemini 12 as quasi-operational flights.

Table 5-1

Actual Gemini Operations and Support Costs

		Manhours
Launch Operations		586,937
Industrial Area Activities	68,336	
Radar Calibration and Pyro Buildup	40,931	
On-pad Assembly Activities	147,664	
On-pad Test Activities	66,234	
Countdown	69,498	
Miscellaneous Activities	194,274	
Mission Control and Support		3,051,053
Mission Control	374,874	
Support Activities	2,676,176	
Additional AGE		814,052
AGE Maintenance		218,043
Facility Activation		220,102
Facility Maintenance		62,064
Totals		4,952,251

The approach followed was to fit curves to the recurring data of Gemini 5 through Gemini 12; to establish values for each category; to readjust the Support category totals downward by the amount calculated for flights two through four; to establish a recurring rate for those costs defined only in totals; and then to determine the relationships to be used in developing the cost model.

Inspection of the data revealed a wide scatter exhibited by nearly all categories. In attempting to obtain meaningful results, certain data points were ignored in fitting curves to the data. These "wild points" can be attributed to the following occurrences:

a. ground equipment failures

b. spacecraft subsystem malfunctions

c. retesting after repairs

d. launch scrubs and recycles

e. "hurry-up" launching

f. weather delays

g. incorrect time charging by personnel

The resulting equations recognize a reasonable amount of "inefficient" activity due to rework and retesting.

The recurring data base is small (Gemini 5 through Gemini 12) and extrapolating trends both to first units and to 50 or more lacks rigor. However, it is still reasonable to expect the results to be meaningful as a planning tool. With this in mind, the data were fit by a "learning curve" equation, $M = aN^b$, for the first 10 units. Beyond this quantity, a hyperbolic or parabolic equation was fitted to the same data. This was an attempt to recognize that there is a significant learning rate early in a program; but, after a certain point in time or in the program, this rate gradually disappears and the value become asymptotic to some constant.

5.1.3 Development of Baseline Values - The launch operations and mission control and support are discussed here. These are the activities normally considered when ETR or WTR activities are discussed.

5.1.3.1 Launch Operations - The recurring adjusted data for Gemini launches 5 through 12 was fit by regression analysis to both a "learning curve" and a hyperbolic equation. In some cases, fewer than the eight data points available were analyzed to adjust the data for the "wild points" discussed previously. For example, the initial analysis for the cost-subcategory of Industrial Area Activities indicated that the greater the number of launches, the greater would be the unit cost. Since such a conclusion does not agree with experience, a deeper analysis of this cost data was necessary.

The industrial area activities for Gemini 5 and 7 were considerably below the trend of the data. These spacecraft were prepared with a minimum of delay, and, in the case of Gemini 7, under great urgency to get the launch off quickly. In contrast, for Gemini 9 an unusually high number of problems during the industrial area activities required extensive retesting and some component replacement. Both situations are non-standard and therefore these three data points were neglected; a much more reasonable "learning curve" equation resulted.

This indicated an approximate learning rate of 76 percent. A similar approach was followed for any cost subcategory where anomalies could be identified but not quantified.

During pad assembly operations, both Gemini 9 and Gemini 12 encountered more than the usual number of difficulties. This ran the man-hours expended in this activity for these two considerably above the trend line. Also, the reverse was true of Gemini 10 which was nearly a "textbook" operation. For the Pad Assembly Operations, the data indicated little "learning" was actually experienced in this activity. Initial data anlaysis indicated a slight negative learning, and the adjusted data indicated about 98 percent learning.

As mentioned previously, Gemini 9 was plagued by problems throughout the Cape operations. In On-Pad Testing, it required about twice as much effort as expected, based on the trend line. During the Countdown Activities it required about 50 percent more effort than expected. In both of these cost subcategories, Gemini 9 data was neglected in developing the equations expressing the trends.

Gemini 6 and Gemini 10 both experienced smooth countdown operations, and were considerably below the trend line. These points were neglected in the curve fitting for the equations representing Countdown Activities.

In the last subcategory of Miscellaneous Operations data for Gemini 5, were neglected as a "wild point". Both equations were fitted to this latter category data since this particular category was expected to experience a high initial learning rate and, after a moderate number of launches, approach some nearly constant value.

Since the equations developed were based upon Gemini data, it seemed reasonable to further adjust the developed equations so that they will reproduce the Gemini launch operation actuals for Gemini 5 through 12. This involves checking the recurring costs for Gemini 5 through 12 against the estimates from the various equations, and adjusting the coefficients of the equations accordingly. The resulting man-hour totals for the Launch Operations is shown in Table 5-2. This represents the estimated actual man-hours expended in launch operations, based upon the developed equations.

operations, based upon the developed equations.

Table 5-2

Adjusted Gemini Operations and Support Costs

		Manhours
Launch Operations		724,313
Industrial Area Activities	112,987	
Radar Calibration and Pyro Buildup	65,823	
On-pad Assembly Activities	204,937	
On-pad Test Activities	98,800	
Countdown	105,699	
Miscellaneous Activities	136,067	
Mission Control and Support		2,533,193
Mission Control	374,874	
Support Activities (general)	1,635,161	
Support Activities (recurring)	523,158	
Additional AGE		814,052
AGE Maintenance		523,501
Facility Activation		220,102
Facility Maintenance		137,090
Totals		4,952,251

These adjusted equations for launch operations provide a unit man-hour cost for each activity as a function of the specific number of the launch. If these are summed over the total number of launches involved, the total man-hours for each activity can be estimated. This total and a labor rate will provide a dollar value for each activity.

The resulting basic equations for the launch activity man-hours per launch as a function of the launch number are:

Industrial Area Activities

$$1 < N \leq 10 \qquad C_1 = \sum_{N=1}^{N} 18590 \; N^{-.40044}$$

$$N \geq 11 \qquad C_1 = \sum_{N=11}^{N} 4977 + \frac{24433}{N}$$

Radar Calibration and Pyro Buildup Activities

$1 < N \leq 10 \qquad C_2 = \sum_{N=1}^{N} 10094 \; N^{-.34937}$

$N \geq 11 \qquad C_2 = \sum_{N=11}^{N} 3413 + \frac{11441}{N}$

On-Pad Assembly Activities

$\text{All } N \qquad C_3 = \sum_{N=1}^{N} 19373 \; N^{-.02465}$

On-Pad Test Activities

$1 < N \leq 10 \qquad C_4 = \sum_{N=1}^{N} 12160 \; N^{-.19683}$

$N \geq 11 \qquad C_4 = \sum_{N=11}^{N} \frac{10^4}{1.45870 - \frac{1.62251}{N}}$

Countdown Activities

$1 < N \leq 10 \qquad C_5 = \sum_{N=1}^{N} 13{,}831 \; N^{-.23839}$

$N \geq 11 \qquad C_5 = \sum_{N=11}^{N} \frac{10^4}{1.44312 - \frac{1.84469}{N}}$

Miscellaneous Activities

$1 < N < 10 \qquad C_6 = \sum_{N=1}^{N} 45{,}325 \; N^{-1.00615}$

$N \geq 11 \qquad \sum_{N=11}^{N} \frac{10^4}{3.67781 - \frac{13.3646}{N}}$

One additional procurement cost usually associated with the launch operations is the cost of propellants and gases. These have been specifically excluded from this analysis, but will be included in the cost module portion of the optimization model.

Based upon the Gemini data, all six cost subcategories indicated that a reasonable learning rate was experienced in the Cape activities. Except for the Pad Assembly Activities and Miscellaneous Activities noted previously, this learning rate was in the 75 percent to 80 percent range. However, as noted, this high learning rate is expected to decrease as the number of launches increases. Thus, the leveling out of the learning rate will begin at about the twelfth launch, and the learning rate will be nearly zero by the fiftieth launch. The equations developed from the data reflect this assumed pattern. These six equations are shown in Figures 5-1 and 5-2.

The average launch operations labor costs for the integral upper stage propulsion system of spacecraft concepts D, E, and F can be approximated by the relationship

$$\bar{C} = 2.79 \times 10^6 \; R^{-.583}$$

This expression was derived from historical data as shown in Figure 5-3. It does not provide for a variation sensitive to propulsion system complexity or system size. As seen in the figure, these launch operations costs are somewhat dependent on vehicle size but the data is insufficient to permit formulation of a relationship expression. The selected expression falls in the expected size range of the vehicles of this study. It should provide a reasonable approximation of the delta costs when limited to the integral upper stage propulsion system.

5.1.3.2 Support Activities - Launch site support involves recurring activities dependent on the launching of a vehicle, and on sustaining activities (continuous cost items) that reflect the cost of being there. The Gemini data had these features and the combined total was listed in Table 5-1. As discussed, this basic data required adjusting to make it more useful.

The recurring Support Activities data was fitted to a "learning curve equation. The resulting equation, after adjusting the data, was:

$$C = \sum_{N=1}^{N} 76{,}301 \; N^{-.31380}$$ and is shown in Figure 5-4

Figure 5-1

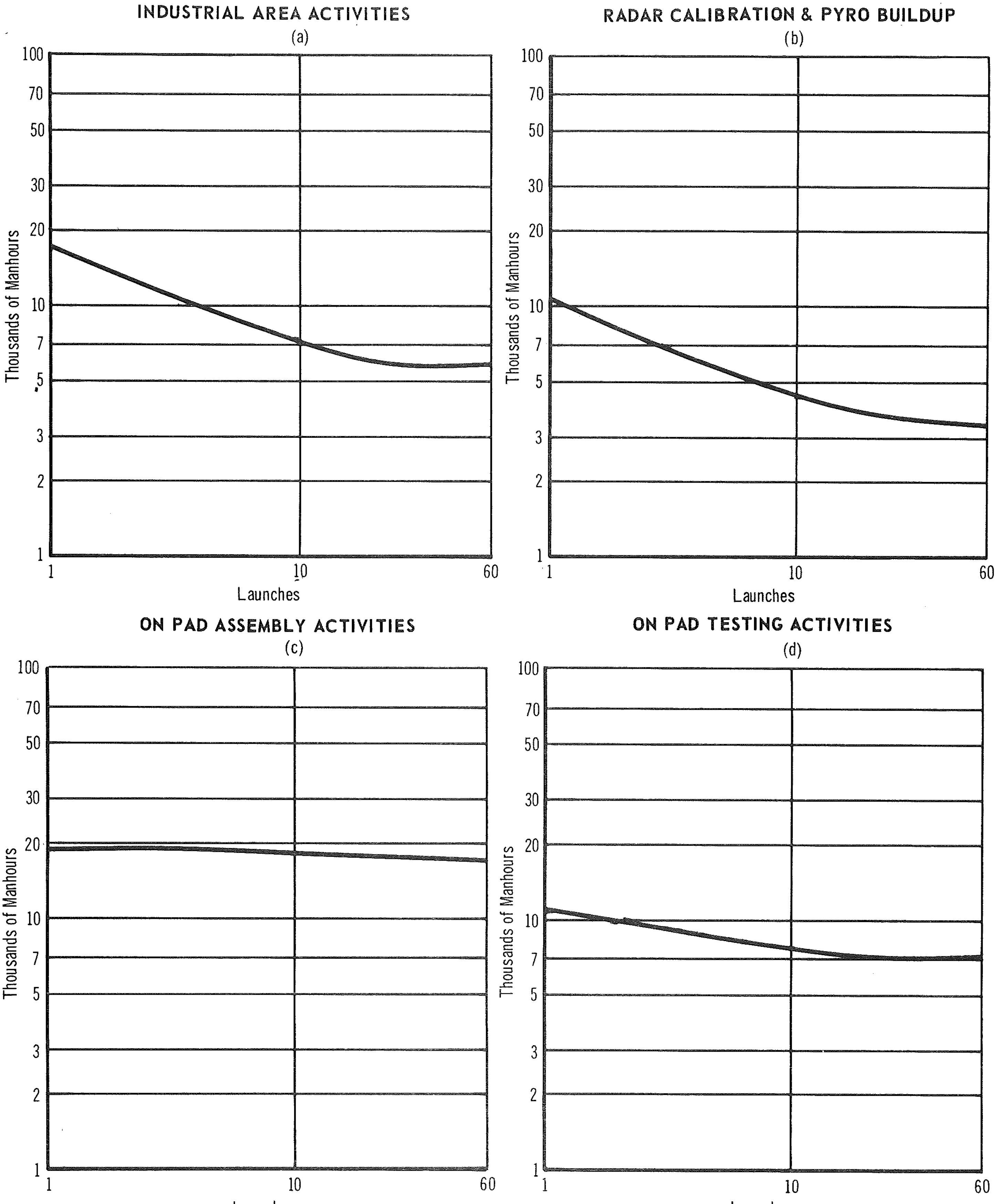
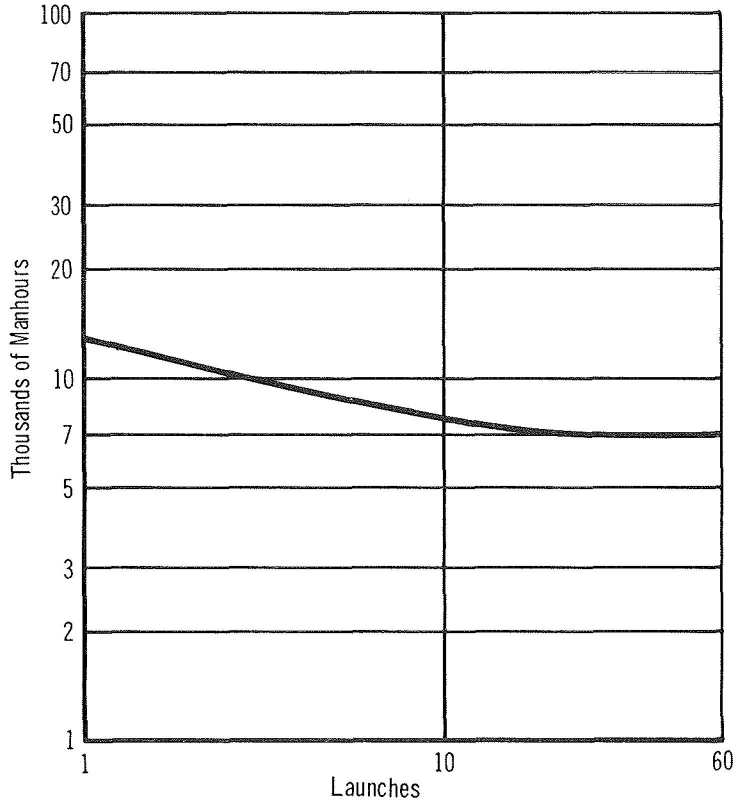

INDUSTRIAL AREA ACTIVITIES
(a)
RADAR CALIBRATION & PYRO BUILDUP
(b)
ON PAD ASSEMBLY ACTIVITIES
(c)
ON PAD TESTING ACTIVITIES
(d)
Thousands of Manhours
Launches
100
70
50
30
20
10
7
5
3
2
1
10
60

Figure 5-2

COUNTDOWN



MISCELLANEOUS ACTIVITIES

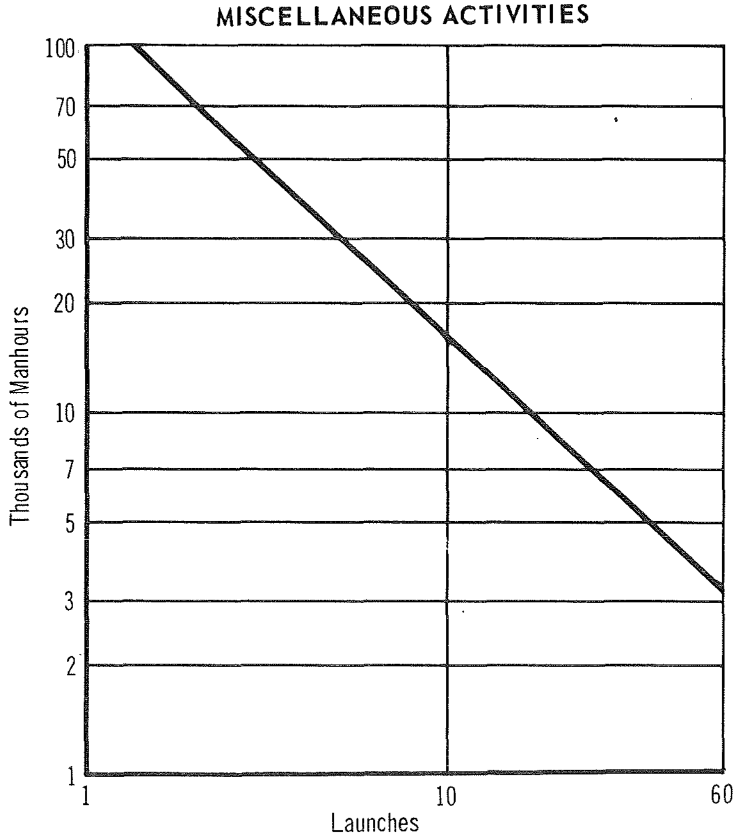


Figure 5-3

LAUNCH OPERATIONS COST
(1969 DOLLARS)

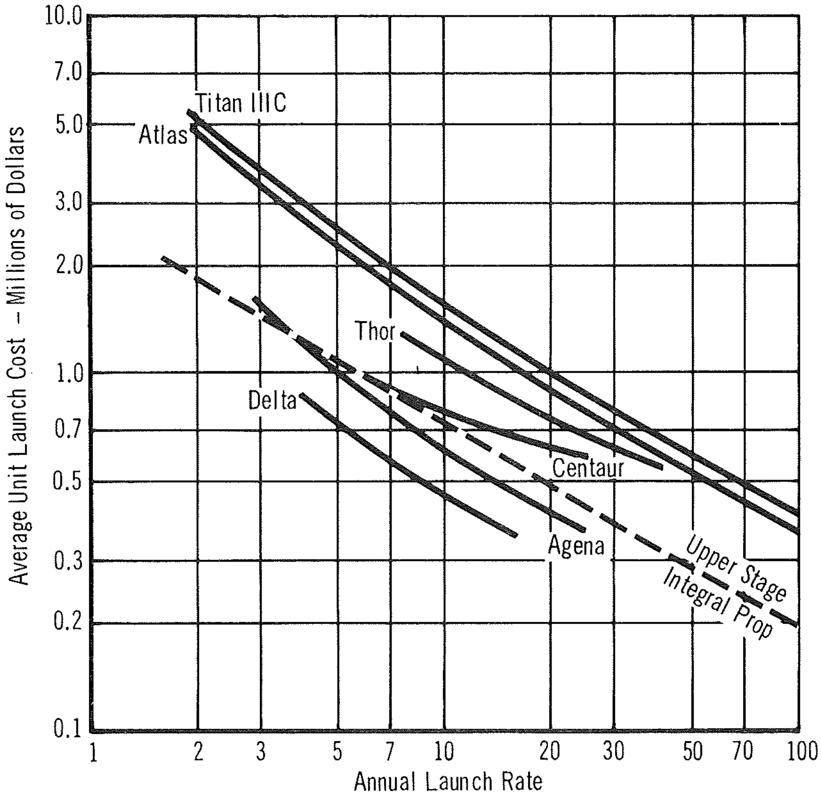
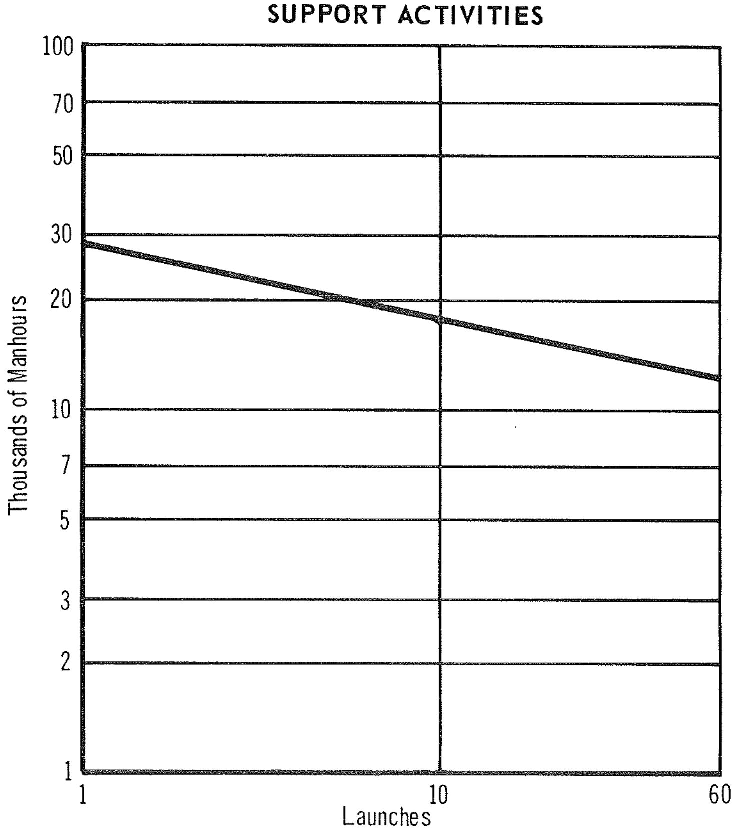


Figure 5-4

SUPPORT ACTIVITIES



These equations were used to determine the unit man-hour costs for the earlier launches and to extend the data to a greater number of launches. The totals for launches 5 through 12 agree with those for Gemini 5 through 12.

The other costs are more difficult to define in parametric terms. These costs are for activities which require a nearly constant staffing for the life of the program; i.e., ground crew training, materials and logistic support, liaison engineering, and indirect technical support all have essentially constant manpower loadings for the life of the program. Therefore, the most realistic parameter is time, either months or weeks of program duration.

The Gemini Cape activity contract ran 64 months from January 1962 to April 1967, but the first eight months and the last two months had very limited staffing. Therefore, for this analysis, it was assumed that the contract started at the ninth month after the basic spacecraft contract, and ran for 54 months. The Support Activities staffing during this time totaled 2,158,319 man-hours (see Table 5-2). The adjusted data discussed above indicated that 523,158 manhours of this was of a launch-related recurring nature. This left 1,635,161 manhours to be spread over 54 months amounting to 30,281 manhours per month, or about 175 persons.

The resulting expression for Support Activities is the sum of the two costs:

$$C_7 = 30,281\ (L - 11) + \sum_{N=1}^{N} 76,301\ N^{-.31380}$$

where L = program life in months

N = launch number

5.1.3.3 Mission Control - Like the continuous costs of support activities, Mission Control Costs of the Gemini were charged agains the total program. Thus, the same approach was used to develop a parametric equation for Mission Control.

The Gemini data of tables 5-1 or 5-2 indicates 374,874 manhours were expended. If these are spread over 54 months, the result is 6,942 manhours per month or about 40 persons. The equation for Mission Control manhours is:

$$C_8 = 6,942\ (L-11)$$

where L = program duration in months

5.1.3.4 Other Cost Categories - There were four other cost categories in the Gemini program contract that are not closely identified with the launch activities as those previously discussed. Two of these are a non-recurring cost and two are a function of the number of launches.

The non-recurring cost activities are Launch Site Peculiar AGE and Facility Activation, both a part of the development phase. These costs are discussed here, only, because they are a part of the original Gemini Contract and were considered in the data analyses. These two costs were carried as constants through the organization and adjustment of the Gemini data and the development of the baseline equations.

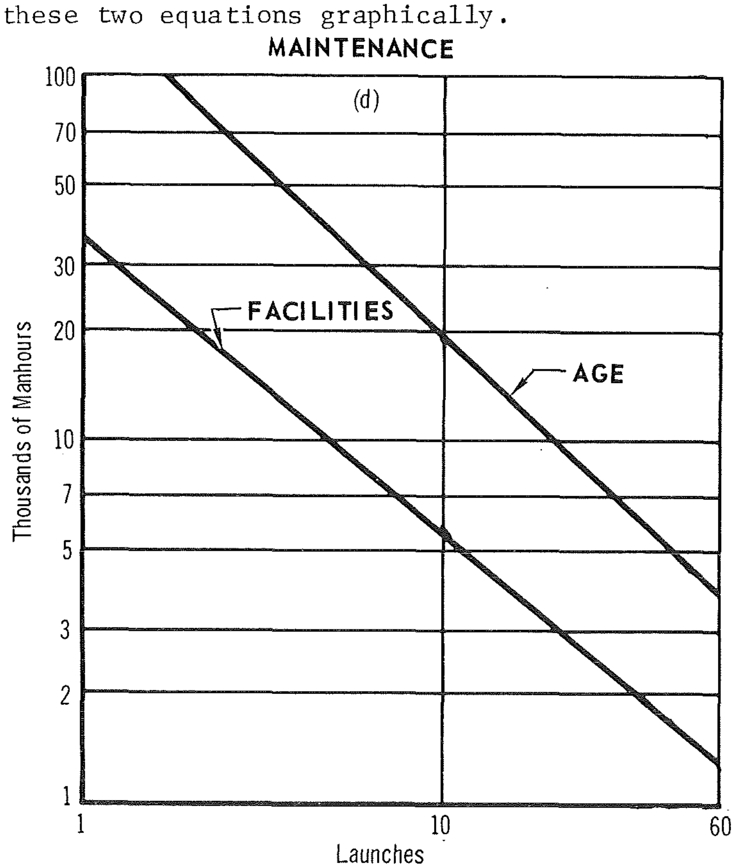
The recurring costs, AGE Maintenance and Facility Maintenance, are both directly related to the number of launches. These two costs were also analyzed. "Learning curve" equations were fitted to the data using the same techniques as those used to evaluate the launch operations data. The resulting equations show a high learning rate and were:

AGE Maintenance $$C_8 = \sum_{N=1}^{N} 162{,}251\ N^{-.93291}$$

Facility Maintenance $$C_9 = \sum_{N=1}^{N} 38{,}218\ N^{-.83142}$$

Figure 5-5 shows these two equations graphically.

Figure 5-5



5.1.4 Size Effects - Launch operations and support activities are influenced by the size of the vehicle being launched. A previous study of Gemini and Mercury launch operations and support activity costs analyzed the data to establish basic parametric relationships. The relationship between launch operations costs and spacecraft size was found to be proportional to the first unit costs of the spacecraft. Since first unit costs are strongly influenced by the type and amount of material and equipment in the vehicle, they are a good measure of the vehicle size and complexity. The relationship between launch operations or support costs, in manhours, and size or complexity has the basic form:

$$\text{Cost in manhours} = K\ (T_1\ \text{Cost})^{.485}$$

where K ≃ 59.8 based upon the previous Gemini-Mercury data analysis. The size factor would have the form:

$$\text{Size Factor} = \frac{K(\text{Cost}_2)^{.485}}{K(\text{Cost}_1)^{.485}}$$

where (Cost_1) was $38.0 millions, the estimated first unit cost of Gemini. For this optimization model, the size effect upon the launch operations, recurring support activities, and facilities maintenance is defined by this relationship:

$$\text{Size Factor} = 2.11 \times 10^{-4}\ (T_1\ \text{Cost})^{.485}$$

where $(T_1\text{Cost})$ is the first unit cost of the complete spacecraft, ie. everything above the booster.

There is no significant size effect upon the duration sensitive costs or upon the AGE maintenance costs.

5.2 On-Orbit Operations - It was assumed that on-orbit operations would be those activities performed while the spacecraft is docked to the space station. During this time, the spacecraft draws its support from the space station and ground control activities are assumed to be only those associated with the space station. Therefore, for this study and the resulting model, there are no on-orbit operations for the logistics mission.

5.3 Recovery Site Selection - Section 4.5 of book 1 discusses the relationship between number of recovery sites, the location of those sites, the cross range or lateral range capability of the spacecraft, the amount of in-orbit loiter time permitted, and the amount of propulsive ΔV needed to satisfy all of the requirements. Further investigation was conducted using a statistical analysis as part of the operational mode trade-off since sites cannot be located as "ideally" as is assumed in a parametric analysis.

5.3.1 Introduction - The nominal mission considered involved a trip to an orbiting space station and return within three days. After the return decision has been made and all checks and preparations for deorbit and entry completed, the return cycle is initiated by separating the spacecraft from the station, utilizing a ΔV of about 10 ft/sec. For a normal mission, the return time is known far enough in advance to compute the orbital ground track of the spacecraft during deorbit and entry, and to be able to determine the crossrange and phasing requirements. These, in turn, determine the number of orbits for waiting and phasing needed to reach a specified return site.

For the M2-F2 spacecraft, the aerodynamic maneuver can provide a 24-hour return capability without the use of a phasing or plane change maneuver. In this case, the spacecraft can remain docked to the space station until one or two orbits before the daily overpass nearest the selected landing site.

For the ballistic spacecraft, the crossrange to reach the selected return site will usually exceed its aerodynamic maneuver capability. Thus, phasing will be required to accomplish the orbit track shift to bring the spacecraft ground track within its maneuver capability of the spacecraft.

The retrograde ΔV for either spacecraft is the same, and a function of orbit altitude. For the nominal 300 na mi orbit, a ΔV of about 500 ft/sec is needed. For a ballistic spacecraft, it is advantageous to orient the retro thrust vector to minimize range dispersion sensitivity.

A cost is associated with either providing additional propulsive maneuver capability to the spacecraft or providing more return sites. This analysis attempts to define the pertinent parameters involved so that a meaningful trade-off can be made.

5.3.2 Statistical Analysis of Return Sites - Much literature is available on spacecraft recovery at land bases (Reference 5-2 through 5-15). A review of this material indicated there was much overlap in the coverage. However, the work of Dr. Chu (Reference 5-7) was probably the most comprehensive. He has developed a computer program to determine the probability of a spacecraft returning to a selected network of return sites, given the crossrange capability of the spacecraft and the orbital inclination and altitude. A similar program has been developed at MDAC and adapted to this study. The results have been used to adjust the parametric data presented in Section 4.5 of Volume II, Book 1.

5.3.2.1 Ground Rules for this Analysis - The guidelines for this return site study are as follows:

a. Spacecraft orbit altitude is 300 na mi.
b. Orbit inclinations are 50 deg, 70 deg and 90 deg.
c. Spacecraft crossrange capability is 150 na mi and 600 na mi.
d. Maximum wait in orbit is 24 hr.
e. Return sites will be active USAF bases.
f. Return sites will be in continental U.S.
g. Return sites will be near navigable waters.
h. Number of return sites will be a minimum.

An initial set of twelve USAF bases located in the northern latitudes of the continental U.S. were screened and, because of one or more of the guidelines, the number was reduced to seven which were:

a.	McChord AFB, Washington	47.5 deg N
b.	Paine Field, Washington	47.92 deg N
c.	Duluth Intl., Minnesota	46.83 deg N
d.	Sawyer AFB, Michigan	46.35 deg N
e.	Wurthsmith AFB, Michigan	44.47 deg N
f.	Plattsburgh AFB, New York	44.65 deg N
g.	Loring AFB, Maine	46.95 deg N

Later in the analysis, Edwards AFB, California was added to the sites under consideration. It was also found that Paine Field has been converted to civilian use.

The candidate return sites were analyzed by the computer program and these five locations were selected:

a. McChord AFB, Washington
b. Sawyer AFB, Michigan
c. Wurtsmith AFB, Michigan
d. Loring AFB, Maine
e. Edwards AFB, California

These sites were selected without considering surrounding terrain, weather, or population concentrations. Also, these sites were considered for missions having orbital inclinations of exactly 50 deg, 70 deg, and 90 deg. Other sites might be selected for missions in the 75 deg to 85 deg range or in the 55 deg to 65 deg range.

One site was not considered as a realistic case because weather or other conditions can deny its use for extended time periods. The parametric analysis of section 6.4 of book 1 did consider the situation where only one site of a two/site network was available.

5.3.2.2 Two Site Recovery Network Requirements - The parametric analysis of section 4.5 in book 1 was based on the assumption that the sites were equally spaced around the world at the latitude specified. This ignored geographical or political considerations. A more realistic assumption is that the sites are all located within the continental United States (CONUS).

Of the five locations noted above, McChord AFB, Washington and Loring AFB, Maine are the obvious choices if only two existing sites are considered. The computer model indicates that at least 180 na mi lateral range capability is necessary to return to these sites from a 50 deg or 70 deg inclined orbit and about 240 na mi lateral range for return from a 90 deg inclined orbit within 24 hours with a probability of 1.000.

Referring to the parametric analysis of section 4.5 in book 1, two ideally located return sites would require the vehicle to have 14 na mi, 170 na mi, or 165 na mi lateral range, respectively, for 50 deg, 70 deg, and 90 deg inclined orbit to return within 24 hours. Thus, more maneuver capability must be provided onboard the ballistic vehicle. The M2-F2 vehicle has adequate lateral range capability.

To provide the additional 30 na mi or 90 na mi of lateral range for the ballistic by orbit phasing and up to 24 hours to return, an additional ΔV of about 15 ft/sec or 35 ft/sec must be provided by the spacecraft propulsion system.

5.3.2.3 Three-Site Recovery Network Requirements - Adding a site between the previous two is the obvious next step in making a three site network. The site selected was Sawyer AFB, Michigan. For this network, the computer probability model indicates that 180 na mi, 180 na mi, and 240 na mi are required to ensure returning to one of these three sites within 24 hours. Comparing this with the previous two site network case shows that adding this site has had little effect on the vehicle. The maneuver ΔV requirements are the same.

The parametric analysis in book 1 indicated that three ideally located sites could provide return within 24 hours from all three orbit inclinations for the ballistic vehicle with 150 na mi lateral range capability. However, this statistical analysis indicates that this is not possible for three sites in the CONUS. Additional maneuver capability in the ballistic vehicle is required.

5.3.2.4 Four-Site Recovery Network Requirements - Adding Wurtsmith AFB, Michigan, as a fourth site in the CONUS recovery network reduces the requirements for the 90 deg inclined orbits. The computer probability model indicates that 180 na mi, 180 na mi, and 150 na mi, respectively, for the 50 deg, 70 deg, and 90 deg inclined orbits are required to ensure return to one of the network sites within 24 hours.

5.3.2.5 Value of Edwards AFB as a Site - Since Edwards AFB, California is currently used for test flights of all types of advanced aircraft and spacecraft, it is an attractive consideration for a return site. All of the tracking and guidance equipment is readily available, the personnel are experienced in handling the operations involved in landing and recovering the type of spacecraft being considered, and the terrain is flat and open.

If Edwards AFB is added to the previous four-site network, a slight improvement is noted. The requirements become:

Orbit Inclination	Ballistic Vehicle	M2-F2 Vehicle
50 deg	15 ft/sec	0
70 deg	0	0
90 deg	0	0

5.3.3 Conclusions - When actual site locations are considered statistically, more sites are required than is indicated by the parametric analyses, or else it is necessary to provide the spacecraft with additional propulsion capability to do maneuvers for phasing or plane change. For the return within 24 hours case, the ballistic spacecraft must do phasing maneuvers to return to a network of sites. Therefore, for "real world" situation, the ballistic spacecraft must be provided with enough additional ΔV capability up to 35 ft/sec to ensure return. The M2-F2 has no such problems until quick return is considered. Quick return analyses were not made using the statistical probability model.

The parametric quick return data of section 4.5, book 1, is satisfactory for the operational mode effects analysis capability to be included in the optimization model. The trade-off between the ΔV required versus the number of recovery sites will be evaluated in the Task 6 analyses.

5.4 Recovery Forces and Costs - In this study it was assumed that the primary recovery mode would be land recovery. Water recovery was considered only for the all-expendable vehicles and as the launch or boost abort mode. The recovery force analysis follows these guidelines and is based on the data of Reference 5-16.

5.4.1 Land Recovery - It was assumed in the case of new sites that a minimum amount of new facilities would be procured. In the case of the horizontal landing recovery sites, one long runway with a few buildings and hangars, and living quarters for a few hundred persons would be built in a favorable (or ideal) location. The parametric analysis of section 4.5, book 1, utilized basic orbit mechanics and location assumptions in developing that data. The orbit mechanics requires that the most favorable recovery site latitude be within $\pm$ 2 deg of the orbit inclination for the ballistic configurations of this study. The two degrees is a function of the cross range capability of the vehicle (assumed to be 150 na mi), and increases with greater cross range capability.

A new facility for a vertical landing system requires a lesser investment because the runway length is significantly reduced, neglecting any consideration of a landing strip for large cargo aircraft to support the transportation phase of the recertification cycle. Also, the vertical landing vehicles inherently have a greater disperison requiring a much greater "controlled" land area surrounding the center of the return site.

This is accomplished by leasing surrounding acreage so as to limit its usage to grazing or crop cultivation. Once the site has been established, it is assumed that it would be turned over to the military for sustaining operation. During each recovery period, all activities not connnected with the spacecraft recovery operations will be suspended for a period of 72 hours or less. The rest of the time the routine military operations would continue. This is similar to how NASA and the military presently operate. For each recovery NASA "hires" the U.S. Navy for a few days.

If existing USAF base facilities are utilized, it is assumed that the only investment would be for the unique equipment required for the spacecraft recovery operations, including tracking and control or guidance command. A small cadre of technicians would be at each return site, the balance of the force would be military personnel "hired" for the few days of each recovery operation. Military vehicles and emergency equipment would also be "hired" or leased for the period.

Basic Cost Data - There are four recovery site approaches, depending on the vehicle and the recovery site philosophy. There is the ideally located site for horizontal or vertical landing and the existing site for horizontal or vertical landing. Cost data has been prepared for each of these, based upon Reference 5-16, and listed in Table 5-3.

A detailed breakdown of these costs is shown in Table 5-4.

In this breakdown, the personnel costs are a function of the recovery rate. The basic data was for a rate of five recoveries per year. As the rate increases, the costs would also increase. There can be some cost improvement as the rate increases. Since there is no data to justify this, a constant cost is used in this study.

Table 5-3

Recovery Site Costs

Ideally Located Site - all new facilities

	Horizontal Landing	
Investment		($8.234 M)
Facilities	$6.019 M	
Equipment	$2.215 M	
Operations		
Personnel	$84,000/recovery	
Equipment Maintenance	$23,083/month	
	Vertical Landing	
Investment		($7.569 M)
Facilities	$2.599 M	
Equipment	$2.270 M	
Land Leases (10 years)	$2.700 M	
Operations		
Personnel	$120,000/recovery	
Equipment Maintenance	$ 20,750/month	

Existing AF Base Site

	Horizontal Landing	
Investment		($2.065 M)
Facilities	-0-	
Equipment	$ 2.065 M	
Operations		
Personnel	$ 84,000/recovery	
Equipment Maintenance	$ 21,500/month	
	Vertical Landing	
Investment		($2.120 M)
Facilities	-0-	
Equipment	$ 2.120 M	
Land Leases	-0-	
Operations		
Personnel	$120,000/recovery	
Equipment Maintenance	$ 19,333/month	

Table 5-4

Site Cost Breakdown

Facilities (Costs in $1000)

	Horizontal		Vertical	
	New	Existing	New	Existing
Runway	$2,507	-0-	-0-	-0-
Lighting	$ 650	-0-	10	-0-
Fueling Equipment	$ 180	-0-	77	-0
Hangars	$ 540	-0-	380	-0-
Fire Station and Equipment	$ 133	-0	125	-0-
Power Station	$ 350	-0	188	-0-
Equipment	$ 125	-0-	125	-0-
Medical Facility	$ 235	-0-	235	-0-
Control Tower and Weather Station	$ 175	-0-	80	-0-
Land Leases (cost/year)	$ -0-	-0-	270	-0-
Land Purchase	$ 333	-0-	45	-0-
Roads	$ 225	-0-	375	-0-
Living Quarters	$ 638	-0-	689	-0-
	$6,019	0	2,599*	0

*does not include land lease cost

Equipment (Costs in $1000)

	Horizontal New	Horizontal Existing	Vertical New	Vertical Existing
Radar	$ 500	500	500	500
Digital Command	$ 300	330	330	330
Computer Data Processor	$ 130	130	130	130
Communications	$ 185	185	185	185
Master Timing	$ 25	25	25	25
Medical Equipment	$ 100	50	100	50
Helicopters	$ 800	800	800	800
Crash and Fire Vehicles	$ 100	-0-	125	25
R/V Retrieval Equipment	$ 30	30	50	50
R/V Crew Retrieval Equipment	$ 15	15	25	25
	$2,215	2,065	2,270	2,120

Operations (Costs per year in $1000)

	Horizontal New	Horizontal Existing	Vertical New	Vertical Existing
Spares, Maintenance, Equipment Leading, Travel	$ 277	258	249	232

Personnel (Costs per year in $1000)

	Horizontal	Vertical
Personnel (5 recoveries/year	$420	600

The equipment costs are not rate sensitive for rates less than 30 per year, but are a continuing fixed monthly cost. This covers the spacecraft and mission unique equipment spares and maintenance, the cost of "hiring" the military equipment, and the routine travel.

5.4.2 Water Recoveries - Water recoveries concentrate on safely recovering the spacecraft crew, with only secondary concern for recovering the spacecraft since it will not be used again. Thus, the focus is on getting to the splashdown site quickly with the flotation equipment and personnel trained in its use. In the abort situations, this force is usually provided by the U.S. Navy "hired" for the period of the launch. Routine ocean recovery of a returning spacecraft will be accomplished by a specialized recovery ship.

5.4.2.1 Abort Recovery Forces - There are two standby recovery forces required at each launch. One is for launch abort on or near the pad, the other is for boost abort during boost from seconds after lift-off to orbit injection. These forces ensure safe recovery of the crew within a few hours should an abort occur.

Launch Abort Recovery Force - A force of two ships, five helicopters, and three rescue aircraft will ensure crew recovery. The ships are on station just offshore on the boost trajectory trace. The helicopters operate onshore and close-in, carrying rescue personnel and flotation equipment which can be dropped to keep the spacecraft afloat until a ship arrives. The aircraft perform the same function further downrange.

Boost Abort Recovery Force - The downrange recovery force size is sensitive to the launch azimuth fan to be accommodated. For a reasonable fan of 10 deg or so, a recovery force of eight ships for a ballistic launch or six ships for an M2-F2 launch is necessary. The force size depends on the crossrange maneuver capability; the bigger the maneuver capability, the fewer ships are required. In present practice, there are several aircraft on-station in the area filling the gaps in the coverage. These gaps are the range limits the recovery ships can travel in a specified maximum time. For example, the ships can all cruise one hundred na.mi.in five hours. The spaces between ships that cannot be covered within five hours are covered by aircraft. It is assumed that five aircraft are necessary.

Abort Recovery Force Costs - The abort recovery forces are assumed to be U. S. Navy or USAF units "hired" for each launch. It is assumed that the surface ships are "hired" for a two day period at each launch attempt and that the aircraft are "hired" for 10 hours of flying time at each launch attempt. For the launch abort recovery force, the estimated cost is $25,000 per launch attempt. The cost of the boost abort recovery force is a function of maneuver capability of spacecraft and, thus, a function of the type of spacecraft. The estimated cost of the recovery force for a ballistic spacecraft launch attempt is $217,000, and for an M2-F2 spacecraft launch attempt - $175,000.

5.4.2.2 Expendable Vehicle Recovery Force - For water recovery, it was assumed that a surplus cargo or landing ship would be converted by retrofit of the necessary equipment. The cost of the modifications and equipment was estimated, but the cost of the basic ship was not. The operating cost is higher, since it takes longer to complete the recovery operations on water than on land. For this study, it is assumed that 14 days are required.

For future spacecraft operations, the landing dispersions for vertical water landings should be as small as those of the last few Gemini flights and recent Apollo flights. The spacecraft should splash-down within six or seven na mi of the target so that a single recovery ship is all that is needed. If additional escort ships are desired, they could be operational U.S. Navy ships but no costs have been estimated for these. The costs are listed in Table 5-5.

Table 5-5

Water Recovery Costs

Vertical Water Landing - per ship costs

Investment		($2.885 M)
Facilities	$1.250 M	
Equipment	$1.635 M	
Operations		
Personnel	$132,000/recovery	
Equipment Maintenance	$ 28,875/month	

5.4.3 Recovery Costs - For this study, two-site and four-site recovery networks were considered. The two-site networks were new, ideally located or existing facilities. The four-site networks were existing USAF land bases within CONUS or a network of four ocean recovery locations favorable for recovery.

The resultant cost relations are listed in Table 5-6 and a typical example is shown in Figure 5-6. Learning was not applied to these costs because of their nature. The rate is very non-uniform, the personnel involved are subject to frequent change, and the costs charged are at a basic fixed rate per hour whether they are for personnel or maintenance. Within the constraints, it seems valid to neglect any cost improvements due to learning.

5.4.4 Application - These data will be utilized in the optimization model to do trade-offs between the cost of ΔV for maneuver and the cost of operating more sites. In quick return cases, there can be a cost reduction to operating more sites and providing less maneuver capability on the vehicle. These operational options will be investigated during the latter phase

5.5 Recertification or Refurbishment - This subject has been the source of much controversy in recent years, but little or no experience has been gained to date. Several vehicles over the past few years have been recovered but, except for those recovered by air snatch, all have been recovered from the water. The effects of the water immersion have completely overshadowed the deterioration due to spaceflight. The Prime program has recovered a few vehicles by air snatch. These vehicles have been in excellent condition, all systems operated within prelaunch tolerances and, excluding the intentional structural damage due to jettisoning of doors and covers, the structure was in excellent condition. However, they were not recertified and reflown.

Another source of comparable data is the X-15 research program. The number of man-hours spent in recertification was extremely high as compared with other recent studies. Some of the factors which have been suggested as contributing to the high recertification are that the amount of hand work is very high, and that it is a research program rather than an operational program.

A recent analysis of aircraft maintenance experience was considered in Reference 5-21. This data was used to validate trends and learning rates developed from the other data, since there is little valid experience on spacecraft systems.

Table 5-6

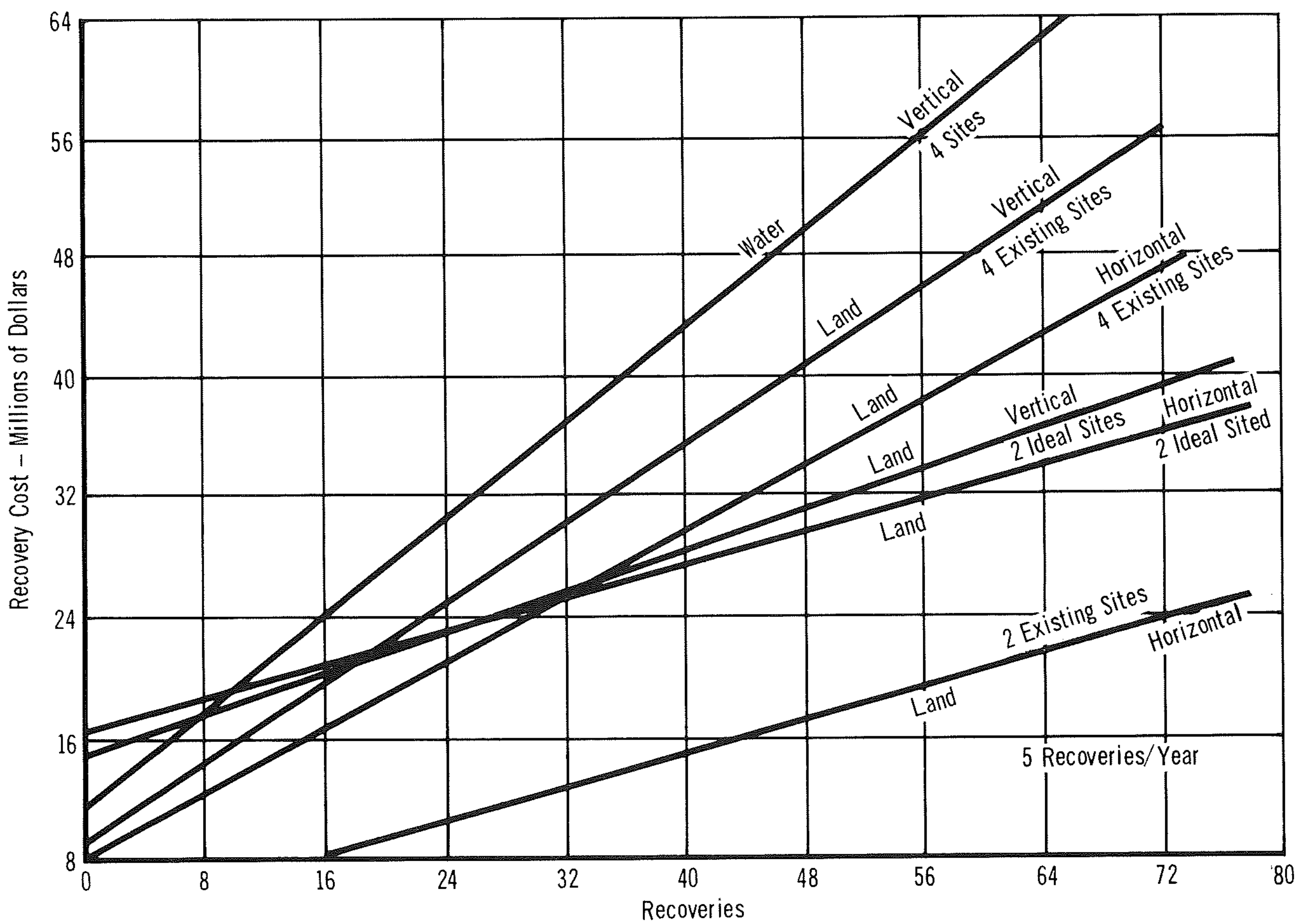
Typical Recovery Costs

(FOR A 5 RECOVERY/YEAR RATE)

	Horizontal	Vertical
Ideally Located Two-Site Network		
Investment	$16 468 M	$15.138 M
Operations/recovery	$278,800	$339,560
Existing AF Base, Two-Site Network		
Investment	$ 4.130 M	$ 4.540 M
Operations/Recovery	$271,280	$333,000
Existing AF Base Four-Site Network		
Investment	$ 8.260 M	$ 9.080 M
Operations/recovery	$542,560	$666,000
Four-Site Water Network		
Investment		$ 11.540 M
Operations/recovery		$805,200
Abort Recovery/launch	$200,000	$242,000

Figure 5–6

RECOVERY COST COMPARISONS



Therefore, the following analyses were based upon recent studies. The man-hours and flow times established are neither conservative nor optimistic, but represent what might be possible in a fully operational program. Initial cycle times require about four months, but learning would reduce this to about two months at about the fiftieth unit. Size, configuration, and degree of integral propulsion are strong factors in determining the cycle time.

5.5.1 Activities Included in Recertification - The term recertification was adopted from aircraft operations terminology. In this analysis and in the resulting optimization model, it includes the following specific cost categories:

Transportation - from the recovery site to the refurbishment site and from there to the launch site.

Refurbishment - the reconditioning of the vehicle into a flightworthy system through a scheduled maintenance program and an allowance for unscheduled maintenance.

Testing - the routine sequential checkout of the refurbished vehicle similar to spacecraft systems tests during final assembly in the production cycle.

Operation Spares - those parts necessary to support the scheduled maintenance program within the refurbishment activities.

Unscheduled Maintenance - repair of systems failures done in parallel with the scheduled maintenance activities.

Replenish Spares - those parts necessary to support the unscheduled maintenance activities.

Hot Firing - when applicable, the test hot firing of large upper stage propulsion systems which are integral to the spacecraft.

Within the refurbishment category, a further breakdown considers the structure and thermal protection system refurbishment and the other subsystems refurbishment as two independent functions. The structural and thermal protection system refurbishment includes removal of access doors and any remaining portions of jettisoned panels such as window covers or landing gear doors, removal of all exterior panels scheduled to be removed, and detail inspection of the remaining exterior surface and all exposed structure and landing gear. This is followed by repair or replacement of any damaged structure or exterior surface (unschedule maintenance) and the installation of all exterior surfaces, except access panels, and detailed inspection.

Concurrent with the structure and thermal protection refurbishment activities, the various subsystems are serviced or replaced and inspected per the scheduled maintenance program. Any other failure or damage is repaired at this time. When both phases of the refurbishment are complete the vehicle goes to the testing activities. There circuit integrity is verified and the overall flight-worthiness of the spacecraft validated.

5.5.2 Data from Other Studies - Several recent studies have considered the problems of recertification or refurbishment (see References 5-17 through 5-20). These studies provided the background data which led to the specific values selected for use in the optimization model. These data had little commonality, exhibiting a wide range of values for such basic parameters as flow time, total man-hours required, refurbishment man-hours, test man-hours, material costs, and cycle costs. The specific values are discussed in following paragraphs.

Flow time is the calendar time required to process the spacecraft through the complete recertification cycle from loading at the recovery site to delivery to the launch site. In this study a minimum 3 day transportation period was included in the total flow time. It is also assumed that the entire operation is on a two-shift, five day week basis. The scope of the landing analysis was limited to: a) vertical on parachutes or horizontal on gliding chutes for ballistic vahicles, or b) horizontal for lifting body vehicles. All vehicles had detachable thermal protection panels. The flow time for these vehicles varied from 43.5 days to 122 days for a ballistic vehicle and from 46 days to 131 days for a lifting body vehicle.

The refurbishment flow time also varied over a wide range of from 21 days to 60 days for ballistic vehicles or from 35.4 days to 65 days for lifting body vehicles. The man-hours expended in this activity on the ballistic vehicle covered an even wider range from a low of from about 2700 to a high of 18,400, but the low value was based on a military staffing rather than a civilian industrial staffing. A more reasonable low value was 6,170 man-hours. The range of values for the lifting body vehicle was from 9,600 to 16,500 man-hours. In addition to these man-hours for the scheduled activities, there was an additional amount of man-hours for indirect labor charges amounting to over three times as much as the direct charges, ranging from about 29,600 to 55,200 for the ballistic and about 43,400 to 49,600 for the lifting bodies.

Similarly, for testing the flow time varied from 8.7 days to 52 days for ballistic vehicles and from 10.6 days to 56 days for the lifting body vehicles. The man-hours involved ranged from 14,600 to 42,000 for ballistic vehicles and from 14,600 to 45,375 for lifting body vehicles. The indirect labor man-hours varied from 93,400 to 126,150 for ballistic vehicles and from 93,400 to 136,125 for lifting body vehicles.

It was assumed that the baseline refurbishment site would be the factory where the vehicle was built originally. This allows a lower indirect rate than was used in the referenced studies since much of the indirect charges would be prorated over all of the factory activities, reducing the amount borne by any single activity. Thus, for the baseline, a 2:1 ratio was used rather than the 3:1. The baseline AGE was assumed to be automatic. This would be compatible with the present ACE facilities at the Eastern Test Range.

Thus, there have been many studies which have not converged to any meaningful values. Therefore, the values to be used were developed by examining the data collected in this analysis and adopting a middle-of-the-road approach.

5.5.3 Subsystem Expected Life Analysis - To evaluate an accurate dollar amount for the hardware for scheduled maintenance (refurbishment) and unscheduled maintenance, the operational life of the major components of each subsystem was developed. A review of historical data centered on both actual experience, i.e., Gemini program, and the results of several related studies (references 17, 19 and 20). The operational life of a component was determined from the estimated total test and operational time starting at the vendor's plant and continuing through the mission. The total useful life of a subsystem is reduced initially by the vendor test time and PIA (preinstallation acceptance) test time. The remaining life of the component is then used in mission operating time and recertification testing for as many missions as possible. The number of missions which can be performed by each component is used to determine the number of components for the entire program. The number of spare components for unscheduled maintenance is based on a percentage of the original refurbishment supply. The minimum percent used was 10 percent. For several components, experience has indicated that higher percents are required for a realistic estimate of the spares quantity. Table 5-7 presents the major components of each subsystem, the expected life in flights, and the percent used to determine the spares quantities.

Table 5-7

Refurbishment and Unscheduled Spares

COMPONENTS	EXPECTED NO. FLIGHTS	SPARES PERCENT
° Electrical Power System		
Batteries	1	20
Fuel Cells	10	10
° Environmental Control		
O_2 Supply and Management	11	10
Heat Transport Circuit	11	10
Water Supply and Management	11	10
° Guidance and Control		
Inertial Measuring Unit	4	100
Computer	11	10
Rate Gyros	7	20
Horizon Sensor Heads	1	10
Radar Altimeters	1	50
Rendezvous Radar	11	10
° Telecommunication		
UHF/AM Transceivers	11	10
Voice Control Center	6	10
° Landing System		
Parachute Subsystem	1	10
Primary Chutes	1	10
Drogue Chutes	1	10
Backup Chutes	3	10
Landing Gear Subsystem	1	10
Nose Gear	8	10
Main Gear Skid	4	10
° Propulsion		
Entry Control		
Engine	5	10
Fuel and Oxidizer Tanks	1	10
Vernier Maneuvering		
Engine	5	10
Fuel and Oxidizer Tanks	1	10
Main Orbital Maneuver		
Engine	5	10
Fuel and Oxidizer Tanks	1	10
Landing Assist Rockets	1	10
Integral - Upper Stage		
Engine	5	10
Lines and Values	5	20
° Launch Escape		
Tower Mounted Solid Motor	1	10
Strapon Solid Motors	1	10
Internal Solid Motors	Indef.	10

5.5.4 Recertification Man-hours - The data presented in Section 5.5.2 must be organized in such a way as to be sensitive to the wide range of vehicle parameters. The activities considered are the structural and thermal protection refurbishment, the other subsystem refurbishment, and testing.

5.5.4.1 Structure and Thermal Protection Refurbishment - There were two important assumptions made concerning the thermal protection systems: (1) all ablative exterior surface panels are removed and replaced each time the vehicle cycles through recertification, and (2) twenty percent of the radiative exterior surface panels is replaced on each cycle through recertification with the exterior surface receiving 100 percent inspection.

The data of Reference 5-18 was adjusted and converted into parametric data which considered the total direct man-hours for removal, replacement and inspection, the surface area involved, and the above assumptions. Radiative panel replacement is limited to 20 percent of the total radiative surface during each refurbishment, but there is still 100 percent inspection of all of the radiative surface. This has the effect of increasing the inspection time relative to the removal and replacement time for the number of panels replaced. The parametric data is based upon the areas actually replaced.

These data are based on the costs for replacing rather small (20 inch square) panels. Panel sizes to 40 inches square are considered in this study. But the effect upon the man-hours required to remove and replace a panel is nearly constant because the time required is for removal of fasteners and straps, inspection of the inner-structure, installation of the new panel and reinstallation of the fasteners and straps. The fasteners are attached at each frame, regardless of how many frames are spanned by one panel. Thus, there is no real difference in whether one 40 inch square panel is replaced or four 20 inch square panels are replaced, the total man-hours involved are the same. Thus, these structural refurbishment costs are not sensitive to panel size. The panel material costs are sensitive to size, and this is considered in the cost model portion of this study. The results were as follows:

Ablative Panels	- 10.4 direct man-hours per square foot actually replaced
Radiative Panels	- 32.0 direct man-hours per square foot actually replaced (approximately 6.4 man-hours per square foot of surface)
Fins, Elevons, Nose Caps	- 6.4 direct man-hours per square foot actually replaced

As the recertification cycle continues, learning should reduce the total man-hours for a given cycle. No data exists on spacecraft recertification, but assuming aircraft experience as presented in Reference 5-21 is representative of the trend, a 75 percent learning is assumed for the initial rate. At the 101st pass through the recertification cycle, this rate changes to an 85 percent rate for all subsequent passes. This is arbitrary, but is based on aircraft experience that indicates distinct changes in learning rates after a certain number of vehicle deliveries.

These man-hour factors will permit the total direct man-hours involved in the structure and thermal protection system refurbishment to be calculated as a function of a vehicle parameter - the wetted area or exterior surface area of the vehicle. In addition to these direct man-hours, there are indirect man-hour costs for this activity. For each man-hour spent directly working on the vehicle, there are two spent in support. Thus, the total man-hours involved in the refurbishment and thermal protection is the sum of the direct and indirect manhours or three times the values calculated by these relationships. These indirect man-hours are required to ensure the materials are at hand for the smooth flow of work as the vehicle is processed through recertification.

Structure & Thermal Protection Subsystem Refurbishment Total Manhours

Ablative Panels	= 31.2 man-hours per square foot of surface
Radiative Panels	= 19.2 man-hours per square foot of surface
Fins, Elevons, Nose Caps	= 19.2 man-hours per square foot of surface

In addition to man-hours, the work force size as a function of exterior surface area was determined from the same data as follows:

Ablative Panels	- 27.1 square feet per man
Radiative Panels	- 8.8 square feet per man

These values reflect the two assumptions previously discussed, particularly that 20 percent of the total radiative surface which includes fins, elevons, and nose caps is replaced on each cycle through recertification. These force size values are consistent with the total man-hours discussed previously.

5.5.4.2 Subsystem Refurbishment - Reference 5-20 presented man-hour values for the servicing and inspection of the subsystems of the vehicle. These were representative of the expected values for a military staffing, but were also representative of the relative effort required to recertify each subsystem. The reference data did not include the servicing of a large integral propulsion system such as this study considers, but for all other subsystems it has provided reasonable baseline data.

The values are presented in Table 5-8 and total 5,176 man-hours for the ballistic vehicles of configuration IB and 5,433 man-hours for an M2-F2 vehicle of configuration IIB. These represent the direct, first unit man-hour cost to refurbish the various subsystems on-board the vehicle. The assumed learning rate is 85 percent. As discussed for the structure and thermal protection system, there is a two-for-one ratio of indirect or supporting man-hours to direct man-hours. Thus, the total first unit subsystem refurbishment man-hours are 15,528 and 16,299, respectively, for a ballistic and M2-F2 vehicle.

For configurations D, E, and F utilizing integral upper stage propulsion, an additional increment of 3600 man-hours (1200 direct, 2400 indirect) for each engine is added to the above values for the refurbishment of the integral propulsion system. This provides for the maintenance and servicing of each engine, the inspection of the valves and regulators on each engine, replacement of squibs and pyrotechnic devices (if any are used), and refurbishment of the feed system. The refurbishment of integral tankage is included in the structural refurbishment through the use of size factors.

5.5.4.3 Testing after Refurbishment - Present aircraft practice, following a major overhaul, is to run tests on all systems to ensure that they are operating within the prescribed tolerances. It is assumed that a similar type of functional testing will be conducted on the spacecraft as the last step in the recertification flow. This testing would be similar to the spacecraft systems test of the production cycle, and, if the refurbishment was done at the production facility, would utilize the same test equipment.

The direct time required is estimated to be 7020 man-hours. Applying the two for one indirect to direct ratio, the total testing man-hours is 21,060 for all vehicles not utilizing integral upper stage propulsion. A 90% learning factor was applied.

Testing of integral upper stage propulsion, configurations D, E, and F, will add an increment to the testing man-hours. There is no data upon which to base a value for this increment but it was estimated that about 1375 man-hours

Table 5-8

Direct Subsystem Refurbishment Manhours

	Direct 1st Unit Manhours
Ballistic Vehicle	
Preparation	731
Propulsion	1080
ECS and Crew Systems	1287
Electrical	320
TTC and V	261
G and N	308
Landing and Chutes	612
Miscellaneous	577
	5176
M2-F2 Vehicle	
Preparation	867
Propulsion	1080
ECS and Crew Systems	1287
Electrical	320
TTC and V	261
G and N	308
Aero Controls	261
Landing	495
Miscellaneous	554
	5433
Increment for Integral Upper Stage Propulsion Engine	1200

(direct and indirect) would be required for each integral propulsion engine being tested. Thus, for these configurations having a single integral propulsion engine, the total testing will require 22,435 man-hours.

If a hot firing test of the integral upper stage propulsion system is required, another increment must be added to account for the man-hours at the test site. The magnitude of this effort is very difficult to assess; but, assuming the effort is comparable to present test firing experience, a value of 12,000 man-hours is estimated for the hot firing test.

For the baseline values above, it was assumed that an automatic checkout AGE which was compatible with present ACE system operations would be used. The effect of a variation in this AGE philosophy on man-hours and flow time is discussed in Section 5.5.6.

5.5.5 Effect of AGE Philosophy - There are four AGE options available to the system manager. These cover the range of philosophy from simple to complex, and each has an effect upon the flow time of the refurbishment cycle by increasing or decreasing the test time.

This study assumed that automatic AGE, compatible with ACE, was the baseline. If the user used semi-automatic or manual test equipment, the test time was assumed to be increased by a factor of 1.15 or 1.35, respectively. For automatic with on-board checkout, the time is reduced to 95 percent of the baseline values.

Thus, the baseline SST test times for each of the AGE approaches is:

	Manhours		Days Flow-Time
Manual	28,500		56.7
Semi-Automatic	24,250		48.3
Automatic	21,060	Baseline	42.0
Automatic w/on-board C.O.	20,000		39.9

It must be stressed that all of these values are estimates with little data to justify any one value. They are an attempt to identify the operational influences on the subject systems.

If SST testing is eliminated, the test times for each approach is:

	Manhours	Days Flow Time
Manual	5700	18.9
Semi-Automatic	4850	16.1
Automatic	4212	14.0
Automatic w/on-board C.O.	4000	13.3

5.6 Turn-around Time - Turn-around time is the time required to transport a spacecraft from the recovery site to the refurbishment facility, recondition and recertify the vehicle including complete testing if desired, transport it to the launch site, and the prelaunch preparation through the countdown. There are three logical parts to this total flow time, and each is discussed in the following sections.

5.6.1 Transportation Flow Time - Transportation can be by any one of three modes, land, water, or air. Air transport would require one day flow time for each movement, or, for a two-move recertification, a total of two days would be allowed for transportation. For land transport, it is assumed that a maximum rate of 300 miles per day could be expected. A typical total trip length from a favorably located landing site to the factory to the Cape would be about 3000 miles, or a trip from near Tacoma, Washington, to Cape Kennedy. Thus, a flow time of at least 10 work days or 14 calendar days is expected.

Water transport is much slower, making about 125 miles per day. Also, a barge trip would much longer in traveling from the recovery site to the factory to the Cape. The total water trip is about 5800 miles, or about 47 calendar days travel time. Preparation for refurbishment involves off-loading the vehicle from its transporter, transferring it to the handling dollys and fixtures for refurbishment, and positioning the vehicle on its dollys at the start of the refurbish line. This is assumed to require a fixed amount of flow time, but a variable amount of man-hours. The flow time assumed was 16 hours or one day for each off-loading.

For expendable vehicles, there is only a one day air trip, a 10 calendar day land trip or a 38 calendar day barge trip from the factory to the launch site. Again the one day off-loading time is required.

In summary the flow time for transportation is:

For expendable vehicle and initial deliveries:

Calendar days flow time = 2 ATS + 11 LTS + 39 WTS

For Reusable Vehicles after First Flight

Calendar Days Flow Time = 4ATS + 16LTS + 49WTS

where:

ATS = Air Transportation Switch 1 = yes, 0 = no

LTS = Land Transportation Switch 1 = yes, 0 = no

WTS = Water Transportation Switch 1 = yes, 0 = no

There are size limitations on land and air transportation modes. Present land transport limits are 12 foot diameter and 60 foot length. The "Super Guppy" will handle up to 25 foot diameter and 70 foot length. The weight limitation for the "Super Guppy" is about 40,000 pounds. There are no real weight limitations for land transportation since the largest vehicle that can be transported is relatively small and of modest dry weight.

5.6.2 <u>Recertification Flow Time</u> - Flow time for recertification is strongly influenced by the size of the vehicle. In flow time, size influences all phases of the recertification cycle. A large integral vehicle can be easily transported only by barge, which is very slow, as compared to air transport, which could move the recovered vehicle across the country in less than one day. The larger the vehicle going through the refurbishment, the longer it will take. If there are upper stage propulsion system components in the vehicle, it can also require a hot firing test which would require about 30 days more flow time.

5.6.2.1 <u>Structural Refurbishment Flow Time</u> - The flow time is a function of the size of the vehicle. Based on data from References 5-18 and 5-20, the following relationships were developed for the first unit flow time:

Ablative Vehicle Flow Time (in hours) $= 120.2 + .05\ A_A$

Radiative Vehicle Flow Time (in hours) $= 120.2 + .06\ A_R$

Mixed Ablative-Radiative Flow Time (in hours) $= 120.2 + .05\ A_A + .06\ A_R$

where: A_A = exterior ablative surface area,

A_R = exterior radiative surface area.

The size effects are provided by the surface area variable since the larger the vehicle the more surface area will be refurbished and the more flow time will be required.

These relationships will define a structural refurbishment flow time which is consistent with the man-hours discussed in Section 5.5.5. A typical small ballistic modular vehicle might have a 138-140 hour flow time or, on a five-day, two-shift week, an eight work-day flow, or a 10 calendar-day flow. Since surface area is a function of configuration, this one relationship will define flow time for both configurations within the context of this study.

5.6.2.2 Subsystem Refurbishment Flow Time - Subsystem refurbishment flow time is essentially a constant value for each configuration, except for an incremental increase when the vehicle has integral upper stage propulsion. The baseline first unit flow time for the ballistic spacecraft is assumed to be 448 hours, and for the M2-F2 spacecraft is assumed to be 496 hours. The small difference is primarily due to the aerodynamic control hydraulic system. It is assumed that 96 additional hours will be required to recondition each of the upper stage propulsion engines during the first recertification cycle. The relationships used in the OCPDM model for first unit flow time are:

For ballistic vehicles:

Subsystem Flow Time (in hours) = 448 + 96 NE

For M2-F2 vehicles:

Subsystem Flow Time (in hours) = 496 + 96 NE

where: NE = number of engines in integral upper stage propulsion.

These values are consistent with the man-hour estimates of Section 5.5.5; and, together with the man-hours, indicate a total work force of about 34 men, direct and indirect, working on a two-shift basis on the subsystem refurbishment.

5.6.2.3 Testing Flow Times - This flow time depends upon refurbishment testing philosophy, the presence or absence of upper stage propulsion, type of AGE, and whether the upper stage propulsion is given a hot firing test during recertification. Each adds to the time required to complete the testing after the vehicle has been refurbished.

In this study we have considered three refurbishment philosophies: (1) scheduled maintenance with full SST testing and hot-firing testing of the upper stage propulsion, (2) scheduled maintenance with full SST testing but no hot-firing testing of the upper stage propulsion, and (3) scheduled maintenance with only continuity checkout - no SST testing nor hot-firing testing. This third approach relies upon the on-pad testing during the pre-launch operations to verify the flight readiness of the vehicle. The AGE effect has been discussed in 5.5.6.

For this study it was assumed that the full SST testing would require 42 work days, testing of the upper stage propulsion would require an additional 4 work days per engine. If a hot-firing is desired, an additional 30 work days will be required. When the testing is limited to the continuity checkout only, it is assumed that it would require 16 work days. All of these are first unit times subject learning discussed in the next paragraph.

In summary, the testing first unit flow time is defined by:

$$(1 - .67\ \text{REF})(42 + 4\text{NE}) + 30\ \text{HFT}$$

where: REF = Test Deletion Switch 1 = yes, 0 = no
NE = Number of Engines in Upper Stage Propulsion
HFT = Hot-firing Test Switch 1 = yes, 0 = no

5.6.2.4 Recertification Flow Time Learning - Based on the various studies reviewed, it was assumed that a 90% improvement rate was a reasonable value to expect for flow time. There is some aircraft data which indicates that somewhere between 85% and 90% is the expected range of improvement on this type of scheduled maintenance, and is very sensitive to the size and performance of the aircraft. These spacecraft are generally more related to high-performance aircraft than to large passenger/cargo aircraft, and hence the 90% rate is used in the OCPDM model. We have used the cum-unit statement of improvement as follows:

$$\sum_{1}^{NR} N^{-.152}$$

where: NR = Number of recertifications.

5.6.3 Prelaunch Flow Time - Every space program requires a finite amount of time to complete the launch operations. This time, from arrival at the launch site until launch, has been called the prelaunch flow time in this study. This time on the Gemini program varied between 120 and 55 days, and did indicate a learning trend.

In the Gemini Program, the first two data points represent the unmanned launches of Gemini II and III. The subsequent data points represent the manned launches. This data was fit by a learning curve equation to determine the trend. The resultant equation is:

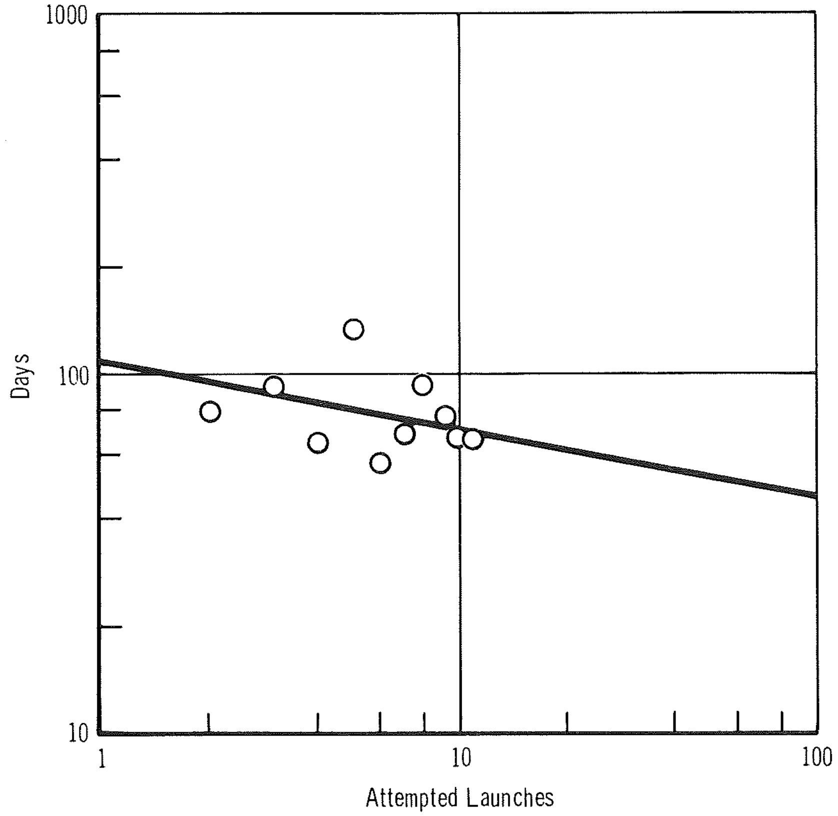
$$\text{Unit Flow Time} = 108\, \Sigma N^{-.188}$$

This equation and the data points are shown in Figure 5-7.

The Prelaunch Flow Time can be divided into two parts, the assembly time and the test and checkout time. Review of the experienced schedules indicates a split of 63% - 37% between industrial area and on-pad flow times. If we also consider the type of AGE in the flow time, the equation takes the form

Figure 5-7

GEMINI DATA
PRELAUNCH FLOW TIME



$$\text{Unit Flow Time} = (68 + 35\ \text{AGEF})\Sigma N^{-.188}$$

where:

AGEF is the AGE factor defined as

Manual, Van mounted AGE: AGEF = 1.35

Semi-Automatic (Gemini): AGEF = 1.15

Automatic (Apollo) : AGEF = 1.00

Automatic with on-board checkout: AGEF = .95

Review of the activities performed during the time the spacecraft was in the industrial area indicated that a great amount of the time was idle time - the spacecraft was there but was not being worked upon. A reasonable estimate of this idle time, based on available data, is that 40% of the total industrial area flow time was idle time. For an operational program, there would be little idle time and the flow time equation becomes:

$$\text{Operational Unit Flow Time} - (41 + 35\ \text{AGEF})\Sigma N^{-.188}$$

which is the equation used in the OCPDM model.

In addition, the prelaunch flow time is influenced by the size of the vehicle. Both the weight and the length of a vehicle affect the prelaunch flow time, but to keep the relationships as simple as possible, we considered only length in developing a size factor. The analysis of various data developed by this study permitted relating length and the size factor used in the cost estimating relationships. It was determined that this size factor could be approximated by the relation

$$\frac{329.68}{348.48 - L} \quad \text{where } L = \text{vehicle length.}$$

The configuration influences the prelaunch flow time also. The M2-F2 vehicle requires 4% more time than the ballistic vehicle, and upper stage propulsion adds 10% to either flow time. Then the final relationship for prelaunch flow time is:

$$[1 + .04(1\text{-BAC})][1 + .10\ \text{USP}]\left[\frac{329.68}{348.48 - L}\right][41 + 35\ \text{AGEP}] \sum_{1}^{\text{NOAL}} N^{-.188}$$

where:

BAL = Ballistic Configuration Switch 1 = yes, 0 = no

USP = Upper Stage Propulsion Switch 1 = yes, 0 = no

L = Spacecraft length

AGEF = AGE factor (see previous equation)

NOAL = Number of attempted launches

6. SUPPORT EQUIPMENT - The preceding discussion has been primarily concerned with the logistics vehicle and costs identified with it. There also are significant total program costs in support equipment, the two cost categories of AGE and facilities. AGE is the ground based equipment to ensure the flightworthiness of the vehicle, servicing equipment to prepare it for flight, the mission control hardware and software to ensure the successful execution, and the equipment to handle and transport the flight vehicle on the ground. Facilities are the production buildings, the test stands, the launch area buildings, the launch complex, the training areas, and the recovery sites necessary to the successful completion of the mission or the logistics program. Facilities include tracking stations and their equipment and mission control centers with their equipment. The costs of these will be defined, for use in the cost model, after a current parallel study has progressed sufficiently to provide equipment quantity requirements to this study.

6.1 AGE - The Gemini program utilized semi-automatic test and check-out equipment. The Saturn S-IVB program was compatible with the ACE system, which is an automatic checkout system requiring a large umbilical interface since the ACE must be connected by hard line to all desired test points.

An improvement on this is to build into the vehicle the capability for On-Board Checkout (OBC) with a radio link to the ACE checkout equipment. This reduces the hard lines and umbilical interfaces to a minimum, at the cost of more on-board equipment and a higher unit price.

In-house effort indicates a limited on-board checkout capability could be designed into the vehicle for weight of 150 pounds and an electrical power load of 480 watts. This assumes that a large number of test points are being monitored in the vehicle for telemetry transmission to the ground. The Gemini had about 350 parameters monitored. The OBC would require monitoring an estimated 500 parameters. For ground testing, the Gemini testing had access to over 1500 test points. A similar level could be assured by combined use of OBC and ACE techniques.

6.2 Facilities - The major facilities problem is providing adequate launch support facilities for the spacecraft at WTR. ETR facilities are more versatile, requiring only modification to make them usable for any new program. WTR will require new industrial area buildings and a full set of ACE basic equipment. At present, the ACE system is unique to ETR. For vehicles which must be launched from either location, the same basic checkout system must be at each location.

The cost of this has been developed in a concurrent study.

Refurbishment of the very large vehicles may require a new or separate facility located with regard to transportation rather than efficient utilization of all equipment. For example, it may be better to utilize the Michoud facility and the Mississippi Test Site for the recertification of a configuration IE or IIE vehicle. Costs of a new facility for these particular vehicles will be based upon historical costs for modification of existing facilities. New facility costs will be based upon current cost estimates available from governmental agencies.

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