48p

[redacted]

23

REPORT NO. AE610363

X63-80391

N74-71738

(NASA-CR-137099) APOLLO. VOLUME 5: IMPLEMENTATION PLAN. BOOK 1: SYSTEMS ANALYSIS, SCHEDULES AND COSTS Final Study Report (General Dynamics/Convair) 61 p

Unclas
00/99 31190

CLASSIFICATION CHANGE
TO UNCLASSIFIED
By authority of E.O. 11652
Changed by L. Shirley Date 8

APOLLO

FINAL STUDY REPORT

VOLUME V | IMPLEMENTATION PLAN

BOOK 1 | SYSTEMS ANALYSIS, SCHEDULES AND COSTS

Available to NASA Offices and NASA Contractors

GD

CONVAIR (ASTRONAUTICS) DIVISION OF GENERAL DYNAMICS CORPORATION AND AVCO CORPORATION

[redacted]

EXCLUDED FROM THE GDS

Code - None

SECURITY NOTICE

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Sections 793 and 794. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

NOTICE OF EXISTENCE OF PROPRIETARY INFORMATION

This report is furnished to the Space Task Group, NASA, under the terms of Contract NAS 5-304, and shall not be released outside the Government (except to foreign Governments, subject to these same limitations), nor be disclosed, used, or duplicated, for procurement or manufacturing purposes, without the permission of Convair-Astronautics, a Division of General Dynamics Corporation, and of Research and Advanced Development Division of AVCO Corporation. This legend shall be marked on any reproduction hereof in whole or in part.

CASE FILE COPY

~~CONFIDENTIAL~~

Offices and
NASA Centers Only

APOLLO
FINAL STUDY REPORT

Report No. AE61-0363

15 May 1961

Contract NAS 5-304

Volume V
IMPLEMENTATION PLAN

Book 1
SYSTEMS ANALYSIS, SCHEDULES AND COSTS

Prepared by:

CONVAIR (ASTRONAUTICS) DIVISION
GENERAL DYNAMICS CORPORATION
and
AVCO CORPORATION

RDF61-026

~~CONFIDENTIAL~~

EXCLUDED FROM THE GDS

VOLUME I | SUMMARY

VOLUME II | SELECTED VEHICLE DESIGN

VOLUME III | SUPPORTING DESIGN ANALYSES

- BOOK 1 | FLIGHT MECHANICS
- BOOK 2 | HEAT CONTROL SYSTEMS
- BOOK 3 | STRUCTURAL ANALYSES AND MATERIALS
- BOOK 4 | PROPULSION AND AUXILIARY POWER
- BOOK 5 | TRACKING, COMMUNICATIONS AND DATA SYSTEMS
- BOOK 6 | GUIDANCE AND CONTROL
- BOOK 7 | AEROSPACE MEDICINE AND RADIATION
- BOOK 8 | ENVIRONMENTAL CONTROL AND LIFE SUPPORT
- BOOK 9 | HUMAN FACTORS
- BOOK 10 | RELATED CONFIGURATION STUDIES

VOLUME IV | GROWTH AND ADVANCED CONCEPTS

VOLUME V | IMPLEMENTATION PLAN

- BOOK 1 | SYSTEMS ANALYSIS, SCHEDULES AND COSTS
- BOOK 2 | RELIABILITY
- BOOK 3 | DEVELOPMENT PROGRAM
- BOOK 4 | MANUFACTURING PLAN
- BOOK 5 | SUPPORT OPERATIONS

TABLE OF CONTENTS

Section		Page
1	PROGRAM MANAGEMENT	1
1.1	INTRODUCTION	1
1.2	SYSTEMS MANAGEMENT PHILOSOPHY	1
1.3	SYSTEMS INTEGRATOR PHILOSOPHY	1
2	PROGRAM SEQUENCE	3
2.1	FLIGHT SEQUENCES	3
2.1.1	Program Operational Scheme	3
2.1.2	Launch Pad and Atmospheric Abort	3
2.1.3	Suborbital Abort	3
2.1.4	Earth-Orbit Flight	3
2.1.5	Ballistic Re-Entry	3
2.1.6	Eccentric Earth Orbits	3
2.1.7	Lunar Operations	10
2.2	MISSION ANALYSIS	10
2.2.1	General	10
2.2.2	Earth Orbit Missions	10
2.2.3	Earth-Probe Missions	14
2.2.4	Circumlunar Flights	14
2.2.5	Lunar-Orbit Operations	16
2.2.6	Landing Site Analysis	16
2.3	SCIENTIFIC TASK DESCRIPTION	18
2.3.1	General	18
2.3.2	Earth-Orbit Scientific Tasks	18
2.3.3	Earth-Probe Objectives	18
2.3.4	Lunar Scientific Objectives	18
2.4	PROGRAM CONTINUITY	22
2.4.1	General	22
2.4.2	Design Phase	22
2.4.3	Testing Phases	22
3	SCHEDULING	23
3.1	SCHEDULE CONTINUITY	23
3.2	DEVELOPMENT PROGRAM SCHEDULE	23
3.3	DEVELOPMENT PROGRAM NETWORK	23
3.4	SUBCONTRACTOR DEVELOPMENT SCHEDULE	25
3.5	PRODUCTION SUPPORT OF TEST AND OPERATIONAL PROGRAMS	25
4	PROGRAM COSTS	39
4.1	GENERAL	39
4.2	CONTRACTOR COSTS	39
4.3	DIRECT GOVERNMENT SUPPORT COSTS	39
4.4	COST PER SUCCESSFUL MISSION	39

LIST OF ILLUSTRATIONS

Figure		Page
1	Systems Management Concept	2
2	Apollo Operational Sequence	4
3	Launch Pad and Atmospheric Abort Sequence	5
4	Suborbital Abort Sequence	6
5	Earth-Orbit Flight Sequence	7
6	Ballistic Re-Entry Sequence	8
7	Eccentric Earth Orbits	9
8	Lunar Operations	11
9	Manned Operations Program	12
10	Apollo Artificial Gravity Provisions	13
11	Apollo/Saturn C-2 Launch Configuration	15
12	Landing Site Locations	17
13	Apollo Photographic Camera	19
14	Micrometeorite Counter	20
15	Typical Magnetometer	20
16	Proposed Radiometer Configuration	21
17	Development Program Summary Schedule	24
18	Development Program Network	26
19	Landing System Development Schedule	28
20	Life Support System Development Schedule	29
21	Display and Control Development Schedule	30
22	Secondary Liquid Rocket Systems Development Schedule	31
23	Fuel Cell System Development Schedule	32
24	Guidance System Development Schedule	33
25	Vehicleborne Instrumentation System Development Schedule	34
26	Ground Instrumentation System Development Schedule	35
27	Abort and Separation Rockets Development Schedule	36
28	Test and Flight Program Schedule	37
29	Apollo Program Funding	40

LIST OF TABLES

Table		Page
1	Lunar Missions Analysis	16
2	Apollo Contractor Manpower (By Fiscal Year)	41
3	Government Support by Fiscal Year	42

1 PROGRAM MANAGEMENT

1.1 INTRODUCTION. As space systems continue to exhibit greater capability and complexity, the task of formulating a management system providing the direction and controls necessary to develop and manufacture a functional, reliable product becomes increasingly difficult. It has gradually become more tedious for management to encompass the many details necessary in directing space programs. This problem led to the evolution of such management aids as automatic data processing, a facet of the Program Analysis and Control Evaluation (PACE) technique. In Section 3 (Schedules) of this book, a brief PACE-type network, indicating major milestones and critical tasks associated with Apollo development is presented. Use of this management technique is highly recommended for the hardware phase of Apollo.

For a system as sophisticated as Apollo, a method must be devised to efficiently manage interface tasks. Project Apollo will require a well administered program; the ensuing sections present such a management plan.

1.2 SYSTEMS MANAGEMENT PHILOSOPHY. The underlying concept for a program such as Apollo, where many separate systems are mated to establish an operational concept, should be the systems management technique. In this instance, the customer would direct the efforts of the prim contractor and any associate contractors. A group from NASA would be drawn up and assigned to administer the task responsibilities of the prim contractor, the associate contractors, and Marshall Space Flight Center in its capacity as launch vehicle manufacturer. The prim and associate contractors would, in turn, select the required subcontractors and vendors and directly regulate their activity. As shown in the organization chart (Figure 1), the systems manager would not have direct contact with the subcontractors. The National Aeronautics and Space Administration is well qualified to undertake the task of technically managing a program such as Apollo, both within its Space Task Group and the technically competent agencies throughout the country. Experience gained from implementation of the Mercury project, as well as other ambitious space programs under NASA cognizance, will prove invaluable in the direction of Apollo. The prime contractor, on the other hand, is more adapted to integrate the design, development, production, and vehicle support functions of a complete system as complex as Apollo. It would be inefficient and ineffectual, and perhaps impossible, for a managerial organization to adequately direct and maintain necessary contact with the details associated with Apollo hardware development and manufacturing. The systems managers would retain veto power and representation within the integrator concept whenever high-level decisions or major policies were formulated, without the perplexity concommitant with technicalities.

1.3 SYSTEMS INTEGRATOR PHILOSOPHY. The systems integrator should be the Apollo flight vehicle contractor. His task would be to integrate the efforts of any associate contractors and subordinate groups, both from technical and operational standpoints. An Apollo project staff would be designated, comprising various control groups and headed by a program director reporting directly to top management of the prim contractor and the customer. Under the project supervision philosophy, task accomplishments would be monitored in all program areas to ensure that scheduling, cost, and product criteria were met.

The PACE technique of systems management should be employed for the Apollo program, thereby permitting the pacing development tasks to receive proportional emphasis and minimizing or eliminating program slippage. This plan necessitates a master data control facility, with development progress information available to each key member of the prime contractor's project staff and to NASA.

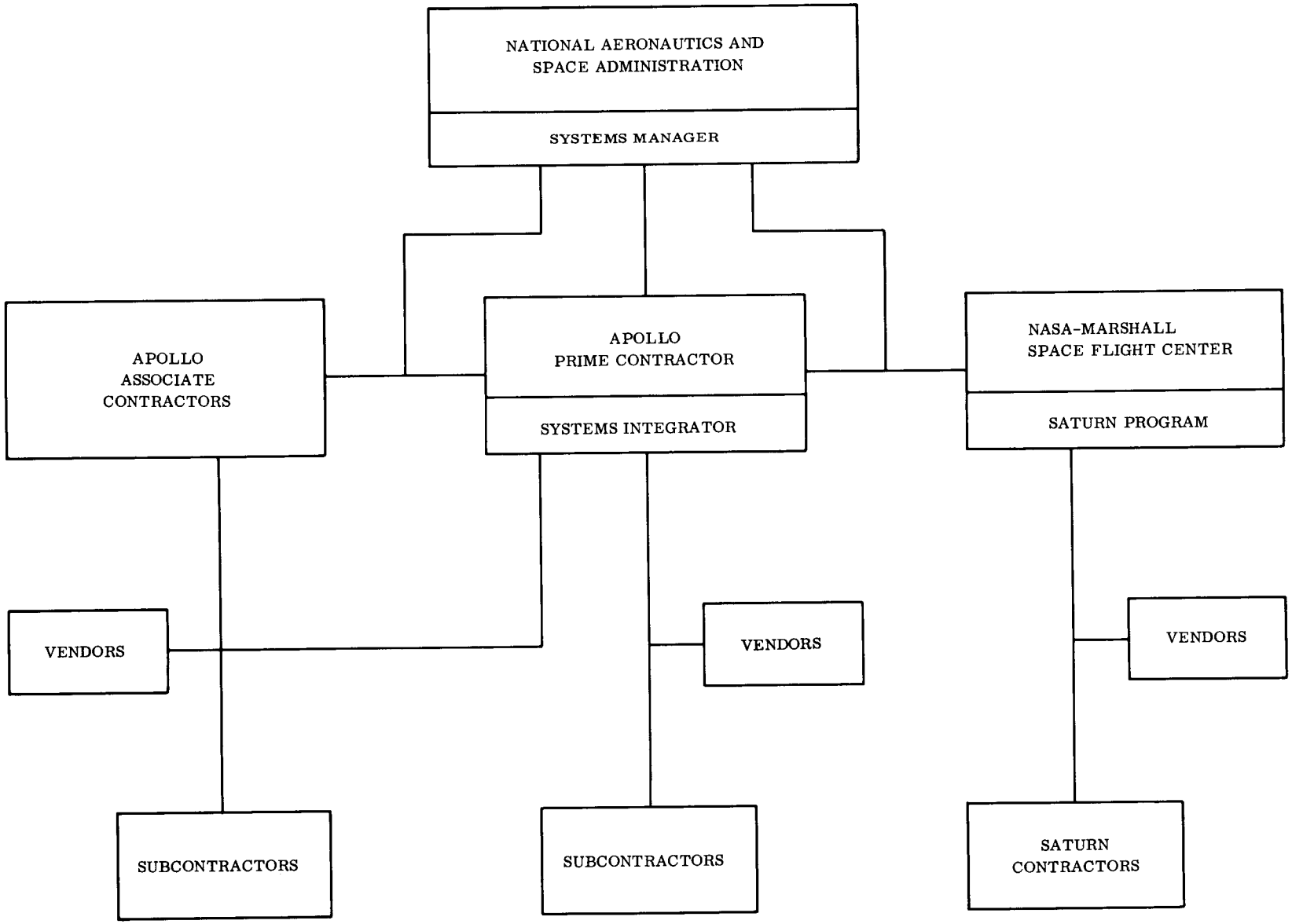


Figure 1. Systems Management Concept

2 PROGRAM SEQUENCE

2.1 FLIGHT SEQUENCES. This section consists of a pictorial presentation and a brief description of the program operational scheme for each type of mission. These missions include abort tests ranging from launch-pad aborts to super-orbital or high-speed aborts, high-speed re-entry, earth-orbital and earth-probe tests (both manned and unmanned), circum-lunar and lunar-orbit flights.

2.1.1 Program Operational Scheme. Figure 2 depicts the operational sequence of the Apollo vehicle from delivery of materials and subcontractors' components to the production facility, through mission completion, and the return of recovered vehicles to the prime contractor for evaluation.

After materials and components have been made into a complete vehicle at the production facility, the vehicle will be transferred to the static test site; there it will undergo a flight readiness firing (FRF). The vehicle is then returned to the factory where it will be sold off and prepared for shipping. The Apollo spacecraft will next be transported to Port Canaveral where it will be transferred to the Apollo hangar for checkout. Preliminary Apollo-Saturn mating checks will provide erection on the launch pad.

In case of an early abort during the launch and boost phases, the Apollo command module would be immediately recovered in the vicinity of AMR. For a normal mission, the Apollo vehicle would go through the typical re-entry and landing sequence. The crew and recovered vehicle would then be returned to major facilities of the customer and contractor for a thorough post-flight evaluation and debriefing of the mission.

2.1.2 Launch Pad and Atmospheric Abort. In the instance of imminent failure on the pad or during powered flight within the atmosphere, as shown in Figure 3, the abort sequence using the solid-rocket escape system would be initiated by the Apollo Flight Safety System (AFSS). For pad abort, the command module is lifted from the mission module with a large solid-propellant rocket to an altitude of some 6000 feet. The rocket system effects adequate Saturn vehicle/command module separation during an atmospheric abort, even at maximum dynamic pressure. Attitude of the vehicle is controlled through small liquid-propellant rockets at the top of the abort tower, both during the powered phase and just prior to separation.

2.1.3 Suborbital Abort. Once the abort tower has been jettisoned at Saturn S-I staging, the crew can abort by simply initiating a normal separation sequence and re-entering the vehicle. However, for reasons of rapid crew recovery, the onboard propulsion system will be used to land in a prescribed down-range location. This makes necessary two separation sequences: 1) the Apollo vehicle from the launch vehicle, and 2) the command module from the mission module, as depicted in Figure 4. Although this sequence is termed a suborbital abort, this emergency maneuver would be initiated for velocities up to about 30,000 fps. Department of Defense and special Apollo recovery vehicles would be stationed at the preselected landing areas for rapid search and recovery.

2.1.4 Earth-Orbit Flight. Figure 5 illustrates the flight sequence for the first eight earth-orbit missions (excluding flight of boiler-plate versions), the first three being scheduled as unmanned tests. After normal Saturn C-1 staging, the Apollo vehicle is injected into a low-altitude circular orbit. Following injection, the vehicle, attached to the S-IV stage with a winch and cable device, is spun by small rockets to simulate gravity. Some of the earth-orbit missions are not planned to have the artificial-g mechanism deployed, for scientific reasons, although the capability will still exist. When orbit ejection is desired, the crew dismembers the cable arrangement, fires the retropack rockets at the proper attitude, and effects normal re-entry.

2.1.5 Ballistic Re-Entry. The sequence shown in Figure 6 pictorially describes a series of parabolic re-entry tests scheduled as part of the command module development program. Although not a part of the manned operation phase, inclusion in the in the program sequence is justified by the importance and complexity of the trajectory. A production-type Apollo re-entry vehicle (command module) will be lofted to an altitude well above the atmosphere by the first two stages of the Saturn C-2, whereupon the S-IV stage will ignite at the proper altitude to "dive" the command module (mounted in a simulated mission module) to a point that matches prescribed re-entry conditions. Since the objectives are to test the structure and heat-protection system exactly under design conditions, it is important to have positive guidance and control throughout the entire powered flight phase. The vehicle would be recovered in the normal fashion for post-flight evaluation.

2.1.6 Eccentric Earth Orbits. The two sequences shown in Figure 7 differ only in the number of obrital passes made. For a multiple-pass mission, the vehicle is injected into a parking orbit and, after a coast phase, is powered into the desired orbit. Following the planned mission duration, a

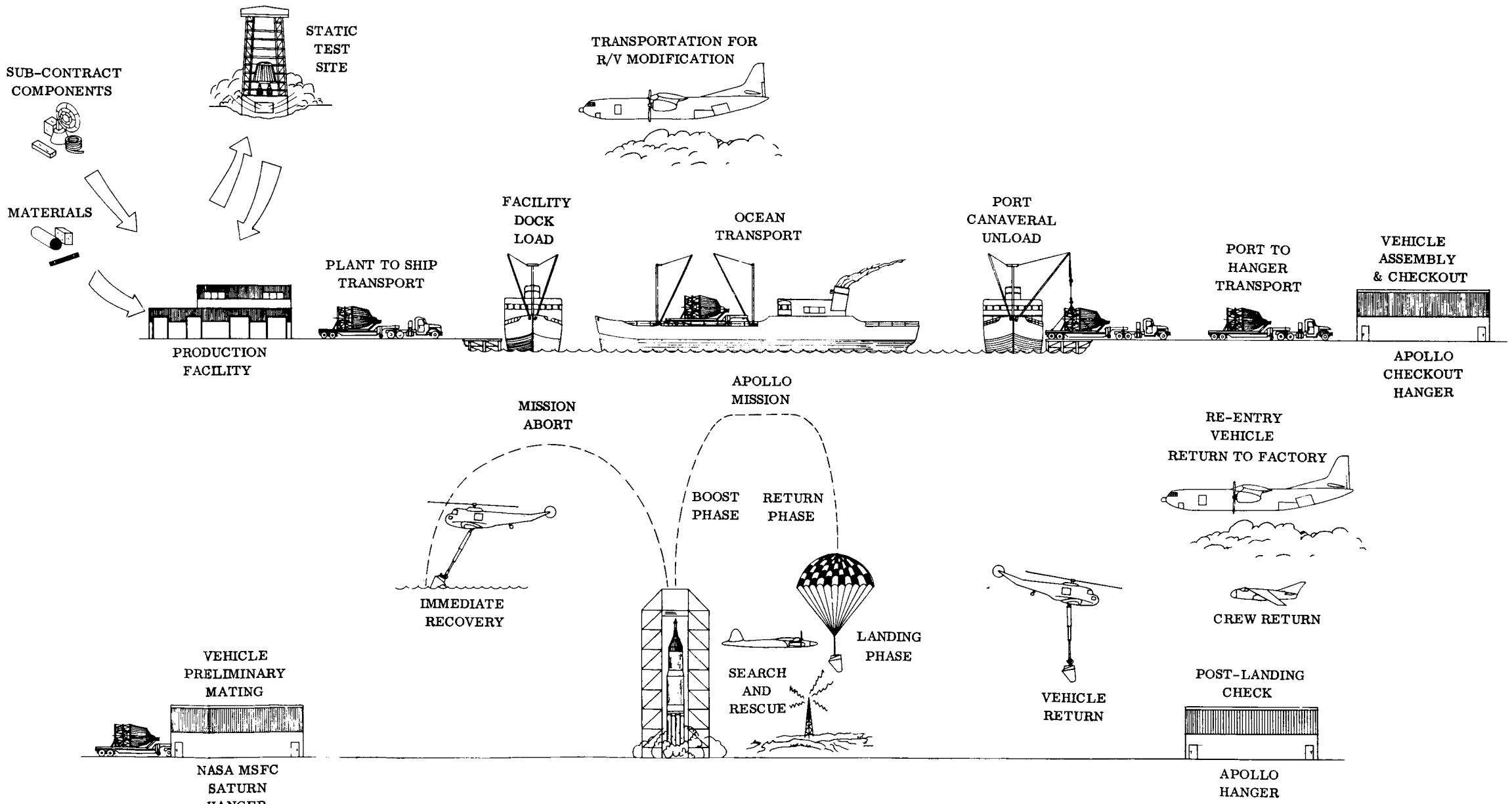


Figure 2. Apollo Operational Sequence

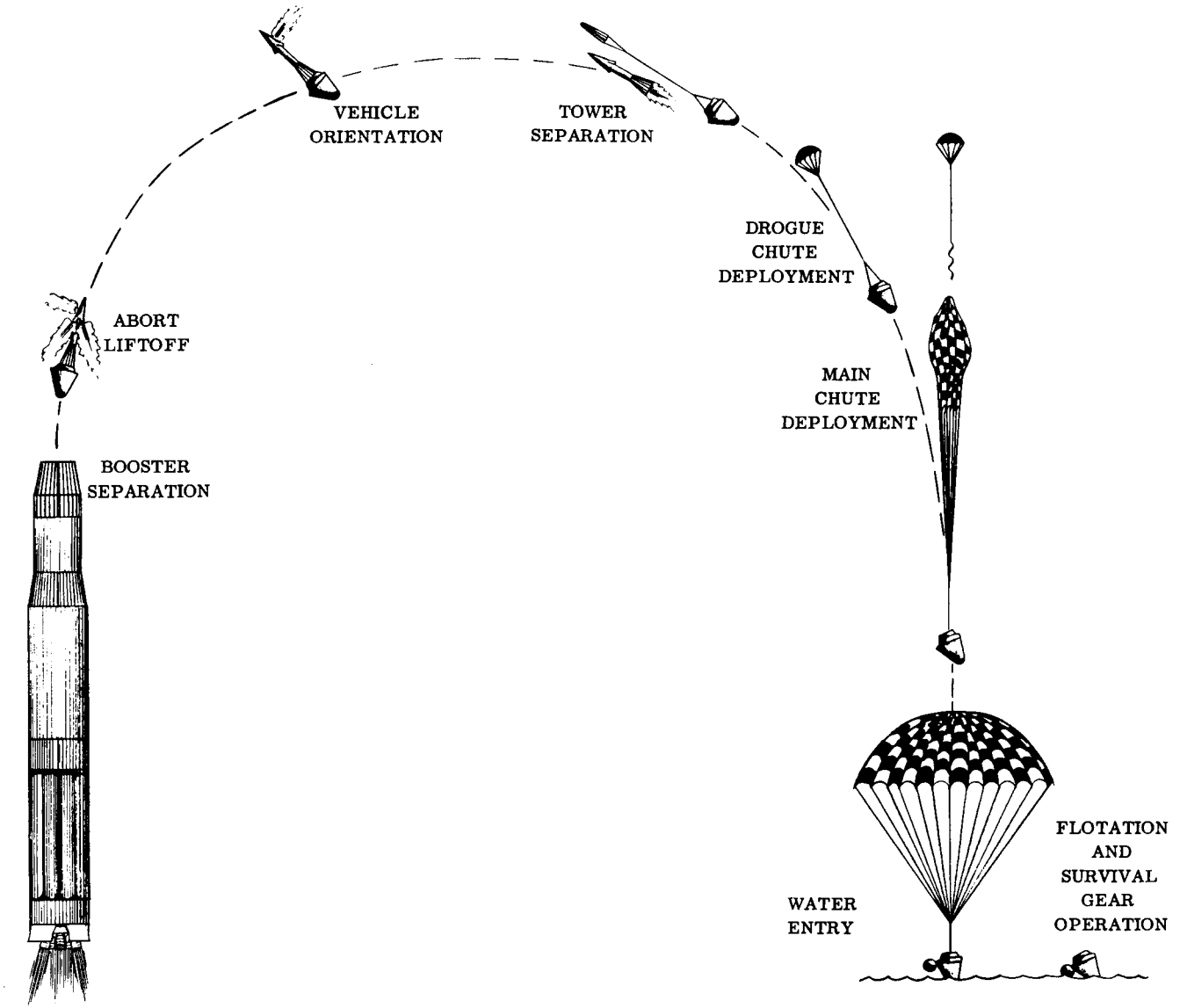


Figure 3. Launch Pad and Atmospheric Abort Sequence

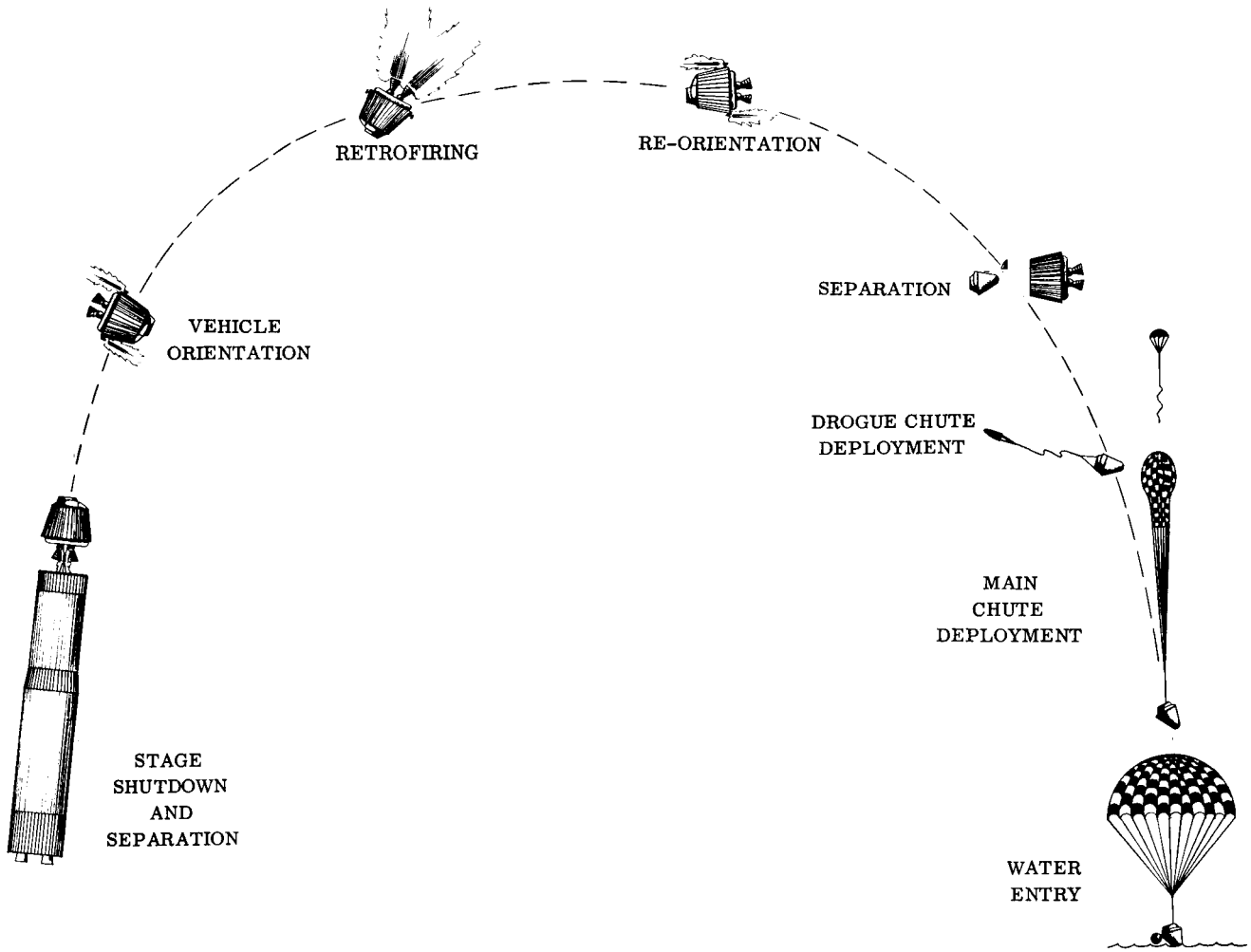


Figure 4. Suborbital Abort Sequence

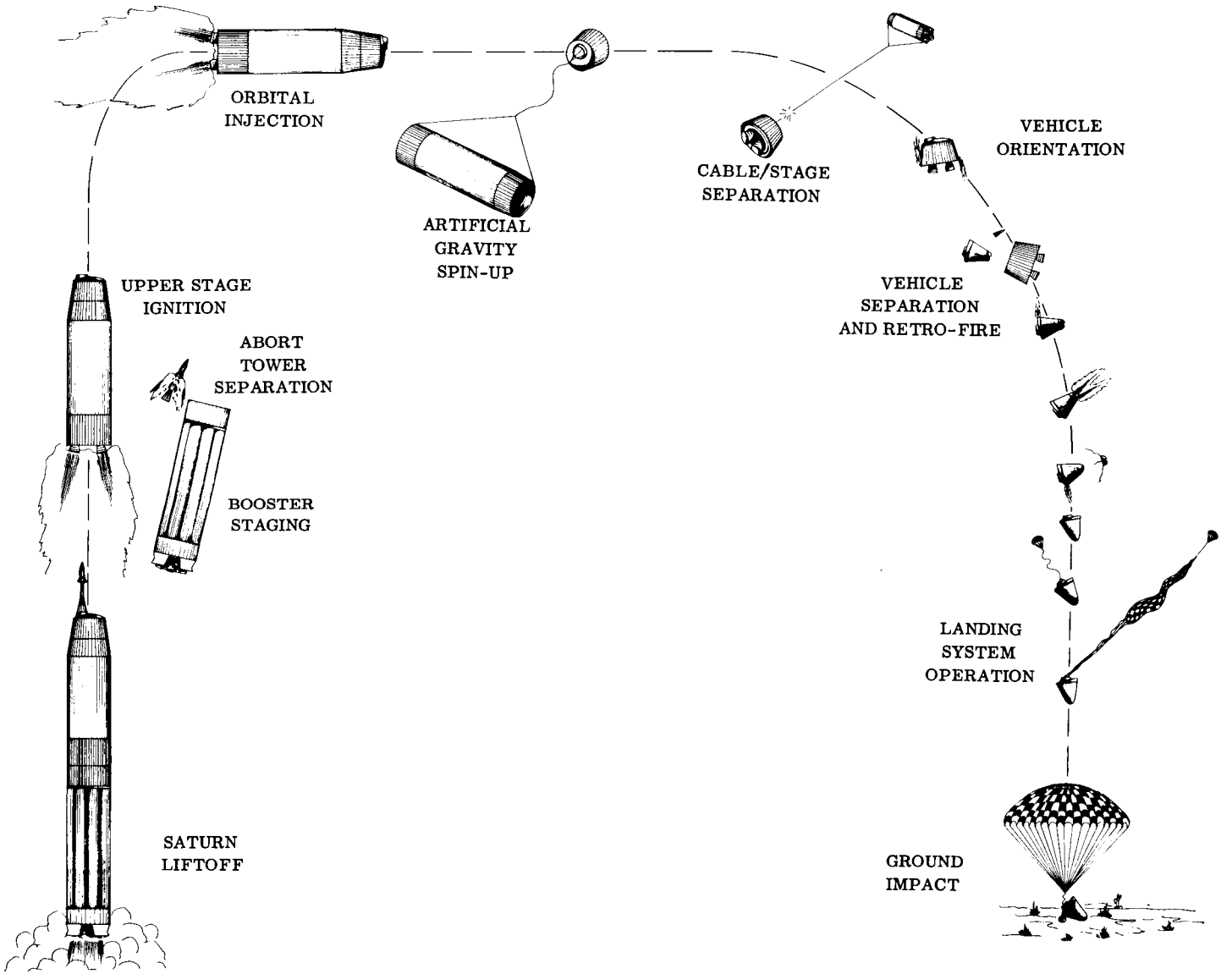


Figure 5. Earth-Orbit Flight Sequence

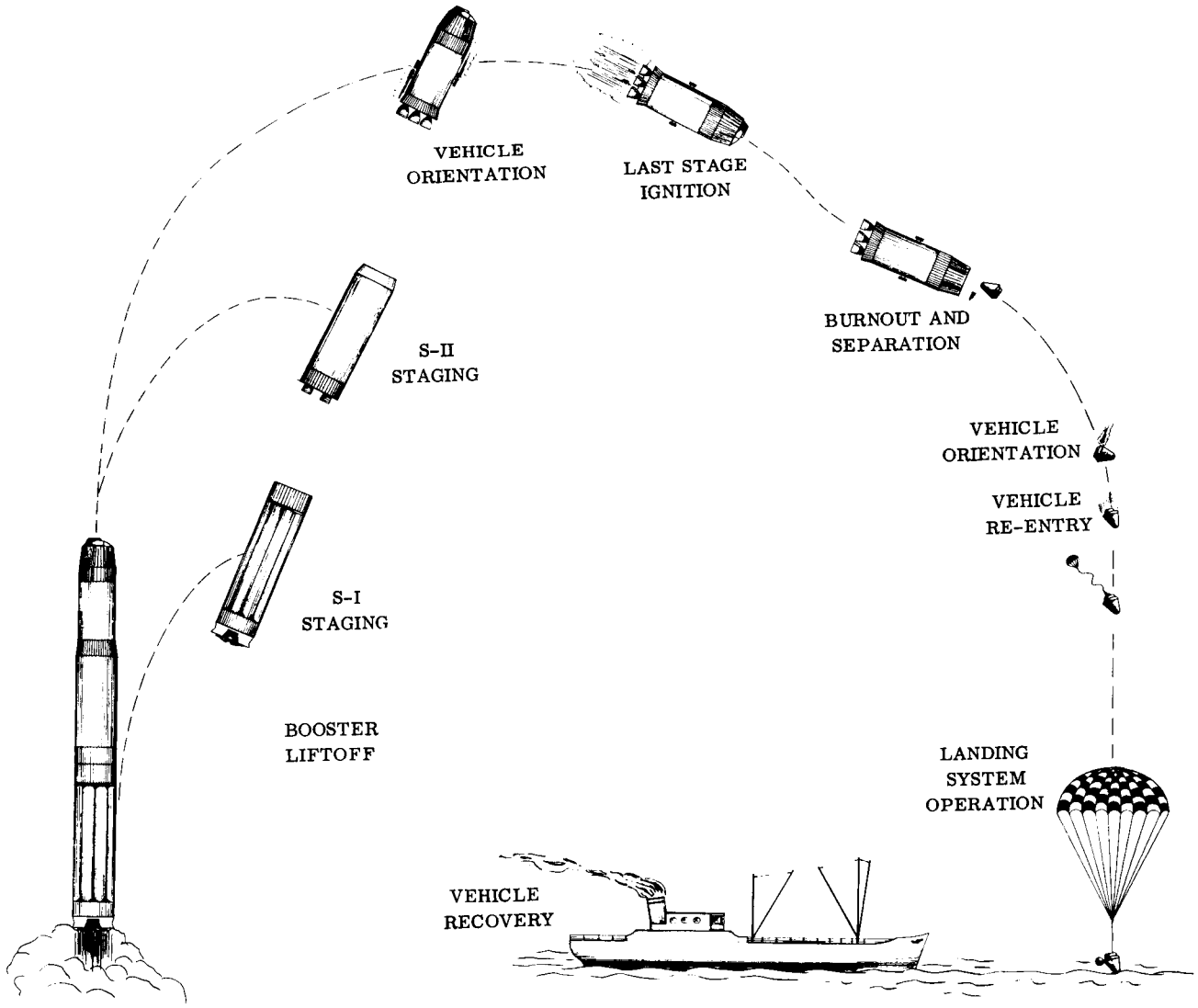
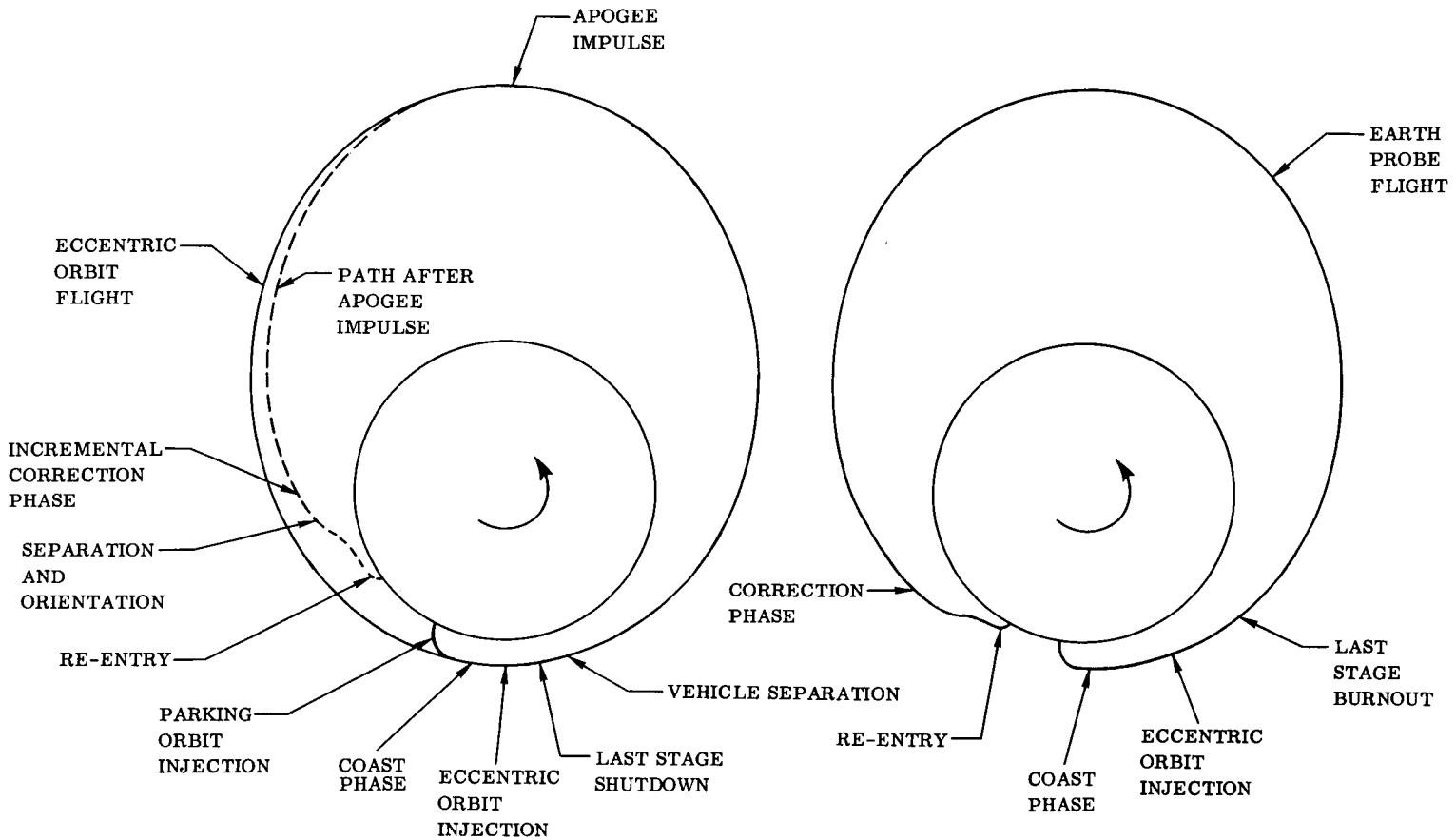


Figure 6. Ballistic Re-Entry Sequence



A. EARTH PROBE TEST, EARTH PROBE/ABORT TEST, AND SECOND MANNED EARTH PROBE FLIGHTS

B. FIRST MANNED EARTH PROBE FLIGHT

Figure 7. Eccentric Earth Orbits

retro-impulse is applied at apogee to lower the orbit path into the atmosphere for re-entry. Figure 7a depicts this sequence for the earth-probe test, the earth-probe/abort test, all manned aborts above 30,000 fps, and the second manned earth-probe flight.

Figure 7b describes a similar sequence for the first manned earth-probe mission except that, since less than one orbital pass is planned, an apogee velocity correction will not be required if proper injection parameters are achieved (velocity and flight-path angle). The final incremental correction phase would still be retained for controlled entry into the re-entry corridor.

2.1.7 Lunar Operations. The circumlunar and lunar-orbit missions shown in Figure 8 would begin in a fashion similar to the earth-probe flights, including the parking-orbit maneuver. Soon after injection into the transfer ellipse, the first midcourse correction impulse would be applied. The second correction maneuver is shown as optional, and would be employed only if the first correction were not instituted, due to loss in ground tracking or telemetry, or if the errors imposed by the first correction were unusually high. The third correction is made during lunar approach, followed by series of incremental impulses to achieve an accurate periselenium altitude. The essential difference between the circumlunar and lunar-orbit missions is that a captive and escape phase at periselenium take place during the latter mission. The return phase for both missions is very similar in sequence to the outbound portion described above.

2.2 MISSION ANALYSIS

2.2.1 General. The manned phase of the Apollo program is merely a continuation of the development and flight test phases; consequently, it is inaccurate to refer to the manned flights as "operational." They are no more operational than the first piloted flight of an aircraft. The first three types of manned missions largely prove the feasibility of the lunar-orbit phase of operations. No unmanned lunar flights are planned. The majority of the manned Apollo flights are justified, not by their scientific or psychophysical objectives alone, but by the proofing task necessary to support subsequent missions. This section presents these manned test operations, culminating in a low-altitude lunar orbit within the prescribed 14-day mission.

2.2.2 Earth Orbit Missions. As is shown in Figure 9, five manned earth-orbit flights are to take place prior to the first earth-probe mission. Primary justification for these flights is provided by acquisition of life-science data. The artificial gravity mechanism (see Figure 10) will have been tested on two occasions, once with primates aboard, prior to this first manned flight. The first manned earth-orbit mission is scheduled for a four-day duration at 300-n.mi. altitude without deployment of the simulated gravity device. The primary objectives for this flight are:

a. Perform earth-orbital flight of four days' duration and re-entry with full crew aboard.

b. Conduct comprehensive studies during the flight on the effects of zero g upon crew body changes, performance, and stress tolerance.

c. Measure effectiveness of zero-g attenuation techniques and devices.

d. Demonstrate crew tolerance for summated stress of four days of attenuated zero-g exposure plus re-entry.

Three post-injection options are available:

a. If there are few or no adverse effects in the crew, complete four-day mission and re-enter.

b. If progressive degradation of crew tolerance and/or performance is apparent in first few days, shorten mission duration to avoid exceeding crew tolerance during re-entry.

c. If marked deterioration of crew is noted early in mission, actuate simulated-g system and test ability to recondition crew, then re-enter within four-day mission time.

A post-landing follow-up program would test the crew in ground-based simulators under controlled conditions, assuming they withstood re-entry stresses well, to ascertain their margin of tolerance remaining and their tolerance limits.

Objectives of the remaining four flights would necessarily depend on the success of the first mission in satisfying its objective. Therefore, a series of three schedules is proposed, dependent upon the test results of Flight 1.

2.2.2.1 Schedule A. Assuming the crew tolerated the stresses of Flight 1 easily and demonstrated a significant margin of g tolerance, based on g simulations conducted on the ground, the second flight would be scheduled for eight days at zero g plus re-entry.

Providing no significant degradation occurred in the crew during the eight days at zero g, they would then complete the planned mission and re-enter. Ground tests would again be conducted as soon after re-entry as possible to determine the margin of tolerance above the re-entry conditions.

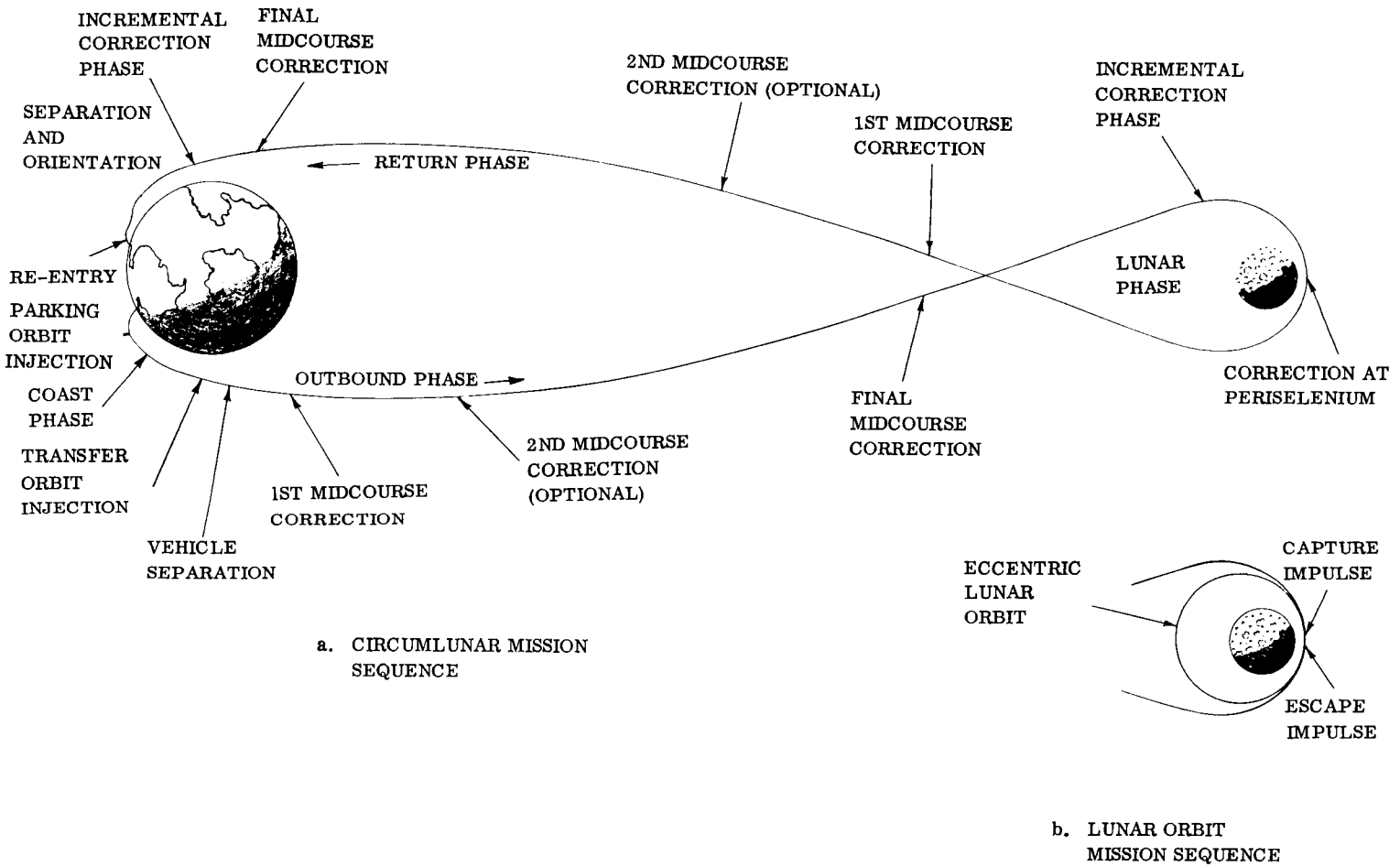


Figure 8. Lunar Operations

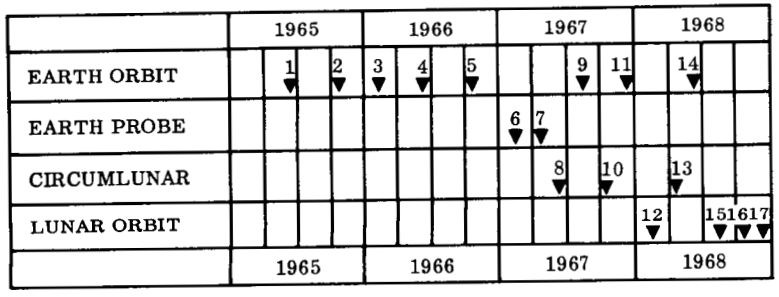


Figure 9. Manned Operations Program

Flight 3 would be planned to utilize simulated g during the first four days of the mission, followed by four days at zero g and re-entry. Effects upon the crew's tolerance and performance during and after the mission would be compared with the effects of the eight day mission at zero g to evaluate the benefits of simulated g.

Flight 4 would be scheduled for fourteen days at zero g. The hazard from crew deterioration from zero g is expected to be much greater on flights of this duration than on flights of eight days or less. The simulated-g system evaluated during Flight 3 would be ready for use on this flight if necessary.

Assuming the zero-g attenuating techniques were effective and no significant crew tolerance degradation were noted, the two-week missions at zero g would be completed prior to re-entry.

Flight 5 would be optional, but undoubtedly would be retained as a specific simulated lunar flight in which the crew would undergo mock phases of a typical lunar mission.

2.2.2.2 Schedule B. If progressive degradation of crew performance became apparent in the first day's zero-g environment on Flight 1, the mission duration would be shortened to less than four days to avoid exceeding crew tolerance to re-entry stresses. Post-flight ground simulator testing would be conducted, as in Schedule A, to determine tolerance reserves of the crew.

Providing a safe margin were evident, Flight 2 would be of the same duration as in Schedule A, with the option of shortening the mission time below eight days if indicated by deterioration of the crew at zero g.

If crew tolerance for Flight 1 stresses were marginal, Flight 2 would employ simulated g during a four-day total mission. If simulated g preserved normal crew tolerances during Flight 2, Flight 3 would be scheduled for a zero-g period equal to the zero-g exposure during Flight 1, to substantiate the early findings. Simulated g would then be applied, enabling evaluation of how reconditioning affects re-entry tolerance. Total duration of Flight 3 would be from four to eight days.

If Flight 3 substantiated inability of the crew to tolerate zero g, as shown in Flight 1, then Flight 4 would be planned for a two week duration, with first days spent at zero g employing modified attenuating techniques based upon experience of previous flights. Providing g attenuation techniques were ineffective, Flight 5 would employ simulated g throughout the two-week mission.

2.2.2.3 Schedule C. If marked deterioration of crew was noted early in Flight 1, Flight 2 would be planned for four days using simulated g.

Providing simulated g preserved normal crew performance and tolerance, Flight 3 would be planned for eight days at simulated g.

Assuming Flight 3 were well tolerated, Flight 4 would repeat zero-g exposures of Flight 1 to validate earlier findings. Simulated g would then be employed to evaluate reconditioning during a total mission duration of eight days.

If crew inability to tolerate a few days of zero-g exposure were evident, despite attempts to improve attenuating techniques, Flight 5 would be scheduled for two weeks with mission time consumed at simulated g.

During all simulated-g flights, the effects of varying magnitudes of g forces would be determined to guide the requirements for subsequent flights.

Earth orbit Flight No. 9 is optional and is planned as a large-scale, orbital-plane-change mission; as such, it would be the first maneuver using the main propulsion system with men aboard. Since the minimum orbit inclination for a vehicle launched from AMR is about 30 degrees, it is impossible to achieve an equatorial orbit without an orbital plane change. A maneuver such as this would require rotation of the velocity vector with an approximate 13,500-ft/sec impulse, which corresponds to roughly 23,000 pounds of additional weight to the lunar configuration of the Apollo vehicle. This flight would require a Saturn C-2 launch vehicle, whereas Flights 1 through 5 would be orbited with the two-stage C-1 configuration.

~~CONFIDENTIAL~~

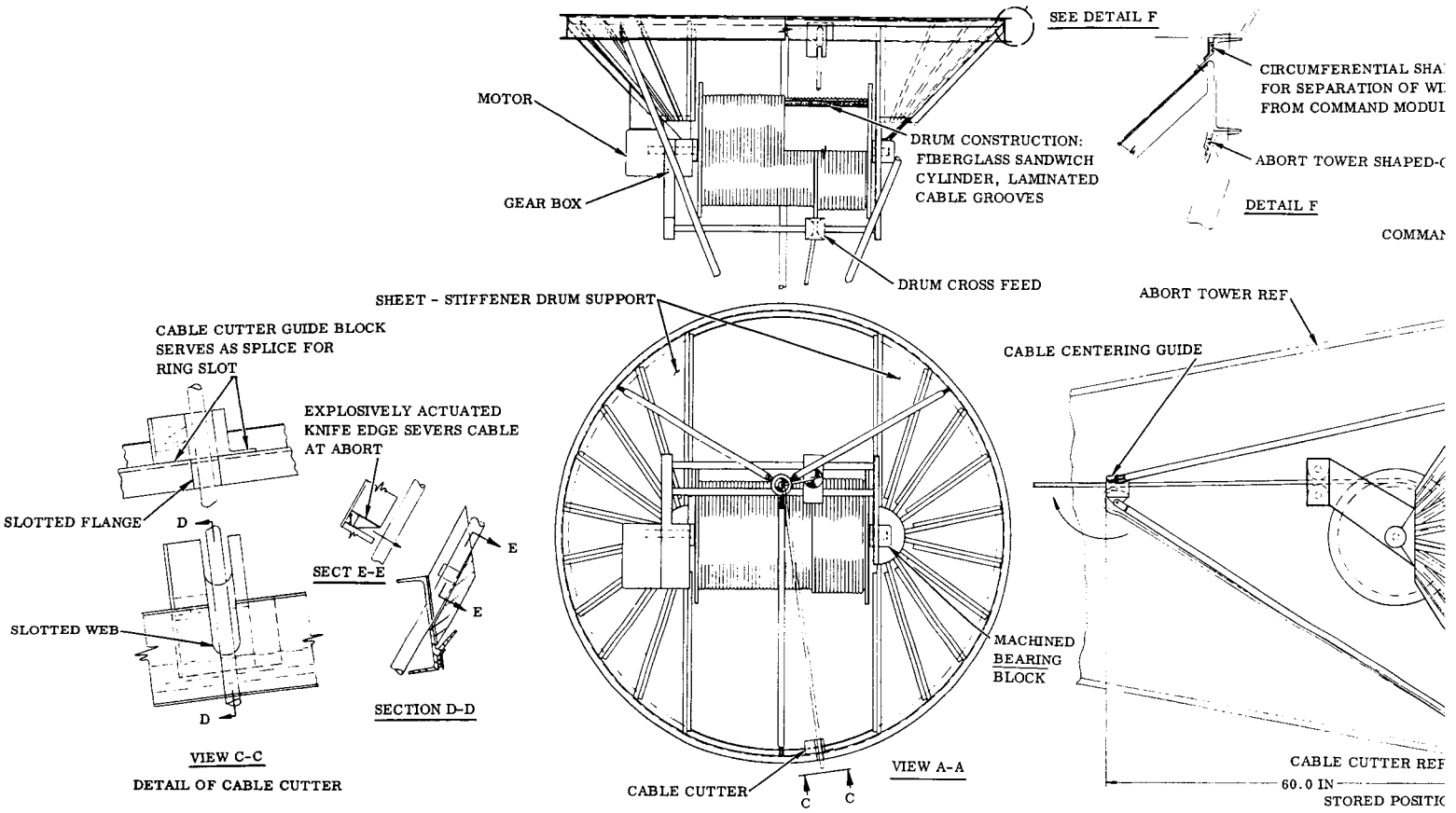
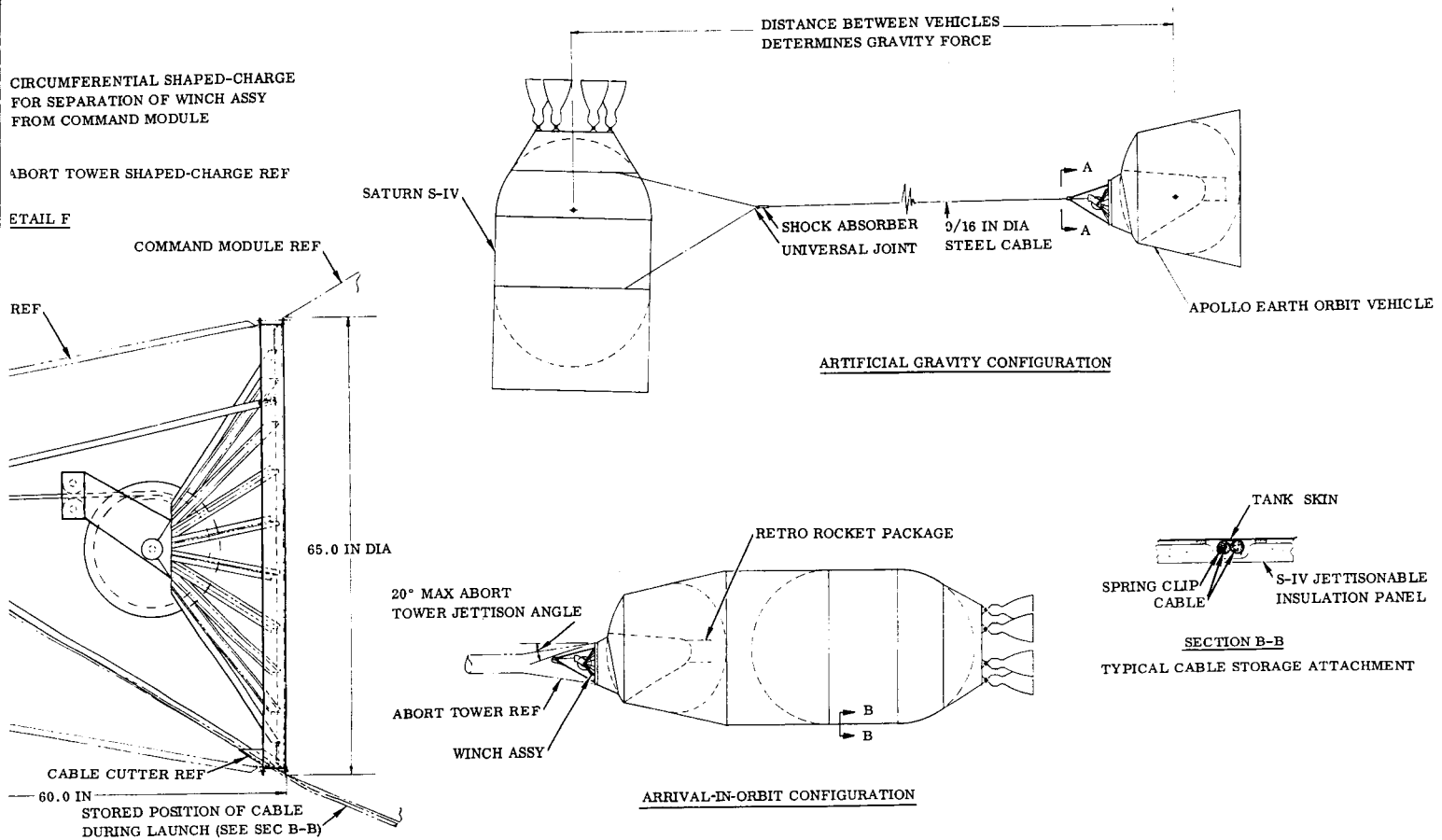


Figure 10. Apollo Artificial Gravity Pr

~~CONFIDENTIAL~~



Apollo Artificial Gravity Provisions

The orbital change could be executed with one or several impulses as the orbit intersects the equator. The prime objectives of this flight are to train the crew in powered-flight sequencing for lunar-orbit injection operations and later rendezvous maneuvers.

Flight 11 of the earth-orbit missions is again optional and is scheduled for a simulated rendezvous mission, wherein the Apollo vehicle is launched from AMR aboard a Saturn C-2 into an orbital plane different from that of the target orbit. This imposes the requirement for a plane change, and for maneuvers to enter the target orbit and to phase in with the target vehicle. An entire rendezvous mission would be carried out in this flight, with the exception of actual physical contact with the target vehicle. The Apollo configuration used for Flight 9, with the enlarged propulsion module, would be capable of performing this mission. Rendezvous training missions are important because of the present emphasis on an early manned lunar landing, in which perhaps the cheapest method available is orbital rendezvous and assembly. Another strong recommendation for this flight is pointed up by the possibility of emergency lunar return maneuvers, wherein the vehicle cannot re-enter but can only enter an elongated earth orbit. The only means for saving the crew in such an emergency would be rendezvous and rescue by another Apollo vehicle designed for this task.

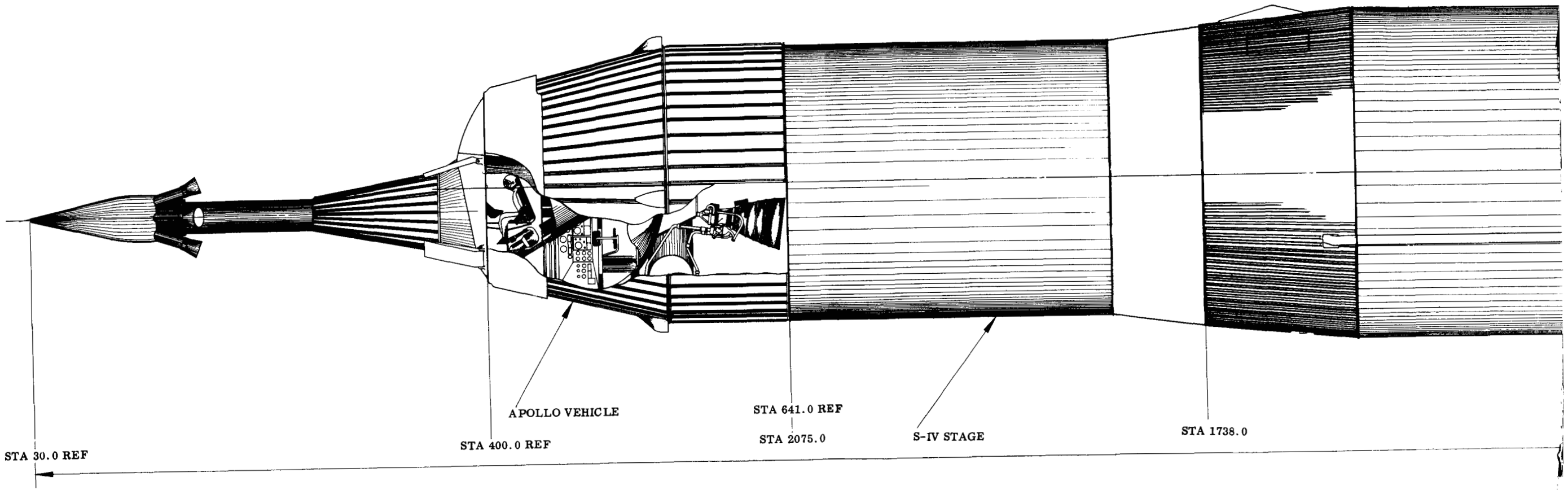
The final planned earth-orbit flight (Flight 14) would also be optional. It is felt that demonstration of Project Apollo to orbit a large, manned space station would be a necessary portion of the expanding national space program. The launch configuration would consist of two Apollo vehicles without propulsion modules. Upon orbit injection with a Saturn C-2, these vehicles would be spun-up with a cable restraint between them. Several approaches to manning such a station are possible: 1) man both vehicles for greater than a two-week period (propellant weight would be traded-off for life support capability), 2) man one vehicle with a "life-line" connecting it with the other vehicle, giving greater than one-month mission duration, or 3) man either or both vehicles and exchange crews and supplies periodically through subsequent rendezvous missions (Apollo boosted by Saturn C-1) for an indefinite period. Orbit altitudes would necessarily be high (300-500 n.mi.) to maintain extended orbital life times and tracking coverage.

2.2.3 Earth-Probe Missions. The eccentric earth-orbit missions are essentially a logical and gradual approach to lunar reconnaissance, since they traverse cislunar space. These flights (6 and 7) are the first Apollo vehicles with full lunar equipment, including the complete lunar guidance system. This type of trajectory imposes nearly the same requirements and conditions upon the crew as a circumlunar transfer would. Passage through the radiation belt is required, midcourse correction maneuvers are necessary, mission durations are on the order of lunar flight times, and re-entry velocity is only slightly less than that imposed by a lunar return. The first of these missions will duplicate the earth-probe/abort test of the flight test program, which is planned to pass through an apogee altitude of about 50,000 n.mi. Only one orbital pass is planned in Flight 6, resulting in a flight time of about 1.7 days. It should be noted that this flight accomplishes the first manned near-parabolic re-entry of the program. Since a correct orbit injection flight-path angle will effect a normal re-entry, the main propulsion system would be used only in case of an abort. The second flight (No. 7) is planned to reach an altitude of some 80,000 n.mi., and two orbital passes are planned. This makes possible more extensive radiation studies, a more precise determination of the orbit parameters, and additional proofing of on-board systems operation. Thus, a mission duration of 5.5 days is planned. During this flight, the crew would undertake a simulated lunar maneuver, in which course corrections, star-sightings, scientific measurements, and communication activities would be accomplished according to a lunar transfer schedule. Each of these vehicles would be boosted into orbit by a Saturn C-2. See Figure 11 for the Apollo/Saturn C-2 configuration.

2.2.4 Circumlunar Flights. The first circumlunar flight is to be similar to the earth-probe missions that precede it, since a minimum of course correction is required. In the circumlunar flight the closest approach to the lunar surface is some 1,000 n.mi., and the transfer ellipse incorporates a free-return capability. Injection flight path angle for lunar flights is about 4.75 at 120 n.mi. Therefore, the demands placed on the guidance system are minimum, yielding a very high probability of mission success. The periselenium altitude is still low enough to effect worthwhile scientific measurements and adequate photography. The second flight, spaced four months from the first (see Table 1), could lower this altitude to about 500 n.mi., still without severe guidance requirements. A free-return trajectory would be employed on the second flight to ensure mission success. If both of these flights progress satisfactorily, the third circumlunar flight (No. 13) would be planned to pass the lunar surface at a 200-n.mi. altitude without a free-return capability.

Each of the three flights would prepare the crew for subsequent lunar-orbit missions, as procedures and sequences for entering lunar-capture orbit would be carried out, except for actual ignition of the engines.

CONFIDENTIAL



CONFIDENTIAL

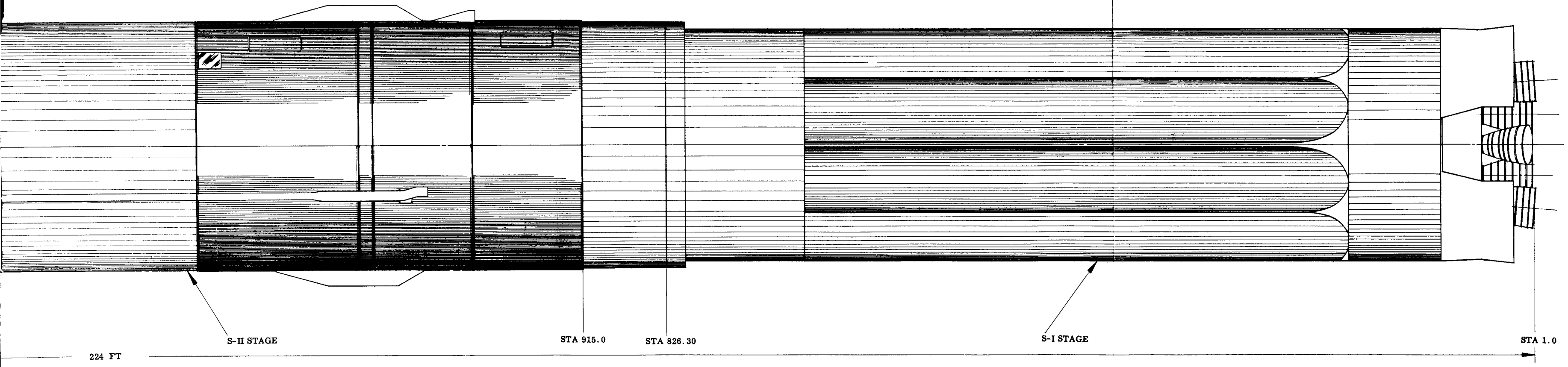


Figure 11. Apollo/Saturn C-2 Launch Configuration

Table 1. Lunar Missions Analysis

PARAMETER MISSION NO.	8	10	12	13	15	16	17
Periselenium Altitude	1000	500	500	200	200	75	50
Aposelenium Altitude	-	-	2500	-	1500	1200	1150
One-Way Transfer Time (Days)	3.2	3	3	3.5	3.5	3.5	3.5
Orbital Period (Hours)	-	-	7.6	-	4.8	4.0	3.8
Orbital Passes	-	-	2	-	4	6	10
Mission Duration (Days)	6.4	6.0	6.6	7.0	7.8	8.0	8.6
Transfer Trajectory	Free Return	Free Return	Free Return	Non-Free Return	Non-Free Return	Non-Free Return	Non-Free Return

2.2.5 Lunar-Orbit Operations. Following the lunar capture and escape maneuvers of Flight 13, full-scale reconnaissance of the moon would commence. Flight 15 would be the first lunar-orbit flight. It would be a counterpart of (circumlunar) Flight 13, in that the periselenium altitude would be 200 n.mi. and a non-free-return transfer would be employed. Aposelenium altitude for Flight 15 would be 1500 n.mi.; transfer time (one-way) would be 3.5 days. The 3.5-day transfer would be used for the remainder of the lunar program, thereby making possible standardization of transfer operations and tasks. The last two lunar-orbit missions approach a final orbit of only 50-n.mi. altitude at the closest approach, and a mission duration of nearly nine days.

2.2.6 Landing Site Analysis. Location of suitable landing locations for the four Apollo missions is a necessary portion of the operational scheme, including recovery, and as such is a systems analysis task. The major requirement to fulfill is that imposed by lunar declination coverage. It was found that three landing sites could adequately accommodate all lunar declinations, making possible a launch at any time of the lunar month. Since latitude is the important parameter in a declination analysis (see inset to Figure 12), many site locations exist.

The first conclusion made was that normal landing and recovery should be directed at land masses, the problems of ocean recovery being the essential argument in favor of this. Initially, a landing site just northwest of the Woomera deep-space tracking facility (see Figure 12) was investigated. The obvious justifications for this site are the ideal communication and tracking facilities, remoteness, and flatness of the local terrain. Another interesting factor is that a fairly large lake exists some 50 miles east of the planned site, facilitating visual reckoning by the crew.

It was felt that at least one of the landing points should be in the U.S. Zone of the Interior. Edwards AFB, an initially attractive location, covers a very small range of declination. Analysis of the southwestern United States yielded the result that an area in Texas seemed most logical. Consideration of local facilities suggested a site southeast of San Antonio. The approach and local terrain is flat and unobstructed, large aeromedical facilities exist at San Antonio, and adequate communications are installed on government property near Corpus Christi. The only remaining task was to fill the middle range of declinations to be covered, which required a site located on land within about 3° of the equator. Political considerations eliminated any large land masses, which left only the array of South Sea Islands and an island off the coast of Equador to consider. The latter was discarded because of undesirable mountain slopes. Most of the islands in the South Pacific are too small or too mountainous for acceptable landing site location; however, Manus Island appears to satisfy most of the requirements. Maximum elevation is only 3000 feet, dimensions of the island are 60 by 15 n.mi., and a tracking facility (with command communication capability) is presently planned in conjunction with the Centaur program.

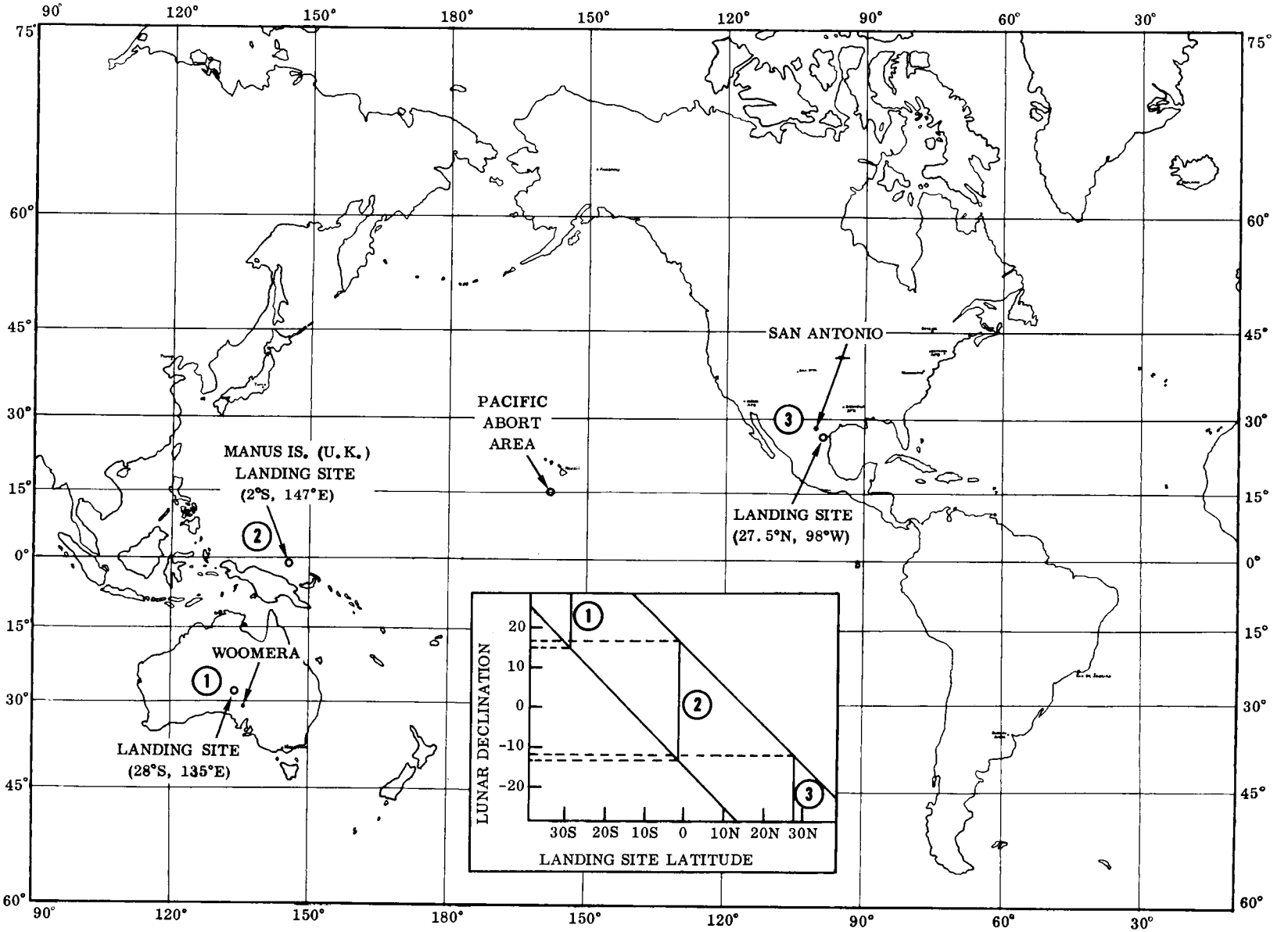


Figure 12. Landing Site Locations

[redacted]

The island, would require site preparation in the form of tree and shrubbery clearance. Port facilities for recovery ships would have to be constructed, and additional airstrip improvement appears necessary.

Each of the three proposed landing sites could adequately accommodate all planned earth-orbit and earth-probe missions. Very little effort and expenditure are required to improve and prepare these areas for Apollo lunar operations.

In addition to the planned normal landing sites, there exist two general abort areas, the Atlantic down-range area and the mid-Pacific location. The mid-Pacific area (some 300 n. mi. southwest of Hawaii) would be used for aborts occurring at flight velocities greater than 30,000 fps (through the use of onboard propulsion). There exist some twelve preselected landing points in the Atlantic and Indian Oceans, into which an Apollo flight could abort depending on velocity and launch azimuth of each vehicle. Since there are four planned launch azimuths, each a function of launch window and recycle time, and three velocity phases for lunar transfer, twelve landing points result. The first four series of locations are 1100 n. mi. downrange, the second series about 2700 n. mi. downrange; the last four sites have ranges of 6600, 7300, 8300 and 9100 n. mi. In addition, there is a launch pad and atmospheric abort area extending some 600 n. mi. downrange.

2.3 SCIENTIFIC TASK DESCRIPTION

2.3.1 General. The foremost scientific objective of the Apollo program is a detailed study of the behavioral aspects, psychological and physiological impositions, and the utility of extended manned space operations. The program is a logical step beyond Project Mercury and extends manned space travel as part of the national space program. Questions as basic as the feasibility of sending man into extra-terrestrial space, instrumented probes versus manned space reconnaissance, extended habitability of cislunar and lunar space, and outer space as a practical scientific laboratory are the prime outputs of a program such as Apollo. Any pure scientific data derived from proposed Apollo missions is secondary to the above objectives. Nevertheless, the lunar astronauts should participate in limited scientific effort.

2.3.2 Earth-Orbit Scientific Tasks. The large payload capabilities of the Saturn C-1 and C-2 launch vehicles offer extensive possibilities for full-scale scientific operations in terrestrial space. An immediate objective of the earth-orbit mission could be to obtain highly resolved photography. A camera suitable for this purpose is described below. Later earth-orbit objectives, as proposed in the mission analysis, might include orbital plane changes, rendezvous maneuvers, and possibly a permanent orbiting space station. Purely scientific tasks will be largely dictated by requirements for the 1965 time period, and an outline of these at this time would be speculative.

2.3.3 Earth-Probe Objectives. The obvious objectives for this mission would be the gathering of radiation data. Micrometeorite, magnetic field, meteorological reconnaissance, and earth-shape experiments could also be considered. A further consideration would be radio-astronomical experiments in conjunction with stellar photographs. The durations of these flights preclude any long-term experiments, because of the apparent radiation hazard to the crew.

2.3.4 Lunar Scientific Objectives

2.3.4.1 General. Visual and photographic observation of the lunar surface are of prime scientific importance. Optical resolution three or four times greater than previous efforts should be possible. With proper instrumentation and design, much of the onboard equipment will also yield valuable scientific information. Examples of this are use of radar altimeter to accomplish topography measurements, a radiation counter for cosmic radiation studies, and the onboard guidance system for generating and improving earth-moon astronomical constants. In addition, micrometeorite measurements, magnetic field studies, and lunar temperature experiments are desirable because of the small weight penalty imposed by equipment for such experiments. Mention should be made of the so-called "free" experimental data from long duration effects of physical phenomena, such as liquid behavior at zero g.

2.3.4.2 Photo Reconnaissance. The photographic camera will comprise the bulk of the scientific weight, close to 135 lbs. The camera, as depicted in Figure 13, will be designed for a 48-inch focal length, employing an f/5.6 lens system. Such a camera should be available in 1962. The film magazine will feature an image compensation (IMC) device to minimize distortion. A mission documentation camera for locating the subject will be included, with a reflex capability for viewfinding. The viewfinder will have roughly a 500-n. mi. field of view, and the prime camera will expose roughly a 17- by 17-n. mi. area, both from a 200-n. mi. altitude. The design resolution at 200 n. mi. is five feet, which corresponds to nearly 200 lines/mm. Studies have indicated that dark side illumination with flares is undesirable, largely due to inconsistent and discontinuous image lighting.

Preliminary orientation of the camera will be accomplished by changing the attitude of the vehicle, and with a 30-degree solid angle adjustment

[redacted]

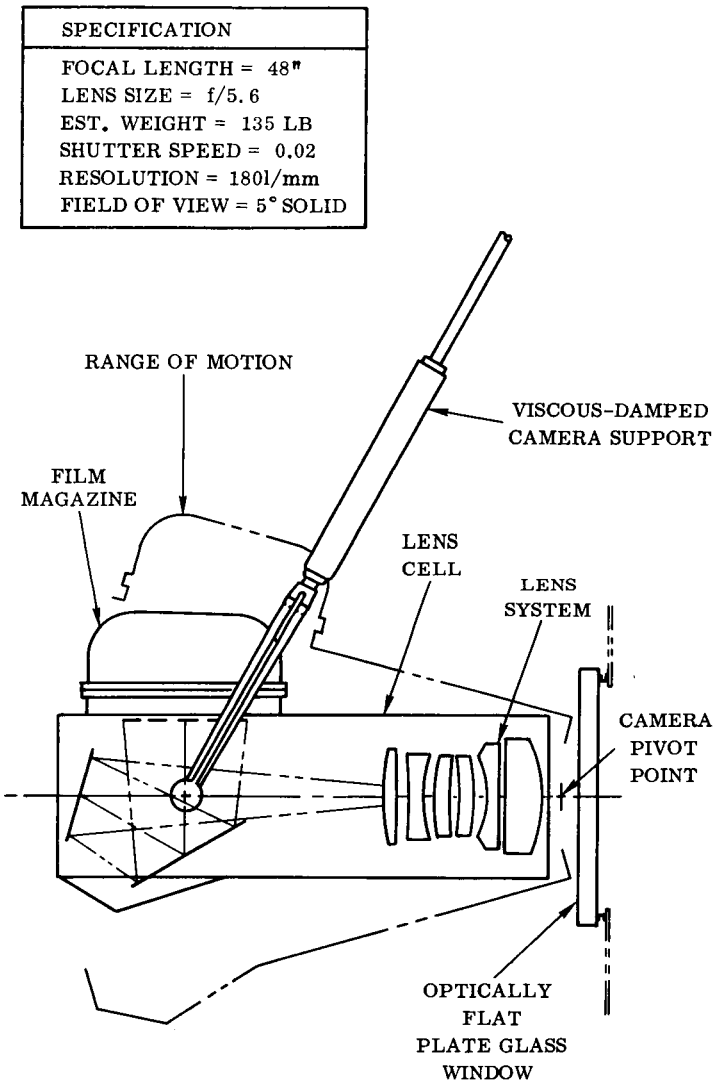


Figure 13. Apollo Photographic Camera

about the camera support, an astronaut will align the target into cross-hairs. A single mechanism will activate both shutters and the IMC. Film should be of a slow variety, probably Kodak SO243 with an ASA number of 3-6, and should employ the maximum standard width of 9 inches. Exposures should be made on single frames at a speed of roughly 0.02 sec. Film should be protected from all forms of radiation during the entire flight, since it probably will not be developed until after return. For minimum weight, the film could be stored in a polyethylene-and-lead-film sandwiched container under the astronauts' seats. It is expected that 150 to 300 pictures will be taken during a lunar mission, resulting in less than 300 feet or about 6 lb of film. This estimate includes pictures taken en-route, which would include stellar, long-range terrestrial, lunar, and possibly solar photographs.

The camera would be pivoted about two axes at a point near an optically flat window, and should be restrained by two linear damping mechanisms. The camera cell, having the advantage of a weightless environment, would be lighter than conventional cameras, and would be stored in a special support during launch and other propulsive maneuvers.

2.3.4.3 Micrometeorite Counts. Measurements of micrometeorite impacts, made on both legs of the mission as well as in the lunar vicinity, could best be accomplished by use of two lightweight, diametrically opposed counters. Figure 14 depicts a probable configuration, which utilizes seven gold-plated crystal detectors (five square inches of detection area). The device proposed not only indicates the number of collisions per unit area per unit time, but measures the momentum transfer of each collision. Its weight is about 2.5 lb and it consumes less than 0.8 watt. Sensitivity range is between 10^{-11} and 10^{-6} grams. Input voltage is 28 vdc, and the scalar readout is 0.5 to 3.5 volts, with an operating temperature between zero and 60°C.

2.3.4.4 Magnetic Field Measurements. A lightweight, sensitive magnetometer for sample measurement of magnetic fields during the entire mission is proposed. Its operating principle is based on optical pumping of rubidium vapor, and since it was carried aboard the Explorer X payload, it is presently available as an off-the-shelf item. Design field range is from 7 to 110 gammas. Since operation of these gas cells is optimum when their temperature is between 35°C and 45°C, present plans are to mount the instrument either at a remote point in the mission module or on the extension area of the communication antenna, with a suitable environment. Distance from onboard stray magnetic fields is, of course, a prime consideration. Some provision must be made for controlling the attitude of the magnetometer, such that field strength vectors may be recorded. The

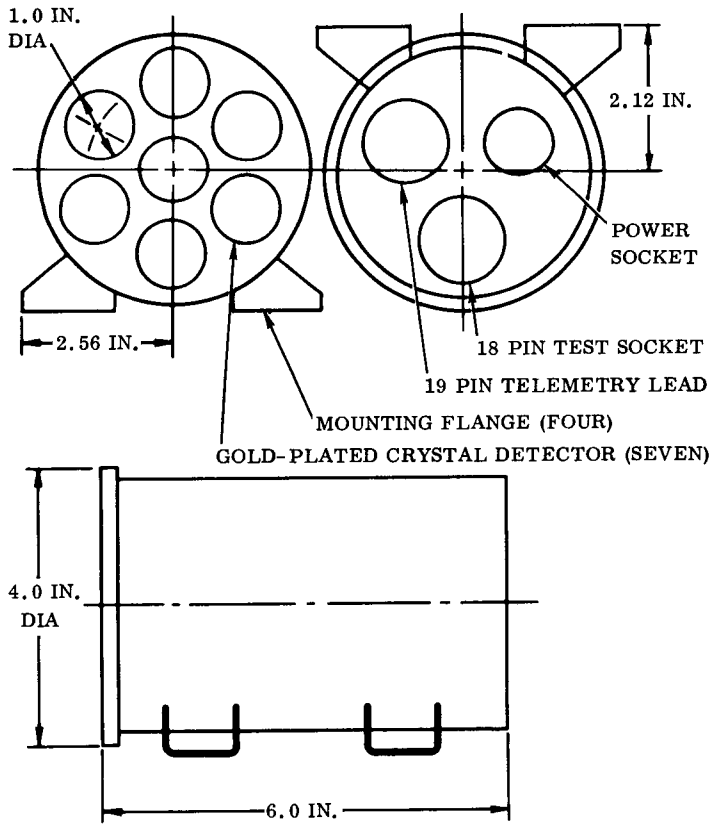


Figure 14. Micrometeorite Counter

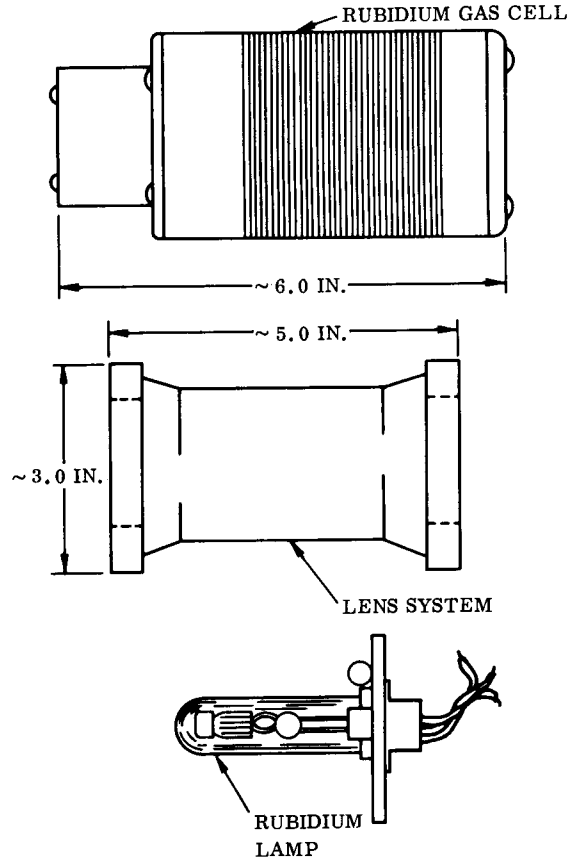


Figure 15. Typical Magnetometer

weight of the proposed equipment is less than three pounds, with assembled dimensions of roughly 15-in. by 3-in. diameter (see Figure 15). Power requirement is in the 5-watt range, but the instrument would merely be sampled periodically. Sensitivities of less than 0.01 gamma are expected for the planned time period.

2.3.4.5 Lunar Temperature Studies. Temperature measurements, especially through the terminator regions of the lunar surface, can best be made with a highly sensitive radiometer. This device consists of three major components: an oscillator, an amplifier, and a detector (the latter includes necessary optics). Development of such an instrument would be required; however, two designs look promising for lunar operation and are depicted in Figure 16. The first of these suspends the thermistor detector on three very fine wires or threads, with the detector anchored by the thermistor lead wires. Since the sensitivity depends on having a good thermal insulation between the detector and the reference junction (in this case, the instrument body), wires fine enough to give adequate sensitivity may be insufficient to take vibration and g-loads. This criterion led to the

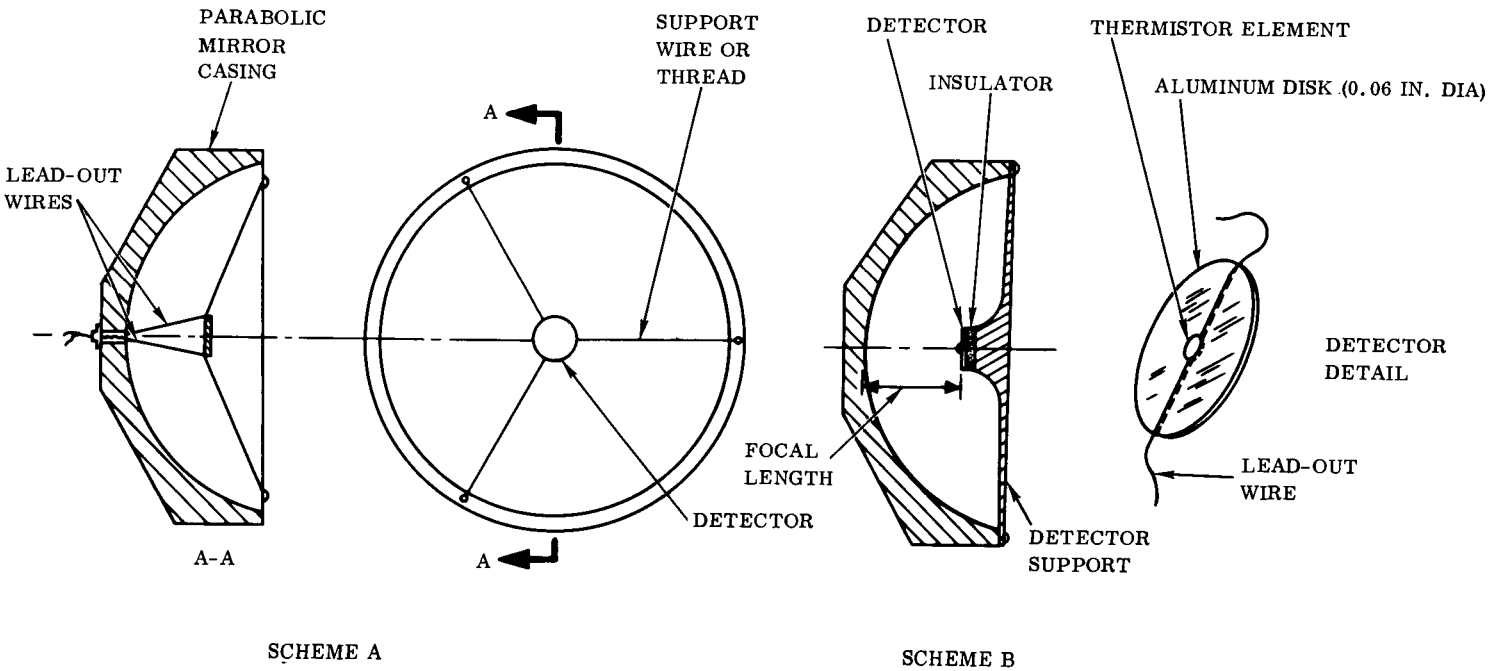


Figure 16. Proposed Radiometer Configuration

second design scheme of placing the detector plate (aluminum) on an insulating disc or ring and mounting this to a rigid support.

The field of view at 200-n.mi. altitudes should not exceed a 10-n.mi. diameter; therefore, with a detector diameter of 0.06 inch, focal length for the parabolic reflector should be about 1.2 inches. Weight of the entire system would be about 8 lb, with a power consumption of less than one watt. A serious problem is the uncertainty of the lunar surface emissivity as a function of wavelength, but it is assumed that lunar probes prior to manned operations will determine this.

2.3.4.6 Additional Considerations. Many scientific experiments will be dictated as the lunar program progresses, either by advances in knowledge or state of the art, or by unforeseen occurrences during lunar missions. In addition, certain scientific tasks appear desirable that require a minimum of equipment and advanced planning:

a. Monitoring of previously landed lunar probes to record and interpret weak signals.

b. Implementation of the return flight of a landed lunar probe using Apollo tracking and guidance.

c. Ejection of a capsule with a known impulse and tracking the capsule to determine local gravitational fields.

d. Ejection of an explosive capsule and passage through the dust cloud to gather lunar soil samples (explosive charge would require a timing device to permit an orbital pass before detonation).

e. Detection or collection of microorganisms, spores, space dust, and hydrocarbons in conjunction with cosmobiological experiments.

f. Lunar atmospheric density experiments by measuring occultation of known "radio" stars with a radiotelescope.

2.4 PROGRAM CONTINUITY

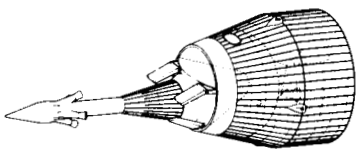
2.4.1 General. Continuity is given considerable emphasis throughout the entire Apollo program. The major program objectives and important milestones progress in a logical sequence from hardware design through completion of the ultimate flight mission: a close survey of the lunar surface. The proper sequence of events covers design, design evaluation, development, manufacturing, and testing. The final phase of the Apollo program will be the manned operations phase.

2.4.2 Design Phase. Primary emphasis during the design phase is on developing vehicle and system designs in an expeditious and thorough manner. Consequently, it will be necessary to resort to experimental procedures for obtaining pertinent data. Design of components for complicated or high-performance systems requires considerable experimentation.

2.4.3 Testing Phases. The testing phase begins immediately after hardware is available and is divided into laboratory, static, and flight testing. Laboratory testing includes aspects required to develop components and reliable systems. It also includes structural, functional, and operational testing of major vehicle systems. The static test phase covers operation of the complete vehicle in a simulated flight environment. The principal value of static testing is establishing the operational reliability of the propulsion system.

Each of the above test areas is limited in some respect by size constraints and other factors which cause the tests to be conducted under conditions different from those expected during the flight test. Ground tests, no matter how complete, cannot be as realistic as the free-flight test.

Flight tests serve to integrate various vehicle components and subsystems into a complete vehicle system, operating under design conditions and in the proper environment. There are also certain features that can be checked out only on a flight test; these should be planned early in the flight test program. Prototype development flights are scheduled as early as possible in order to isolate serious defects prior to production-vehicle flight tests. The latter portion of the flight test phase serves to demonstrate the vehicle's design capability and operational reliability over its intended range of missions.



3 SCHEDULING

3.1 SCHEDULE CONTINUITY. The schedules contained in this section illustrate the continuity of the program proposed. All subsystem laboratory, development, environmental, and qualification testing is integrated into the master schedule to support full-scale static and captive testing. As the design becomes functionally proven, the boilerplate, prototype, and production vehicle testing is arranged, with continuity as the ground rule. Whenever possible, the primary objectives of a particular flight are assigned as the secondary objectives of subsequent flights, thereby providing a realistic backup. Test objectives of development and flight tests, and constraints of manned missions, become progressively more demanding; discontinuities are held to an absolute minimum. For example, manned earth-orbit flights begin with a planned duration of four days and become more extended with each flight. This orbital period of manned operations logically progresses into the earth-probe phase, the first of these flights requiring no velocity corrections by the crew except for small incremental impulses after one orbital pass. The second earth-probe flight is scheduled for two passes, and requires a velocity correction at apogee. These two missions are extremely similar in nature to the first circumlunar flight which then follows. After two circumlunar missions have been completed, a lunar orbital flight with exactly the same mission parameters (transfer time, periselenium altitude, lunar ephemeris, etc.) as the previous circumlunar mission is planned. This philosophy continues until the final flight, which satisfies the requirement of a lunar capture at 50 n.mi. altitude. Although the success of a program primarily depends on design integrity, the degree to which continuity and logical, efficient sequencing of operations is incorporated determines the ease with which this success is achieved.

3.2 DEVELOPMENT PROGRAM SCHEDULE. The schedule summary (Figure 17) assumes a go-ahead of 3 January 1962, delivery of first prototype vehicle in December 1963, and first vehicle with complete production subsystems in December 1964. Following presentation of current study results, pre-design efforts must continue until go-ahead, terminating in a configuration freeze. Guidance and life-support subsystems are anticipated to be the pacing design tasks. The initial vehicle will require sixteen months to fabricate. Some subsystem fabrication may have to be subcontracted.

The complete vehicle consists of four major components: command module, mission module, abort tower and interstage adapter. Manufacturing time only is expressed for the abort tower and the interstage adapter on the schedule summary because design, procurement, and tooling efforts of these two components are well within the time spans for the corresponding elements of the command and mission modules. The command module, abort tower, and interstage adapter are scheduled to be completed and ready to mate with the mission module at the same time, five months prior to vehicle acceptance.

Scale model and boilerplate command modules will be a separate and parallel effort to the manufacturing program for prototype/production components. The structural configuration and equipment needs of each scale model and boilerplate version vary and are described fully in Volume V, Book 3. Prototype modules and vehicles, as noted on the schedule, represent a combination of production and prototype subsystems totaling less than that required in a truly complete production vehicle. Equipment needs vary with each prototype unit and are also expressed in Volume V, Book 3.

Production subsystems (e.g. guidance and life support) reflected as receipts on the Material Procurement line cover installation on a flight vehicle and are not the first production sets built. Not shown on the schedule summary are articles built earlier for contractor and subcontractor testing, including two complete sets of production articles for qualification testing, which are scheduled to be available at least six weeks prior to the first set designated for flight vehicle installation.

Crew training will utilize the first complete vehicle after it has been used for captive testing and refurbished, and all equipment not available during original manufacture has been installed.

3.3 DEVELOPMENT PROGRAM NETWORK. The Development Program Schedule is a bar chart summary, and cannot reflect the relationship or proper sequencing of events. Therefore, the Development Program Network Chart (Figure 18) presents highlights of the same events, but only to indicate the above-mentioned factors. This brief network utilizes the PACE (Program Analysis and Control Evaluation) concept.

PACE is a management control tool for defining and integrating what must be done to accomplish program objectives on time. PACE is a statistical technique, diagnostic and prognostic, for quantifying knowledge about the uncertainties faced in completing activities essential for timely achievement of program deadlines. It is a technique for focusing management attention on danger signals that require remedial decisions, and on areas

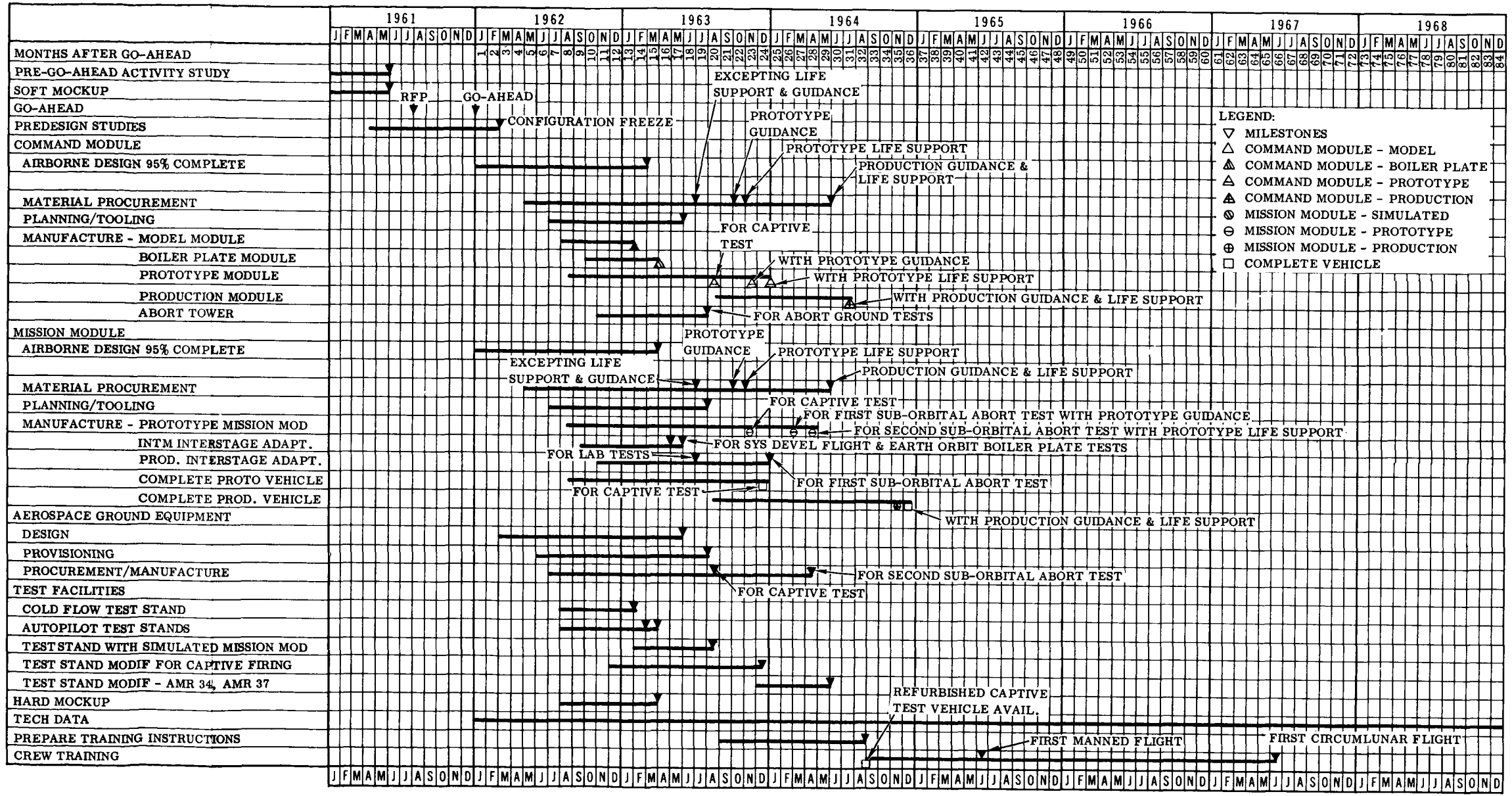


Figure 17. Development Program Summary Schedule

of effort for which tradeoffs in time, resources, or technical performance might improve capacity to meet major deadlines.

PACE analyzes current validity of approved plans and schedule, progress to date against program objectives, and the outlook for meeting ultimate objectives on time without further executive action.

With the help of a computer, PACE performs the following functions:

a. States the sequence and interrelationship of significant finite events (progress benchmarks).

b. Synthesizes network and time data to meet program deadlines.

c. Reveals the relative criticality among areas of effort required to meet end-objectives. The longest path based on PACE expectations may be longer or shorter than the schedule deadline.

d. Tailors outputs and analyses to the appropriate levels of management and technical interests.

e. Provides top management with the integrated summary picture of total progress and progress outlook on a continuous basis.

f. Simulates the time impact of proposals for change, and of optional courses for remedial decision, on the outlook for meeting end-objective deadlines.

The PACE chart (Figure 18) briefly indicates the major milestones and critical paths expected for the Apollo Program. Use of charts of this type and adoption of its philosophy are highly recommended for the Apollo development program.

3.4 SUBCONTRACTOR DEVELOPMENT SCHEDULE. The development program has been scheduled on a basis of coordinating contractor functions with subcontracted activities. Contractor activity covers in-house fabrication and procurement of items now developed or expected to be in the off-the-shelf category by program go-ahead. This includes items such as structural, electrical, hydraulic, pneumatic, power supply (less fuel cells), main propulsion, propellant tank and plumbing systems.

The following bar charts of subcontracted systems (Figures 19 through 27) show subcontractor go-ahead as 18 to 26 weeks following contractor go-ahead. Subsequent to contractor go-ahead, but prior to subcontractor go-ahead, the following steps occur:

a. Contractor configuration freeze, including dimensional, weight and requirement considerations.

b. Contractor preparation of detailed specification and parameter documents and drawings.

c. Requests for bids, evaluation, and placement of purchase order.

Subcontractor deliveries are scheduled to allow for transportation to and receipt by contractor, inspection, and proper availability in the major component manufacturing sequence.

3.5 PRODUCTION SUPPORT OF TEST AND OPERATIONAL PROGRAMS. Production requirements shown on this schedule (Figure 28) represent components and/or complete vehicles ready for delivery two or more months in advance of test facility usage, allowing time for transportation, erection and checkout. Scheduled production completions for the entire program are based upon the following factors, listed in order of importance:

a. Scheduled need of test event.

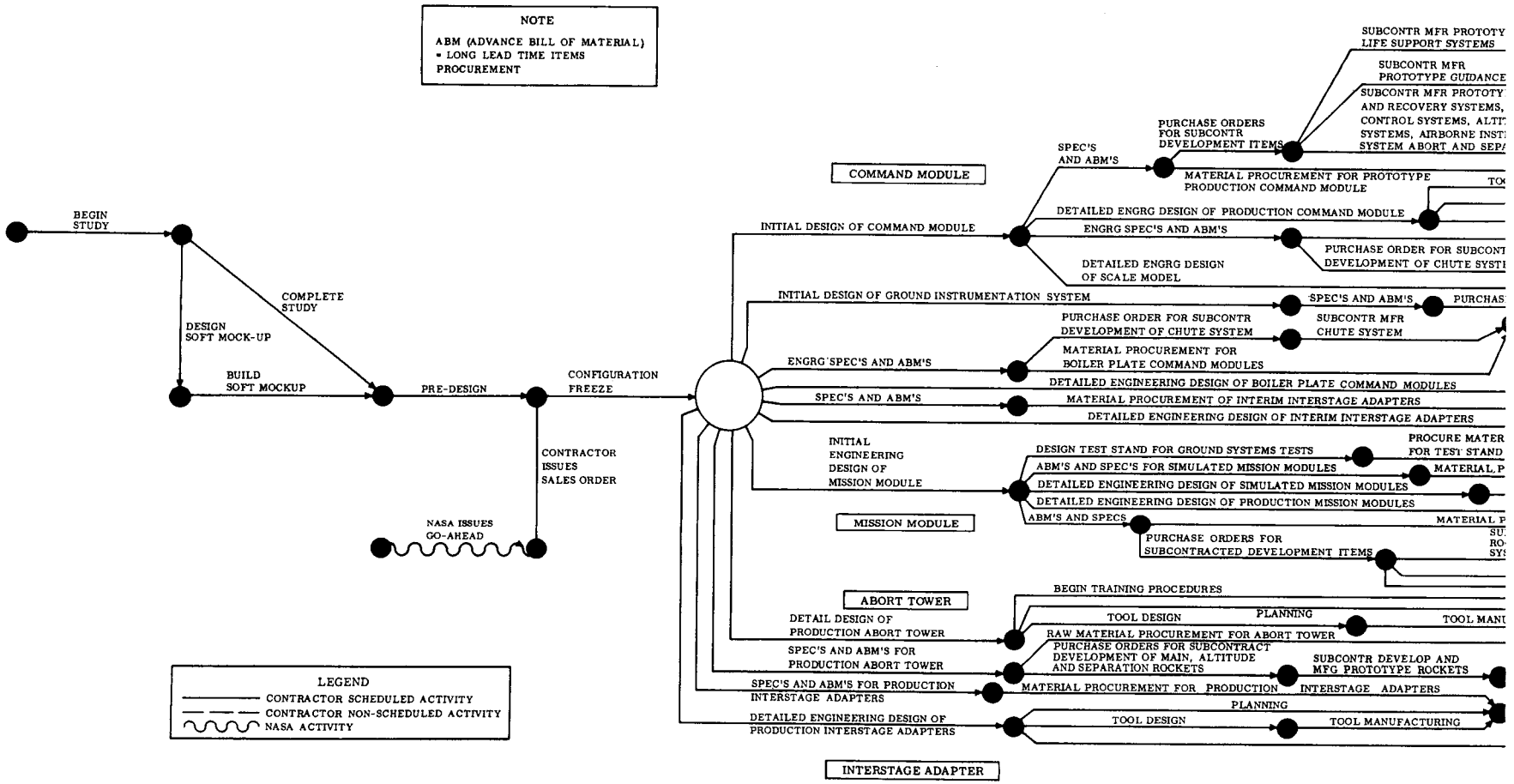
b. Minimum tooling and labor during manufacture.

c. Constant rate of component completions through the program to allow for configuration changes and rescheduling of the flight test program.

The top line of this schedule expresses the number of months after go-ahead which is assumed to be 3 January 1962. Each type of component and vehicle listed in the left margin is followed by a total number of units to be manufactured in parentheses.

The numbers listed immediately beneath components and complete vehicles (on the schedule proper) are to assist in relating the scheduled manufacturing need of an item to its eventual usage in the test program. For example, the fourth boilerplate command module identified as 7 is completed in the nineteenth month and, allowing for transportation to and erection at a test facility, is launched as an earth-orbit test 22 months after go-ahead.

Each component not assembled into a complete vehicle bears a separate number. Each complete vehicle has its number, and the command and mission modules specifically manufactured for installation into a complete vehicle are identified with the same number as the final vehicle.


NOTE
ABM (ADVANCE BILL OF MATERIAL)
= LONG LEAD TIME ITEMS
PROCUREMENT
BEGIN STUDY
COMPLETE STUDY
DESIGN SOFT MOCK-UP
BUILD SOFT MOCKUP
PRE-DESIGN
CONFIGURATION FREEZE
CONTRACTOR ISSUES SALES ORDER
NASA ISSUES GO-AHEAD
COMMAND MODULE
INITIAL DESIGN OF COMMAND MODULE
SPEC'S AND ABM'S
PURCHASE ORDERS FOR SUBCONTR DEVELOPMENT ITEMS
SUBCONTR MFR PROTOTY
LIFE SUPPORT SYSTEMS
SUBCONTR MFR
PROTOTYPE GUIDANCE
SUBCONTR MFR PROTOTY
AND RECOVERY SYSTEMS,
CONTROL SYSTEMS, ALTI
SYSTEMS, AIRBORNE INST
SYSTEM ABORT AND SEP
MATERIAL PROCUREMENT FOR PROTOTYPE PRODUCTION COMMAND MODULE
DETAILED ENGRG DESIGN OF PRODUCTION COMMAND MODULE
ENGRG SPEC'S AND ABM'S
PURCHASE ORDER FOR SUBCONT
DEVELOPMENT OF CHUTE SYST
DETAILED ENGRG DESIGN OF SCALE MODEL
INITIAL DESIGN OF GROUND INSTRUMENTATION SYSTEM
SPEC'S AND ABM'S
PURCHAS
PURCHASE ORDER FOR SUBCONTR DEVELOPMENT OF CHUTE SYSTEM
SUBCONTR MFR CHUTE SYSTEM
ENGRG SPEC'S AND ABM'S
MATERIAL PROCUREMENT FOR BOILER PLATE COMMAND MODULES
DETAILED ENGINEERING DESIGN OF BOILER PLATE COMMAND MODULES
SPEC'S AND ABM'S
MATERIAL PROCUREMENT OF INTERIM INTERSTAGE ADAPTERS
DETAILED ENGINEERING DESIGN OF INTERIM INTERSTAGE ADAPTERS
INITIAL ENGINEERING DESIGN OF MISSION MODULE
DESIGN TEST STAND FOR GROUND SYSTEMS TESTS
PROCURE MATER
FOR TEST STAND
ABM'S AND SPEC'S FOR SIMULATED MISSION MODULES
MATERIAL, P
DETAILED ENGINEERING DESIGN OF SIMULATED MISSION MODULES
DETAILED ENGINEERING DESIGN OF PRODUCTION MISSION MODULES
MISSION MODULE
ABM'S AND SPECS
MATERIAL P
PURCHASE ORDERS FOR SUBCONTRACTED DEVELOPMENT ITEMS
ABORT TOWER
BEGIN TRAINING PROCEDURES
DETAIL DESIGN OF PRODUCTION ABORT TOWER
TOOL DESIGN
PLANNING
TOOL MANU
RAW MATERIAL PROCUREMENT FOR ABORT TOWER
SPEC'S AND ABM'S FOR PRODUCTION ABORT TOWER
PURCHASE ORDERS FOR SUBCONTRACT DEVELOPMENT OF MAIN, ALTITUDE AND SEPARATION ROCKETS
SUBCONTR DEVELOP AND MFG PROTOTYPE ROCKETS
SPEC'S AND ABM'S FOR PRODUCTION INTERSTAGE ADAPTERS
MATERIAL PROCUREMENT FOR PRODUCTION INTERSTAGE ADAPTERS
PLANNING
DETAILED ENGINEERING DESIGN OF PRODUCTION INTERSTAGE ADAPTERS
TOOL DESIGN
TOOL MANUFACTURING
INTERSTAGE ADAPTER
LEGEND
CONTRACTOR SCHEDULED ACTIVITY
CONTRACTOR NON-SCHEDULED ACTIVITY
NASA ACTIVITY

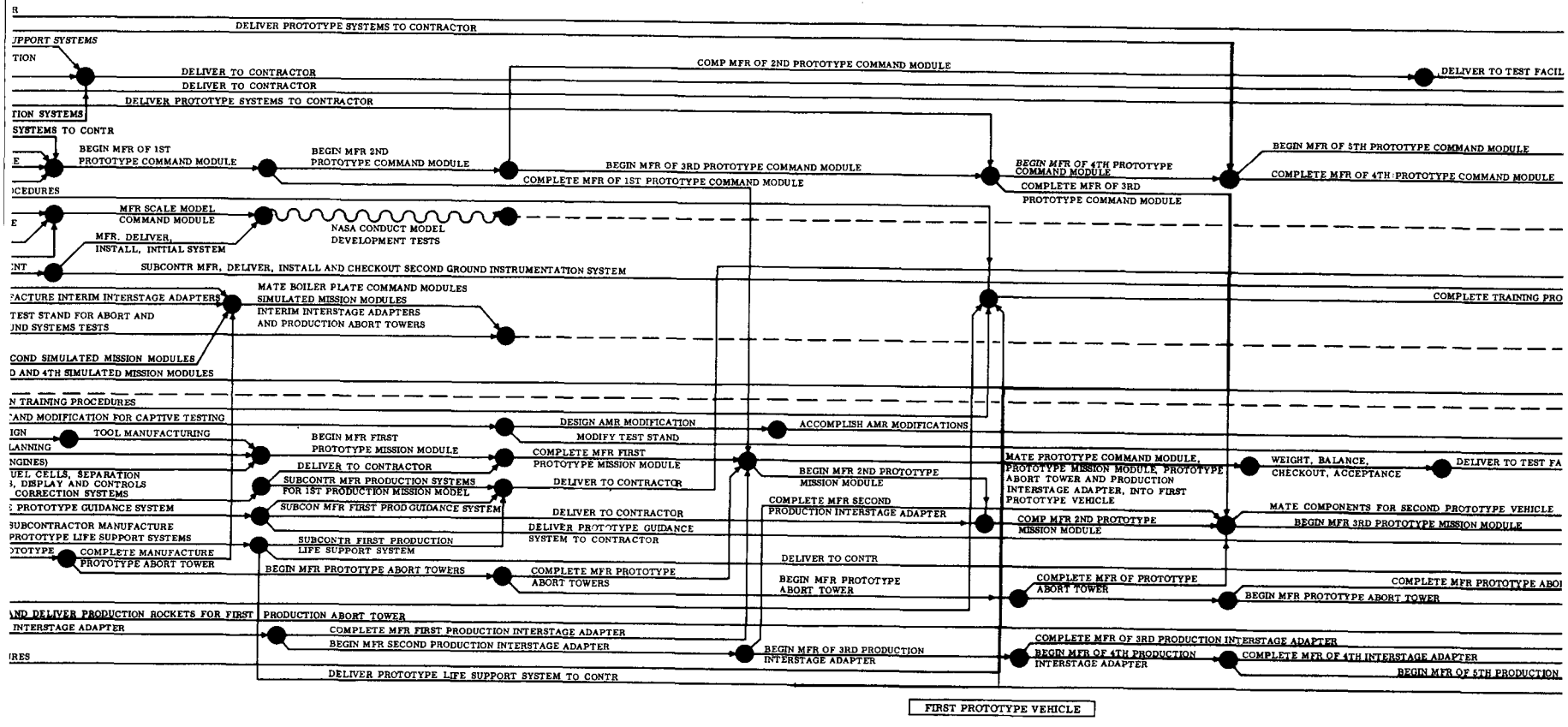
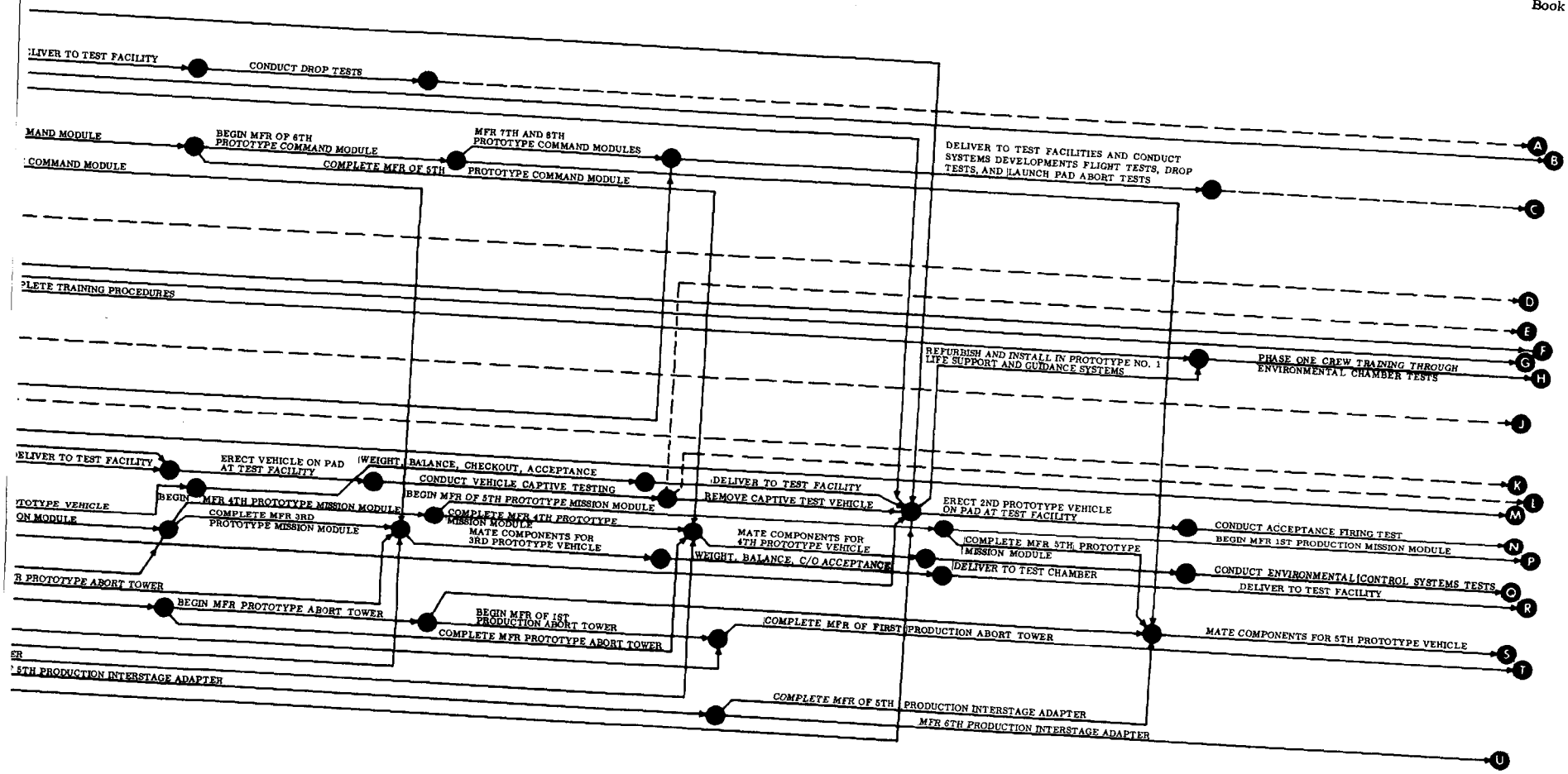
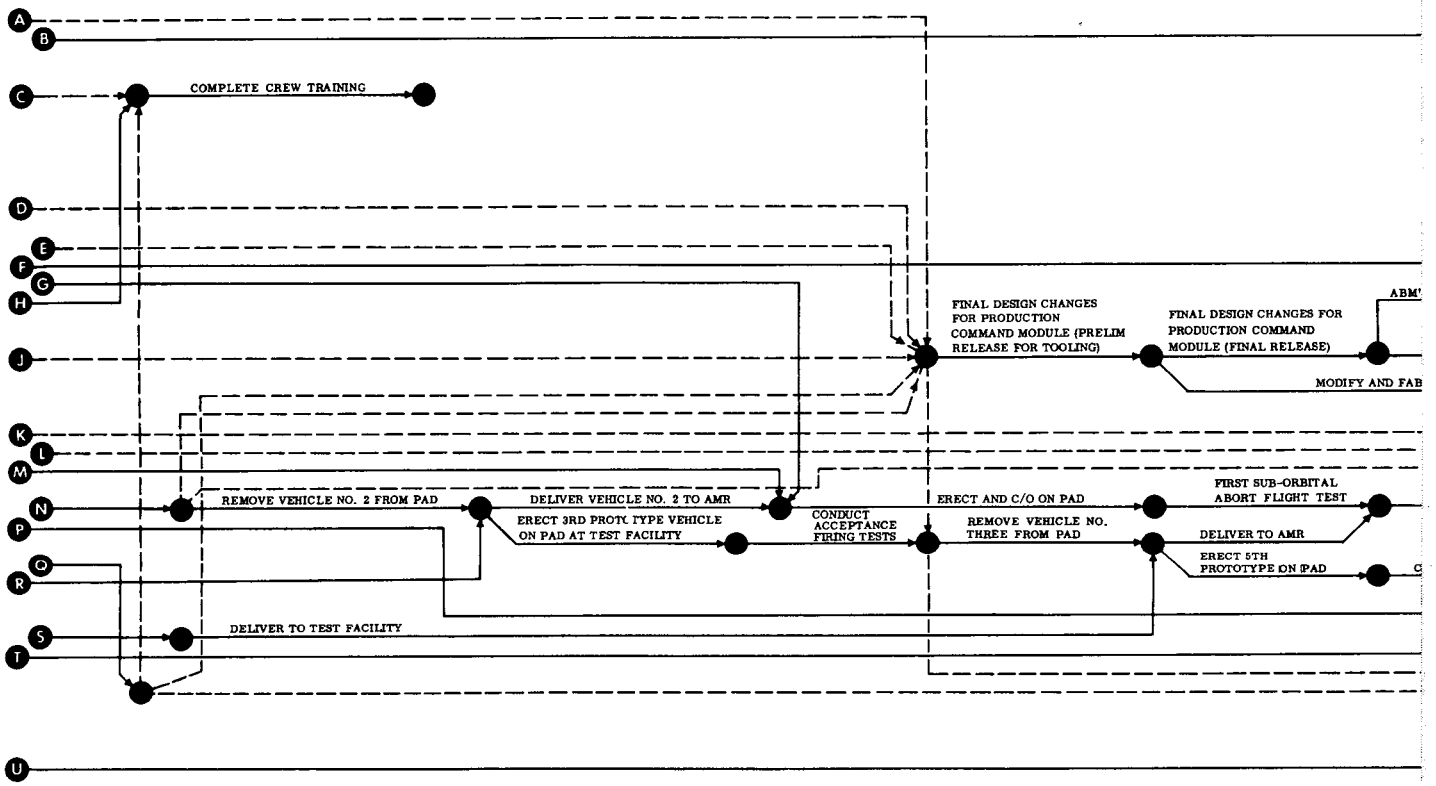


Figure 18. Development Program Network (Sheet 1 of 2)


LIVER TO TEST FACILITY
CONDUCT DROP TESTS
MAND MODULE
BEGIN MFR OF 6TH PROTOTYPE COMMAND MODULE
MFR 7TH AND 8TH PROTOTYPE COMMAND MODULES
COMMAND MODULE
COMPLETE MFR OF 5TH PROTOTYPE COMMAND MODULE
DELIVER TO TEST FACILITIES AND CONDUCT SYSTEMS DEVELOPMENTS FLIGHT TESTS, DROP TESTS, AND LAUNCH PAD ABORT TESTS
PLETE TRAINING PROCEDURES
REFURBISH AND INSTALL IN PROTOTYPE NO. 1 LIFE SUPPORT AND GUIDANCE SYSTEMS
PHASE ONE CREW TRAINING THROUGH ENVIRONMENTAL CHAMBER TESTS
DELIVER TO TEST FACILITY
ERECT VEHICLE ON PAD AT TEST FACILITY
WEIGHT, BALANCE, CHECKOUT, ACCEPTANCE
CONDUCT VEHICLE CAPTIVE TESTING
DELIVER TO TEST FACILITY
REMOVE CAPTIVE TEST VEHICLE
TOTYPE VEHICLE
BEGIN MFR 4TH PROTOTYPE MISSION MODULE
BEGIN MFR OF 5TH PROTOTYPE MISSION MODULE
ON MODULE
COMPLETE MFR 3RD PROTOTYPE MISSION MODULE
COMPLETE MFR 4TH PROTOTYPE MISSION MODULE
MATE COMPONENTS FOR 3RD PROTOTYPE VEHICLE
MATE COMPONENTS FOR 4TH PROTOTYPE VEHICLE
WEIGHT, BALANCE, C/O ACCEPTANCE
ERECT 2ND PROTOTYPE VEHICLE ON PAD AT TEST FACILITY
CONDUCT ACCEPTANCE FIRING TEST
BEGIN MFR 1ST PRODUCTION MISSION MODULE
COMPLETE MFR 5TH PROTOTYPE MISSION MODULE
DELIVER TO TEST CHAMBER
CONDUCT ENVIRONMENTAL CONTROL SYSTEMS TESTS
DELIVER TO TEST FACILITY
R PROTOTYPE ABORT TOWER
BEGIN MFR PROTOTYPE ABORT TOWER
BEGIN MFR OF 1ST PRODUCTION ABORT TOWER
COMPLETE MFR PROTOTYPE ABORT TOWER
COMPLETE MFR OF FIRST PRODUCTION ABORT TOWER
MATE COMPONENTS FOR 5TH PROTOTYPE VEHICLE
ER
5TH PRODUCTION INTERSTAGE ADAPTER
COMPLETE MFR OF 5TH PRODUCTION INTERSTAGE ADAPTER
MFR 6TH PRODUCTION INTERSTAGE ADAPTER
A
B
C
D
E
F
G
H
J
K
L
M
N
P
O
R
S
T
U

~~CONFIDENTIAL~~



~~CONFIDENTIAL~~

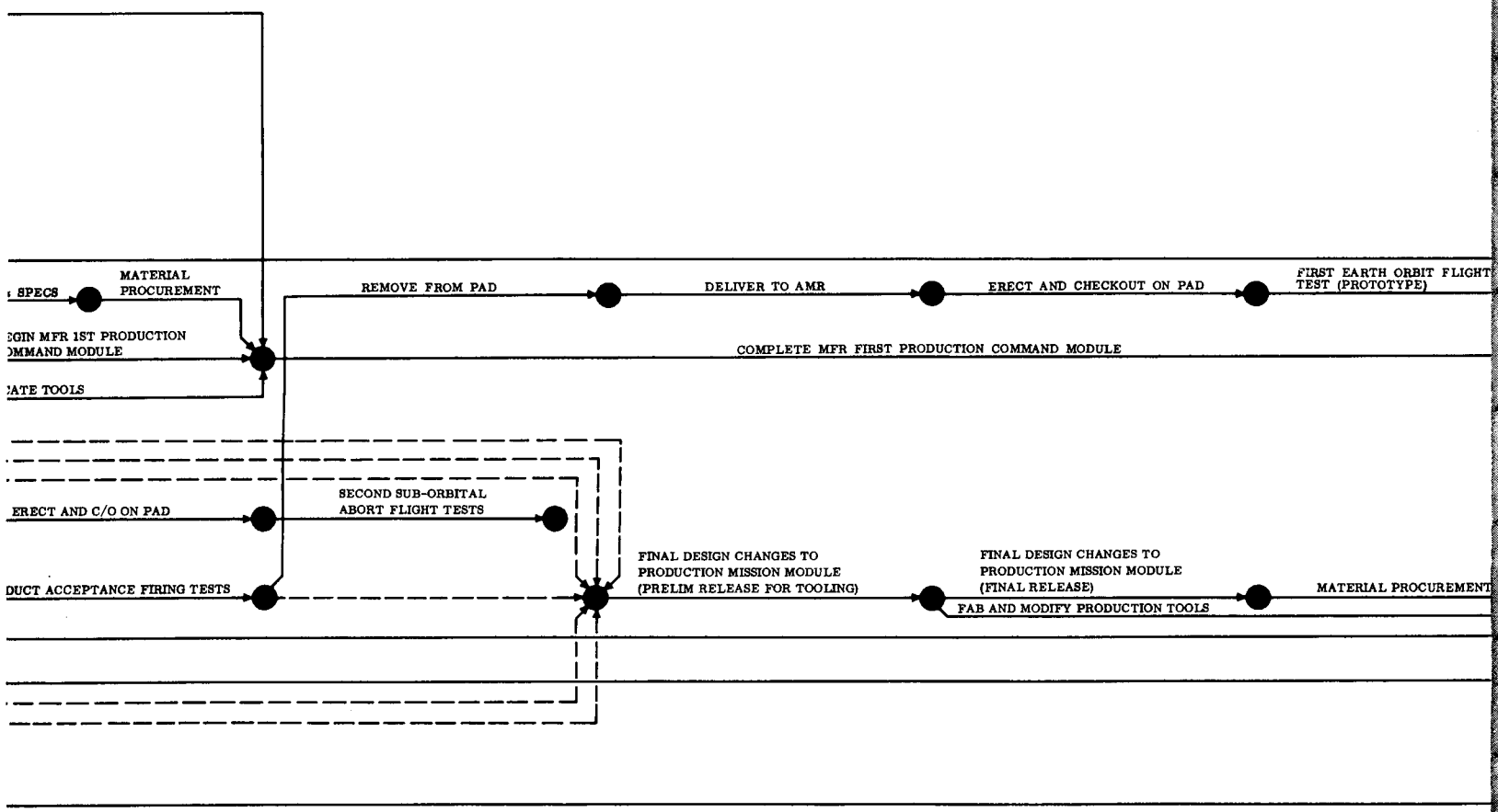
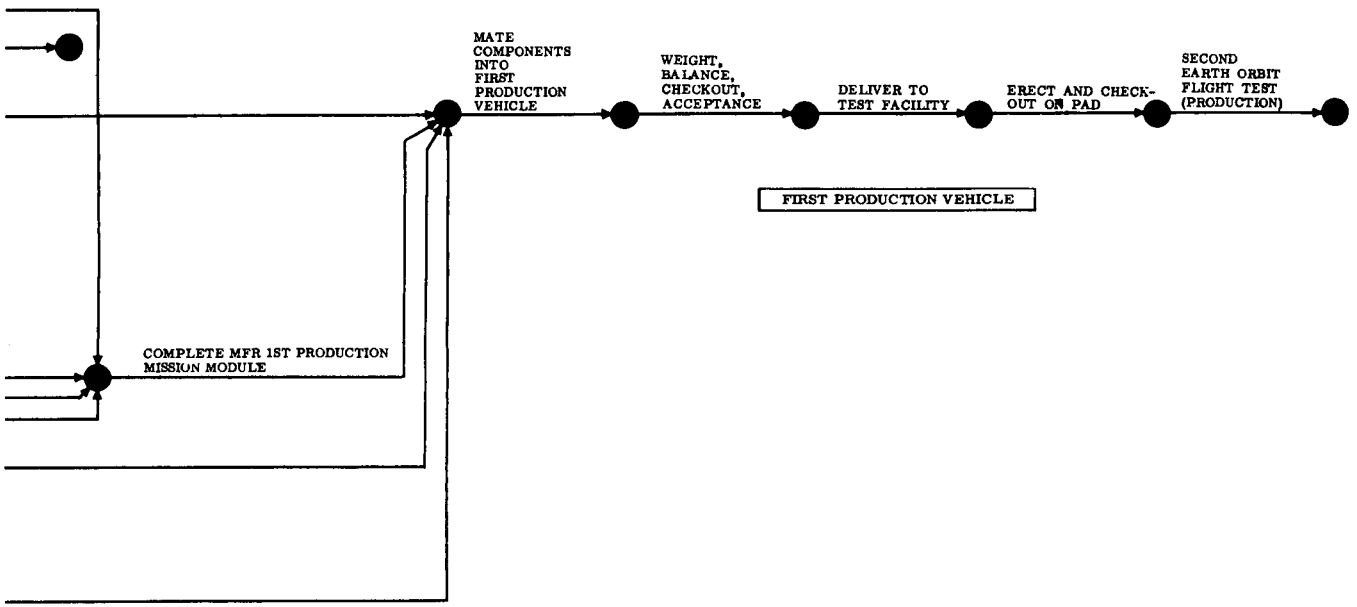


Figure 18. Development Program Network (Sheet 2 of 2)


MATE COMPONENTS INTO FIRST PRODUCTION VEHICLE
WEIGHT, BALANCE, CHECKOUT, ACCEPTANCE
DELIVER TO TEST FACILITY
ERECT AND CHECK-OUT ON PAD
SECOND EARTH ORBIT FLIGHT TEST (PRODUCTION)
FIRST PRODUCTION VEHICLE
COMPLETE MFR 1ST PRODUCTION MISSION MODULE

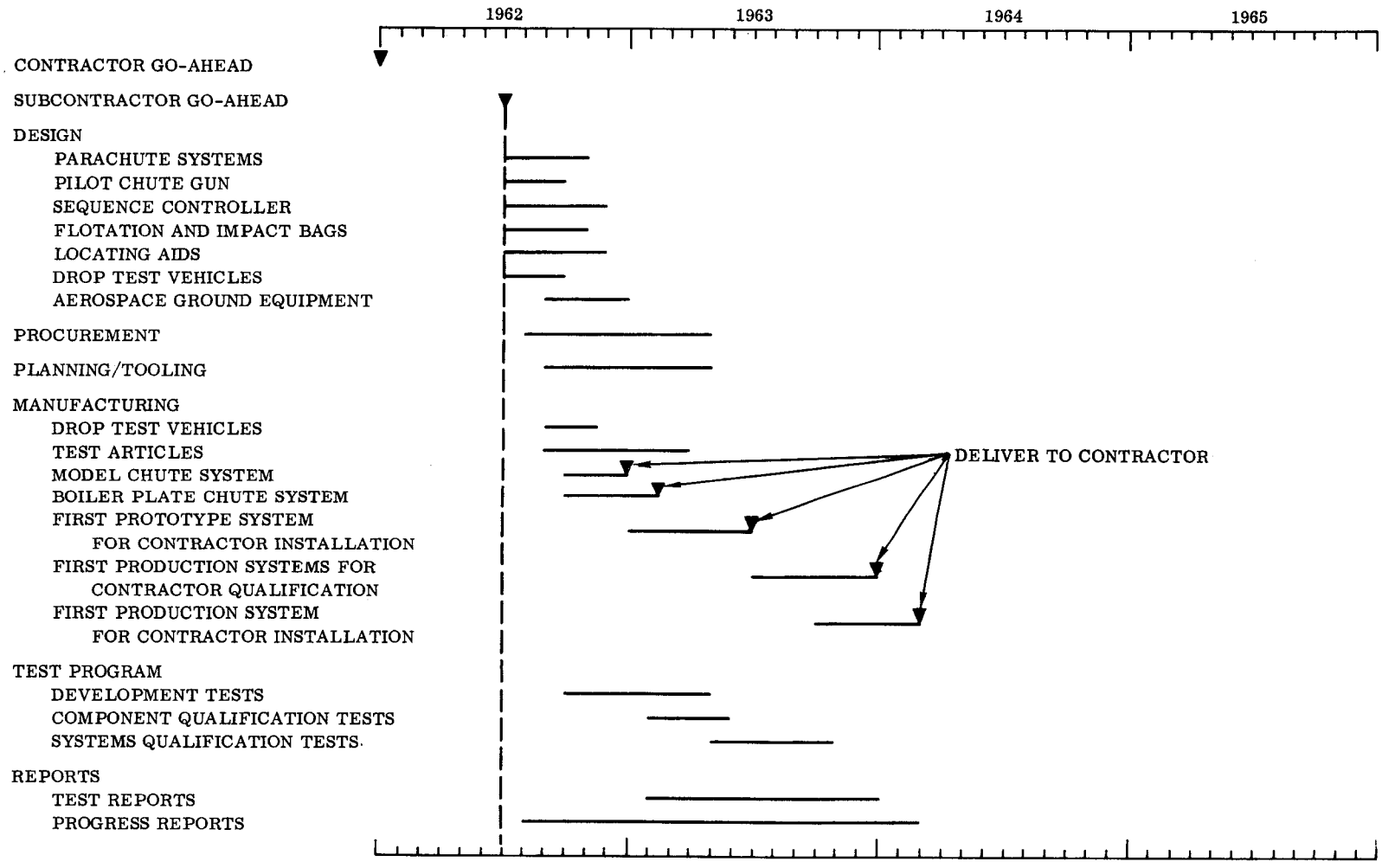


Figure 19. Landing System Development Schedule

~~CONFIDENTIAL~~

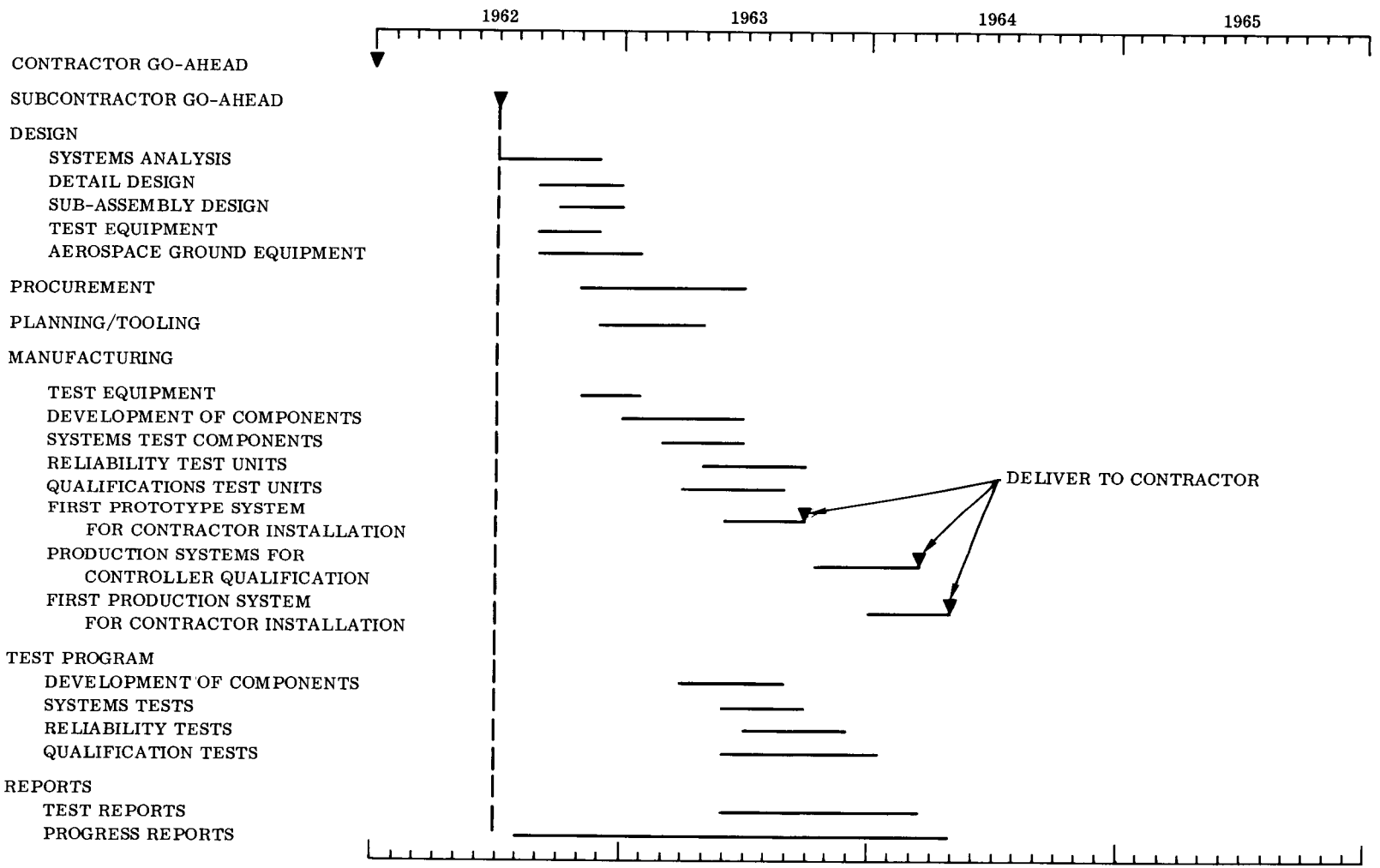


Figure 20. Life Support System Development Schedule

~~CONFIDENTIAL~~

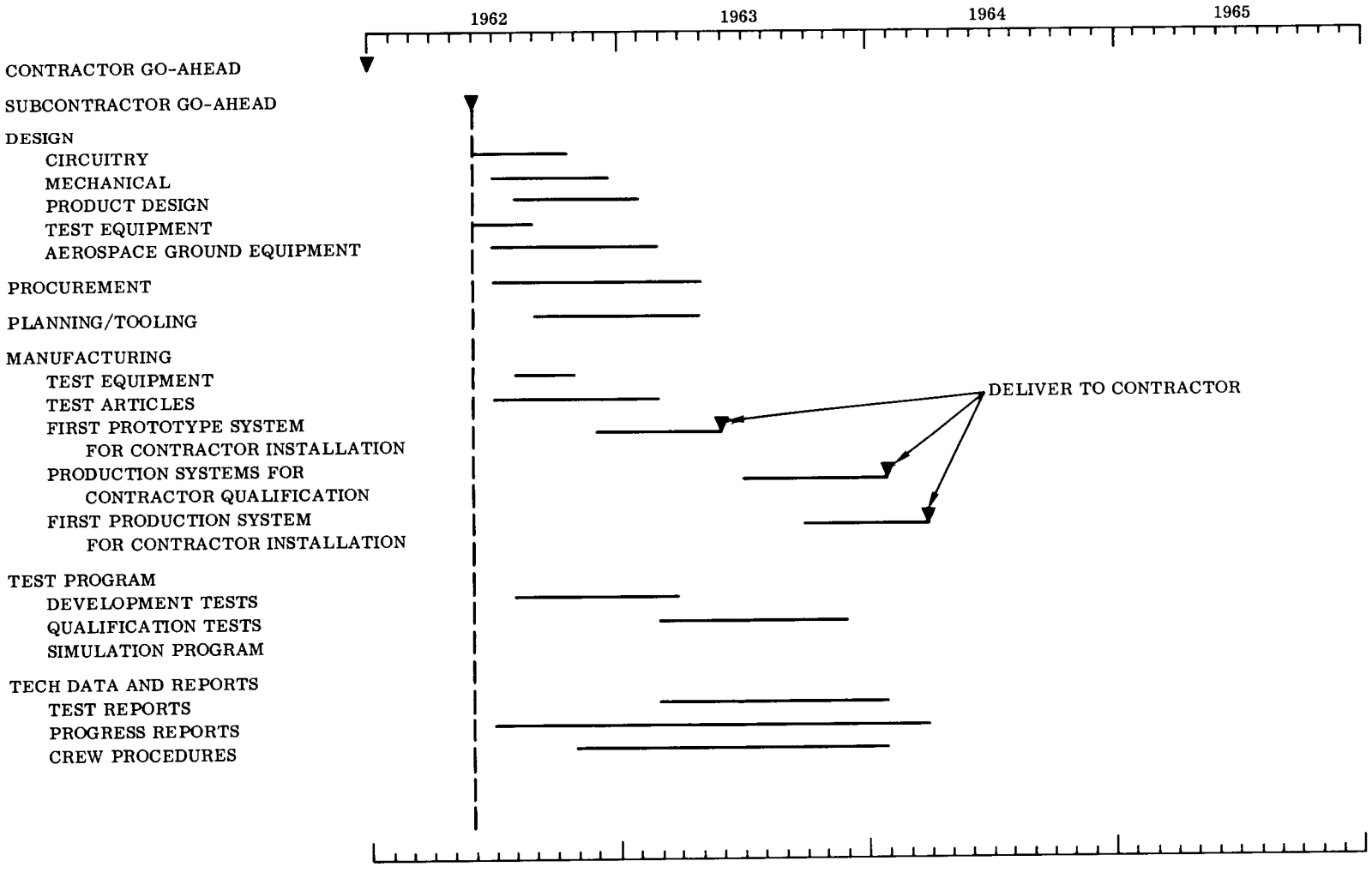


Figure 21. Display and Control Development Schedule

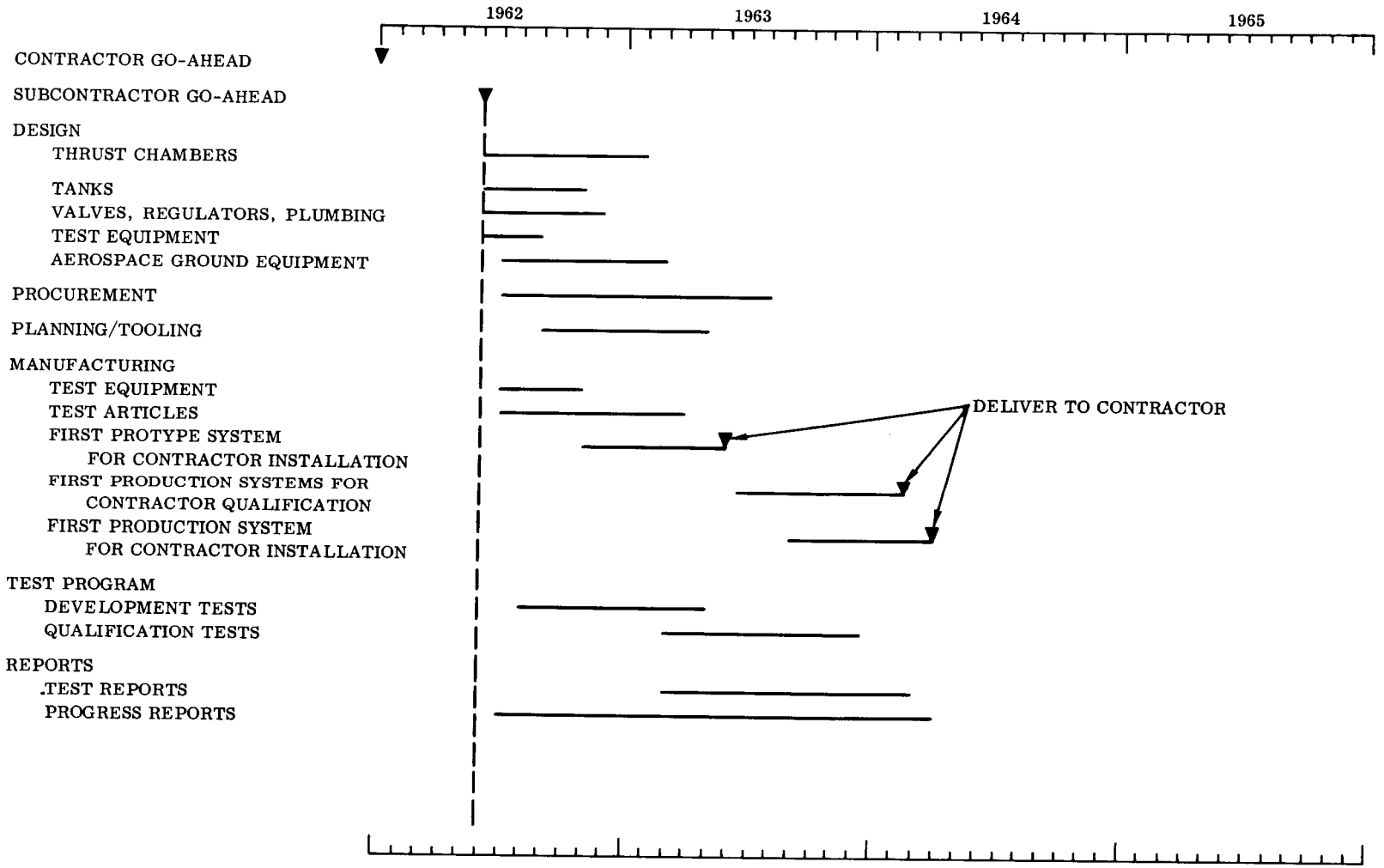


Figure 22. Secondary Liquid Rocket Systems Development Schedule

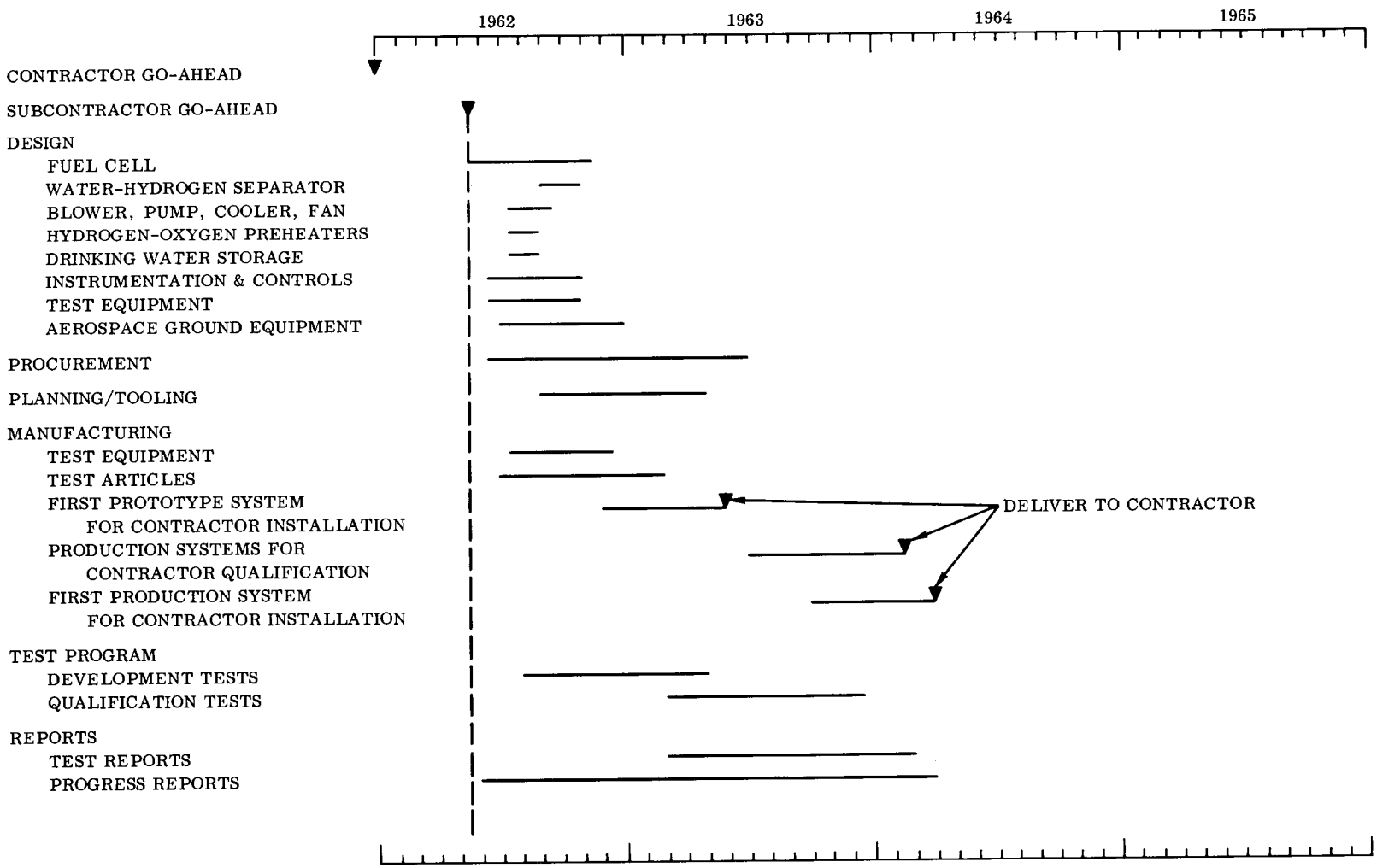


Figure 23. Fuel Cell System Development Schedule

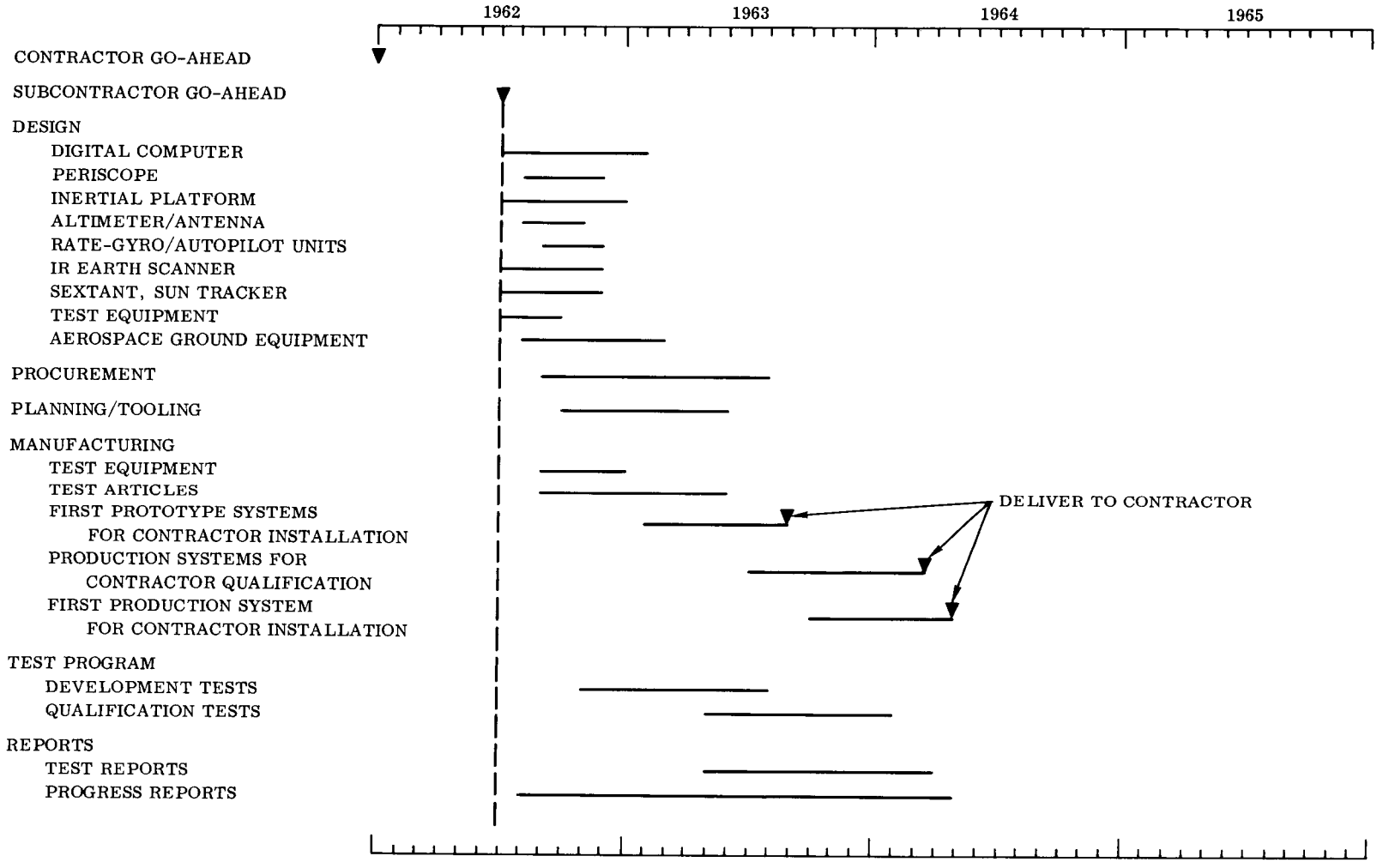


Figure 24. Guidance System Development Schedule

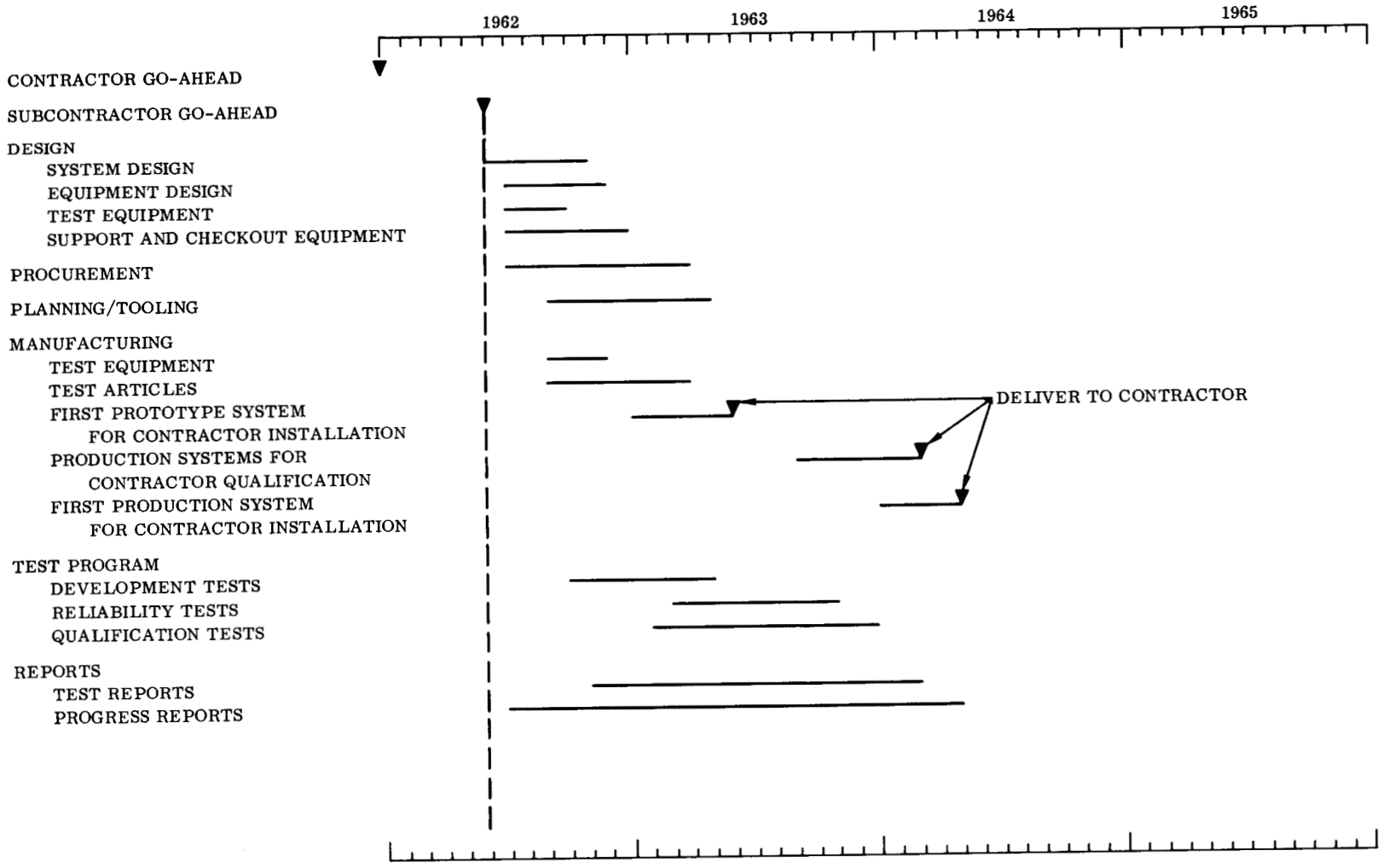


Figure 25. Vehicleborne Instrumentation System Development Schedule

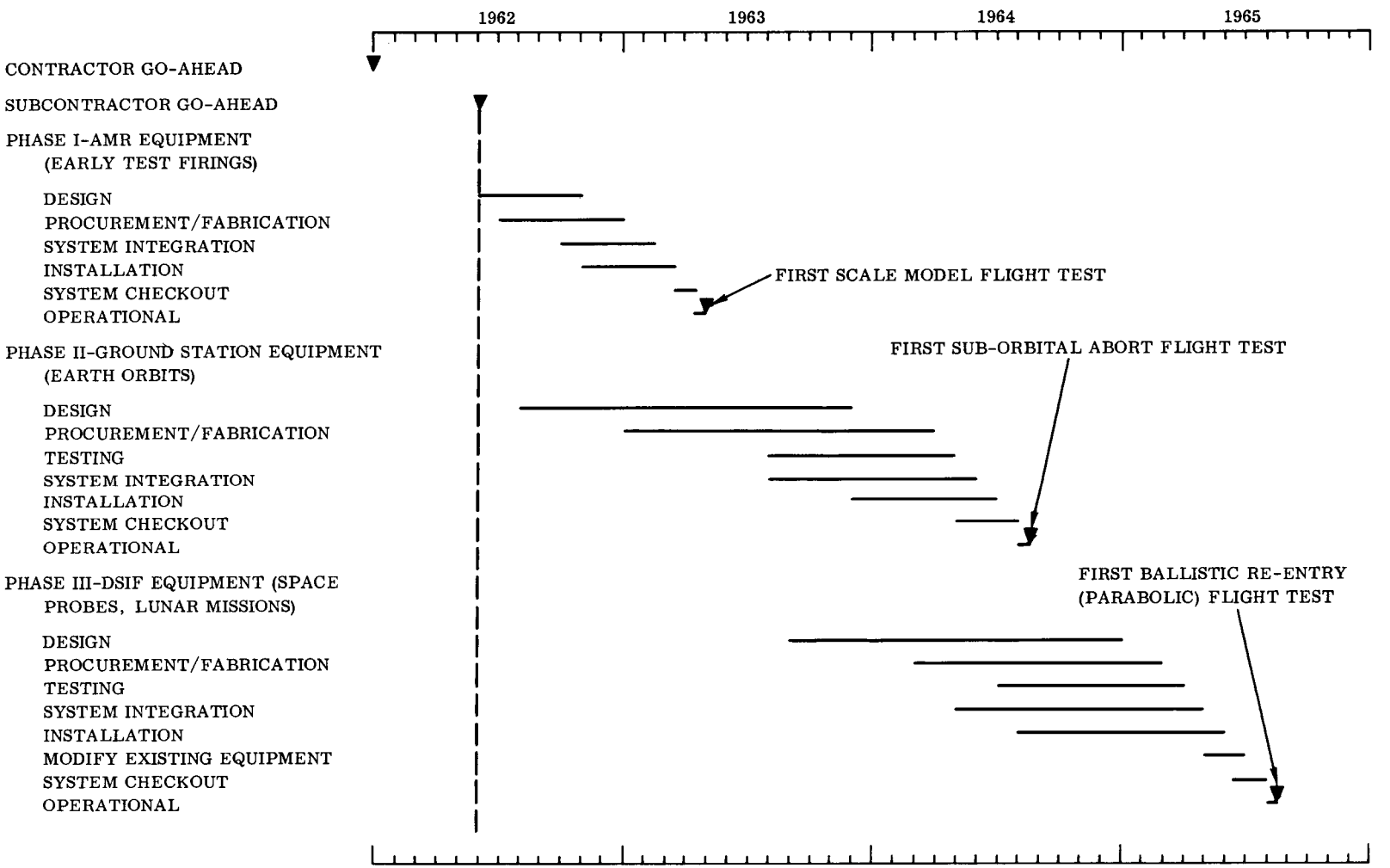


Figure 26. Ground Instrumentation System Development Schedule

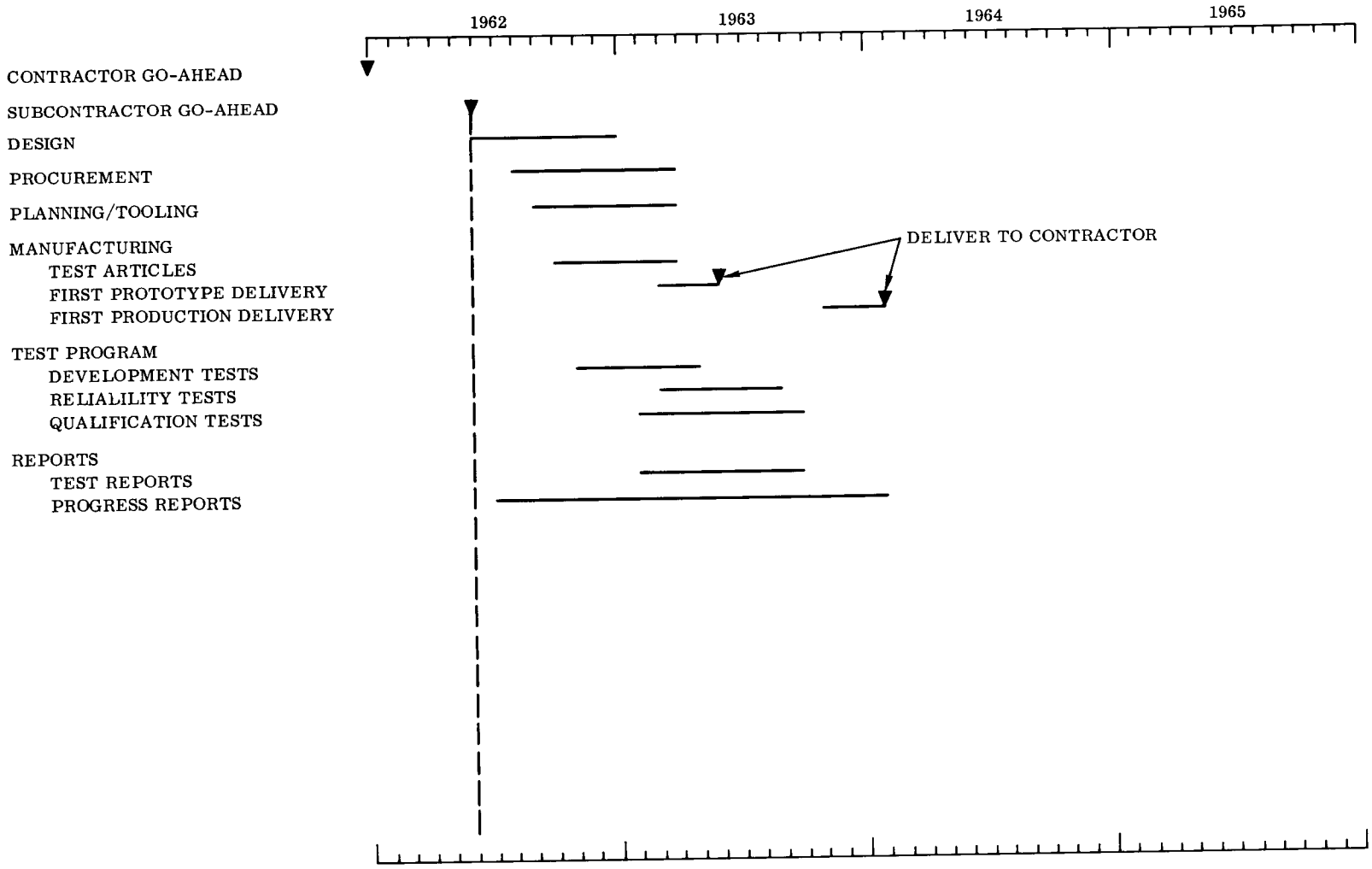


Figure 27. Abort and Separation Rockets Development Schedule

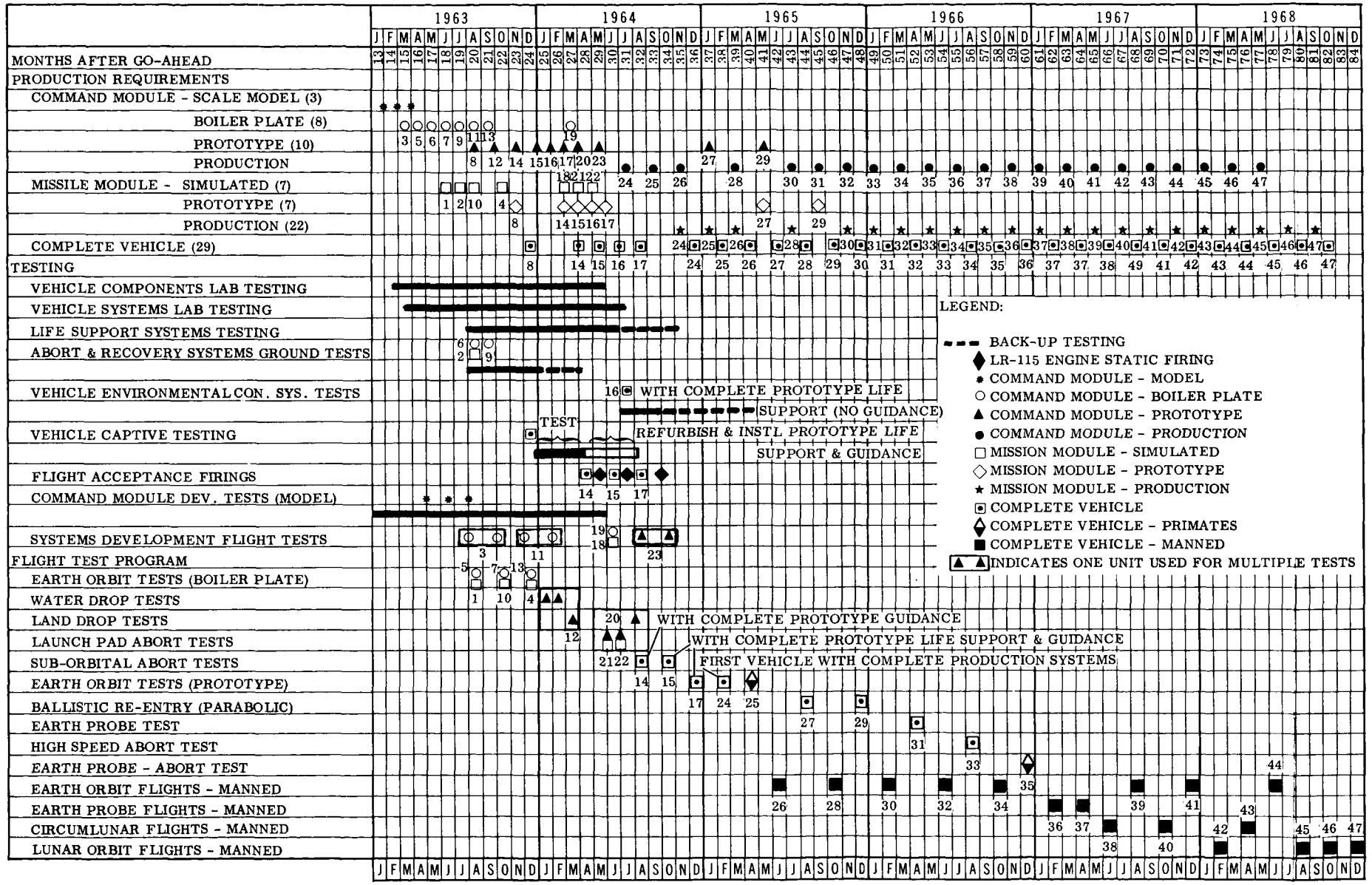


Figure 28. Test and Flight Program Schedule

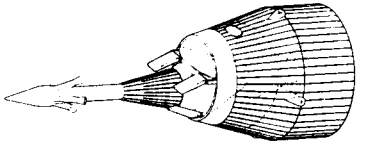
Interstage adapters and abort towers are not reflected under Production Requirements in order to minimize entries on the schedule. However, one of each is required for every complete vehicle and both are scheduled for completion as production components, simultaneously with the command module designated for each complete vehicle. In addition, interim interstage adapters and prototype abort towers (also not shown on this schedule but identified on the Development Program Schedule) are required for tests outlined in Volume V, Book 3.

Simulated mission modules are a separate and parallel effort to the prototype/production manufacturing program. Prototype command and mission modules (as noted on the production support schedule) are, in general, anything less than a complete unit with production systems. Depending upon its use in the test program, each component or vehicle identified on the schedule as a prototype represents a different configuration solely in a sense of completeness.

The first complete vehicle (8) is composed of all subsystems (prototype or production) except life support and guidance. The second complete vehicle (14) lacks only a complete life support subsystem. The third and fifth vehicles are complete but some of the subsystems are truly prototype. The fourth vehicle (16) will not have a guidance subsystem. The sixth vehicle (24) is complete and contains strictly production subsystems. The same is true of all subsequent vehicles with the exception of vehicles (27) and (29) which are designated prototype only because the life-support subsystem is not required, and therefore has been intentionally omitted.

Captive testing will utilize the first complete vehicle, and will be completed in time for the same facility to receive subsequent vehicles for flight acceptance firings. The three vehicles used for engine static-firing tests will be available for second usage in the two suborbital abort flight tests and the first earth-orbit flight test. The vehicle used for captive testing will be refurbished, will receive complete systems, and be further used for crew training.

Lab testing of life support systems will be completed prior to start of vehicle environmental control systems tests. In turn, the latter tests will be completed prior to the second suborbital abort flight, which will be the first flight of a vehicle containing a complete life-support subsystem.



4 PROGRAM COSTS

4.1 GENERAL. Cost estimates have been prepared for each major subsystem. The various contractors working throughout the study have supplied estimates covering their individual areas of responsibility for research, development and production, including support of the various project-wide activities, such as static and flight testing. These costs have been integrated into a combined funding requirement to arrive at a summary figure for contractor efforts. In addition, a figure is included to show the cost of necessary hardware and services (primarily boost vehicles) assumed to be government furnished in support of the program.

The costs assume the continuance of existing programs (for example, Pratt and Whitney engines for Saturn and Centaur) and use of present facilities on a cost-free basis. No costs are included for flight facility modification, except installation and checkout of Apollo equipment. This is because Apollo is a primary mission for the Saturn Program, and service tower, umbilicals, blockhouse and other provisions for Apollo should be included in the initial implementation of Saturn facilities.

4.2 CONTRACTOR COSTS. The cost breakdown has been organized to identify cost components by major subsystem and fiscal year (see Figure 29). Airframe contractor costs shown as such include the cost of integrating the various elements shown as subcontracted costs and are based on manpower estimates listed in Table 2. Ground support equipment is generally included as a cost of the particular subsystem with which it is used. Airframe contractor ground equipment is divided into that which would be shop made and that which would be subcontracted.

4.3 DIRECT GOVERNMENT SUPPORT COSTS. The costs included in this section (see Table 3) cover estimated costs of hardware plus launch for the three Atlas/Centaurs, seven Little Joe Seniors, 11 Saturn C-1's and 16 Saturn C-2's. A B-58 aircraft is required on a bailment basis during the capsule-drop test program. Additionally, a six-month boost-vehicle compatibility test program at Marshall Space Flight Center, cost of special recovery crews at the three intended landing sites, and the use of a C-133 aircraft for return of command module and crew are included. In the event that a sea landing is necessary on an emergency basis, it is assumed that pickup and return services would be performed cost-free by the Navy.

No estimates are included for NASA in-house studies, program management expenses, unallocated range costs, or use of existing government capital facilities.

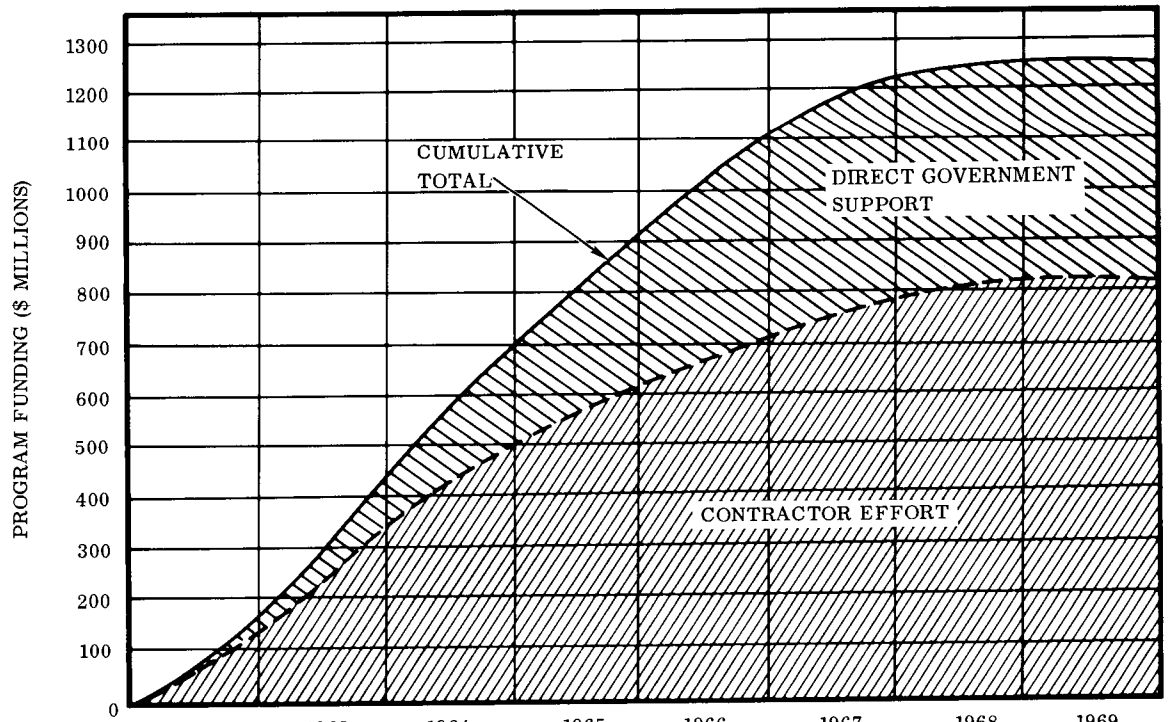
Costs of the ground tracking and communication system were developed on the basis that contractor personnel will man these facilities during the lifetime of the program.

4.4 COST PER SUCCESSFUL MISSION. The total cost per successful mission is tabulated below:

Airframe Structure and Systems	$3.35M
Life Support System and Equipment	.65M
Electrical Power Generation	.69M
Main Propulsion Package	.30M
Secondary Impulse Systems (Attitude Control) (Mid-course Correction) (Abort Rockets)	.22M
Guidance	1.20M
Communication, Instrumentation and Scientific Payload	.57M
Total Apollo Vehicle	$ 6.98M
Launch Vehicle	13.50M
Launch and Recovery Operations (Including Tracking and Communications)	3.90M
Spares and Contractor Support	.90M
Total Cost/Launch	$25.28M

At a mission reliability of 0.872, the cost per additional mission accomplished becomes

$$25.28M/0.872 = \$29.00M$$



FISCAL YEAR	1962	1963	1964	1965	1966	1967	1968	1969
CONTRACTOR	$59.5	164.0	197.8	133.5	108.0	84.3	61.0	5.8
GOVERNMENT SUPPORT	12.5	59.0	82.5	89.9	94.0	94.0	1.5	1.0
YEARLY TOTAL	72.0	223.0	280.3	223.4	202.0	178.3	62.5	6.8
CUMULATIVE	72.0	295.0	575.3	798.7	1000.7	1179.0	1241.5	$1248.3

Figure 29. Apollo Program Funding

Table 2. Apollo Contractor Manpower (By Fiscal Year)

FISCAL YEAR / ITEM	1962	1963	1964	1965	1966	1967	1968	1969
Vehicle Contractor								
Design and Development	555	1860	1860	1120	760	555	405	25
Support Flt. Prog. (AMR)	0	0	50	60	60	60	60	10
Manufacturing	210	670	1050	870	810	610	505	10
Direct Support Functions	55	55	70	65	60	55	55	10
Subtotal, Vehicle Contractor	820	2585	3030	2115	1690	1275	1275	55
Command Module Contractor	565	1050	950	770	640	455	310	35
Guidance Contractor	340	1000	1080	690	540	465	400	0
Tracking and Communications	125	310	310	410	375	350	320	170
Other Subcontractors	370	850	1250	830	670	525	210	0
Total Direct Manpower	2220	5795	6620	4815	3915	3070	2265	260
Allowance for Indirect (65%)	1440	3760	4300	3130	2540	2000	1470	170
Total Apollo Manpower	3660	9555	10,920	7945	6455	5070	3735	430

Table 3. Government Support by Fiscal Year

FISCAL YEAR		COST (MILLIONS OF DOLLARS)
1962	3 Atlas/Centaurs - Including Launching Costs	12.5
1963	7 Little Joe Seniors - Including Launching Costs	14.0
	Modifications (Including Design) to B-58	2.0
	Government Operations - Drop Test Program	1.5
	3 Saturn C-1's @ $13.7M	41.0
	Equipment for Saturn-Apollo Compatibility Test Program	0.5
	Total	59.0
1964	6 Saturn C-1's @ $13.7M	82.0
	Saturn-Apollo Compatibility Test Program	0.5
	Total	82.5
1965	2 Saturn C-1's @ $13.7M	68.5
	4 Saturn C-2's @ $15.5M	15.5
	First Increment Bailment C-133	0.3
	Recovery Team	0.2
	Total	89.9

Table 3. Government Support by Fiscal Year (Cont)

FISCAL YEAR		COST (MILLIONS OF DOLLARS)
1966	6 Saturn C-2's @ $15.5M	93.0
	Bailment C-133	0.5
	Recovery Team	0.5
	Total	94.0
1967	6 Saturn C-2's @ $15.5M	93.0
	Bailment C-133	0.5
	Recovery Team	0.5
	Total	94.0
1968	Bailment C-133	0.5
	Recovery Team	1.0
	Total	1.5
1969	Bailment C-133	0.5
	Recovery Team	0.5
	Total	1.0
Total Direct Government Support		432.4