Grumman LEM

PROGRAM PLAN (U)

CONTRACT NO. NAS 9-1100
LINE ITEM NO. 022
PRIMARY NO. 022
TYPE 1 DOCUMENT
PRELIMINARY—NASA APPROVAL PENDING

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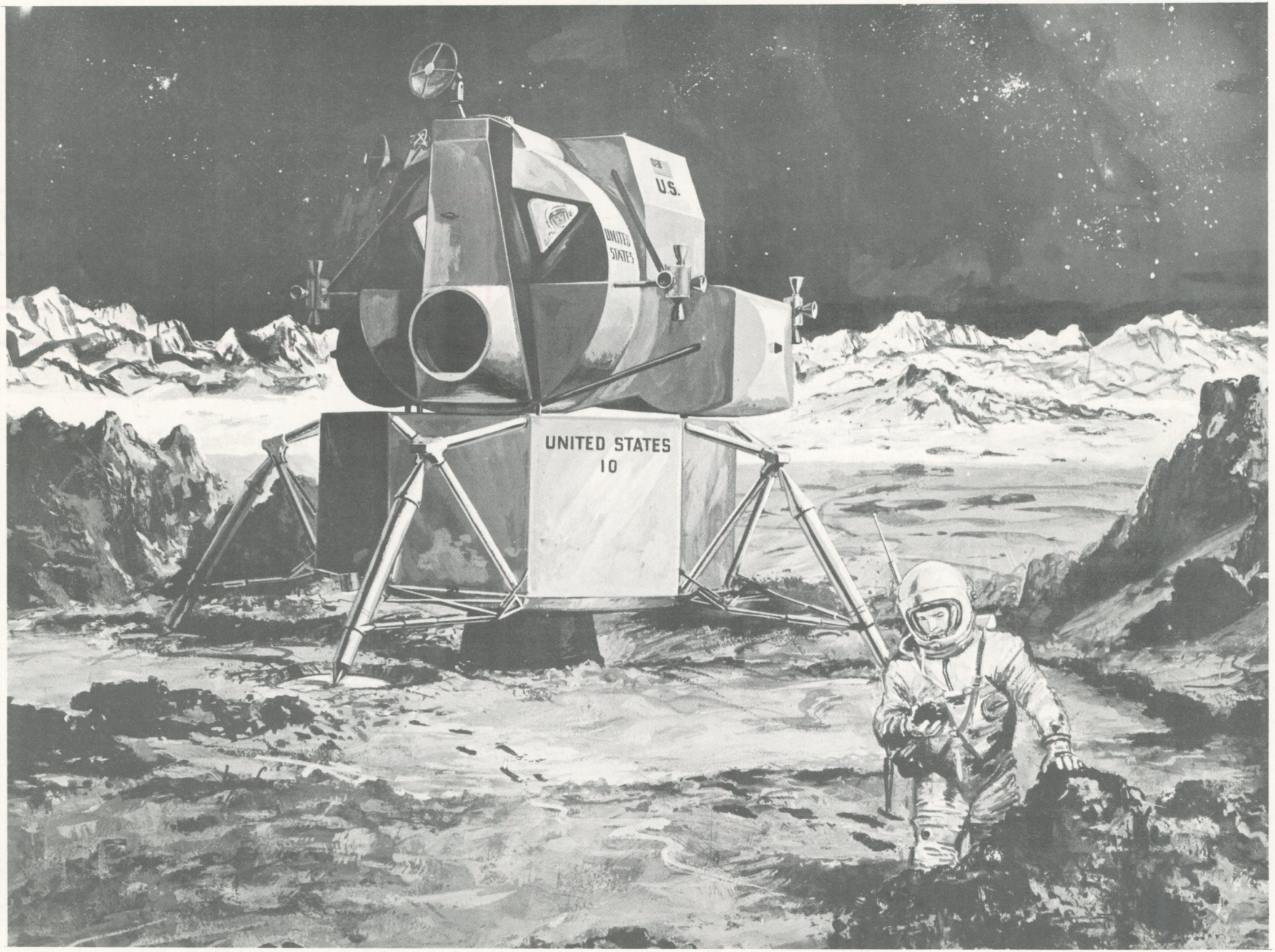
REPORT NO. LPL 13-1A
REVISED 1 JULY 1964
COPY NO. 1

GRUMMAN AIRCRAFT ENGINEERING CORPORATION



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SECTION 1
INTRODUCTION

The Grumman Aircraft Engineering Corporation, under contract to NASA's Manned Spacecraft Center, is responsible for the design, development, testing, delivery, and support of the Lunar Excursion Module, figures 1-1 and 1-2. This Program Plan presents the method by which Grumman intends to comply with the requirements of the contract.

The Management Section presents how the LEM Management team operates; its functions and responsibility. This section also reflects the relationship of the LEM program to the over-all Corporate organization, how the program is controlled internally, and Grumman's relationship with MSC, the Apollo principal contractor, associate contractors, and subcontractors.

The Phasing Charts reflect the over-all schedule of the program. These, together with the detailed subsystem charts, show the development and test schedules for the various test models and flight vehicles, and graphically present the program milestones.

Summaries of the eight major LEM Program planning documents are also included.

The Program Plan is a Type I Document requiring MSC approval. Approval of the Program Plan by MSC indicates approval of the method by which Grumman intends to comply with the requirements of the contract. Approval of the Plan does not, however, indicate specific approval of each detailed Phasing Plan or activity summarized in the document. The Program Plan will be revised or amended at intervals to reflect changes thereto, and will, as a result, reflect the status of the LEM Program Planning as of the date of publication or revision. Date of revision is affixed to individual pages, as required.

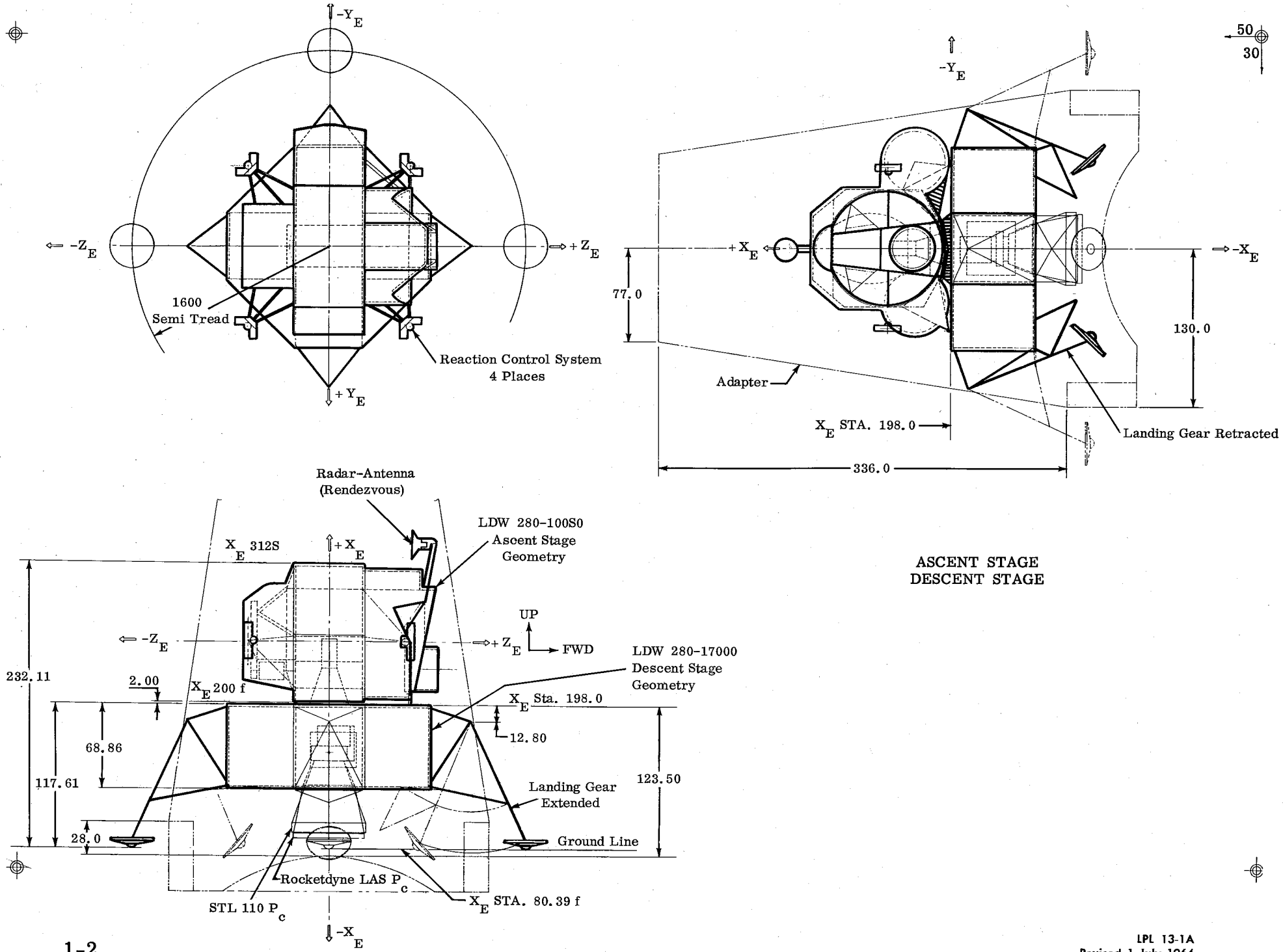


Figure 1-2. General Arrangement

SECTION 2
PROGRAM MANAGEMENT

2.1 MANAGEMENT RESPONSIBILITIES

The LEM Program is directed by Vice President, J. G. Gavin, Jr., as shown in figure 2-1. Figure 2-2 shows the position of the LEM organization in relation to the Grumman Corporation. The LEM organization is supported by all corporate departments but is solely responsible for the LEM.

To provide quick response to program requirements and continuous corporate support, the Executive Committee has designated its Chairman, Mr. Wm. T. Schwendler, to act as the President's Representative to assure successful completion of the program.

To assist in attaining the goal of the program, an Executive and Technical Review Board has been established. The function of this board, made up of senior personnel, is to review the program progress on a semi-monthly basis.

The LEM Program Organization has the structure of a "single-product company", solely concerned with the successful development of the LEM vehicle.

The LEM Program Manager, R. S. Mullaney, controls the program through the authority and responsibility which he has delegated to the Quality Control, Business, Test and Support, Engineering and Manufacturing Managers. In daily system and subsystem engineering review meetings, weekly production and procurement meetings, and weekly technical staff group meetings, these managers review progress in their respective areas including subcontractor as well as direct Grumman effort. The Program Manager in turn conducts a weekly meeting to review each manager's report of achievement during the past week, of expectation during the coming week, and of current problems.

A monthly review, by line item, of subsystem cost and performance is held to review program performance on

an orderly basis. This presentation covers performance against schedule and PERT, over-all cost--actual vs. budget, engineering manhours--actual vs. budget, subcontract cost if applicable, and current or foreseeable problem areas.

Internal and external report documents such as weekly Engineering report, Grumman and subcontractor PERT networks and biweekly up-dates, monthly progress reports and financial management reports, provide the Program Manager with a more formal means of control.

Meetings with NASA, associate contractors and with subcontractors are another means of program control. Subcontractors are required by Purchase Order to hold Quarterly Program Review Meetings and Bi-Monthly Meetings for program review and monitoring by Grumman. Direct or delegated participation by the Managers in scheduled MSC Panel, Management, Systems Meetings, MSFC Panel Meetings and the like, form the basis for many decisions in conducting the program.

These formal and scheduled meetings, reports, PERT, schedules, etc. help the Program Manager to assure that the many diverse efforts associated with the program are properly channeled to produce the end product. Equally important, however, are the innumerable impromptu meetings and discussions that occur every working day and are an excellent means of learning about new ideas, problem areas, etc.

The Program Manager is aided by the Assistant Program Manager who performs delegated duties and acts for the Program Manager in the latter's absence.

The Business Manager represents the Program Manager in all program cost matters. He reviews the contractual performance of Grumman and its subcontractors, maintains records to establish performance versus dollars expended, and establishes program budgets both internally and for subcontractors. He advises the Program Manager on all purchase orders, contract change proposals, and subcontractor change proposals. He directs and coordinates the activities of the Contracts Administrator, the Subcontracts Manager, and, in cost matters, the Administrative Assistants and Buyers assigned to subsystem engineers.

The Engineering Manager directs the technical progress of the program and supports the Program Manager in all such matters. The Engineering Manager approves all technical data prior to submittal to NASA or release for fabrication and directs and reviews subcontractor technical efforts and technical relations with subcontractors. He supervises all systems and subsystems engineers through the Project Engineers. This supervision includes

reliability engineering and all subsystem and system testing conducted at Grumman subcontractors and home facilities, establishment of an integrated ground test plan, and determination of configurations for Test Models, Propulsion Rigs, LTA's and their associated GSE.

The Test and Support Manager conducts at field sites all testing, including preparation, use and maintenance of test vehicles and supporting equipment and facilities. He is responsible to provide the material and documentary support and training necessary for these testing activities. He organizes and directs field site operational/support personnel, and maintains coordination with NASA, the Principal Contractor, Associate Contractor and vendor activities in the field. In line with the field service activities, he assures timely action at Bethpage to schedule activities or resources to meet field operation requirements, and he reviews all system and vehicle design during the design-manufacture-assembly phases to assure ease of maintenance of the vehicle and GSE at the test site.

The Manufacturing Manager has the responsibility of converting engineering data into tooling and processes for producing parts, subassemblies, final assemblies, as well as follow-through acceptance testing and field operations. He supervises tooling and manufacturing design and fabrication, schedules shop processes, and establishes internal and external lead-times in accordance with schedules and budgets. He also oversees production planning schedules, including the availability of major subcontracted systems, and coordinates with the Business Manager to assure timely delivery of subcontracted components. He supervises tooling coordination between Grumman, subcontractors and associate contractors to assure compatible interfaces.

The Quality Control Manager is responsible for assuring that the LEM, including all systems and components, meets all performance and reliability test requirements and complies with all program specifications and standards. He prepares and maintains the Program Quality Plan and approves subcontractor quality plans and procedures. He supervises all inspection and quality assurance activities, and coordinates the Grumman quality assurance program with NASA, the Principal Contractor, and Associate Contractors.

The Reliability Director reports directly to the Program Director, and monitors, throughout the entire LEM Program, reliability and quality control considerations which bear on the achievement of LEM mission success.

2.2 GROUP RESPONSIBILITIES

2.2.1 Business Management

The Business Management Group (figure 2-3) consists of three sections: Contract Administration, Purchasing and Subcontract Management.

The Contract Administration Section handles all contractual, financial, and business relationships with NASA, including the preparation of all related reports for submittal to both Grumman LEM Program and Corporate Management, and to NASA. This section coordinates preparation of cost estimates, proposals and change proposals, the preparation, administration and surveillance of LEM Program budgets, and the supervision and direction of cost control procedures.

The Purchasing Section is responsible for the procurement of material and services for the LEM Project. The Buyers in this group negotiate and draft subcontracts and purchase orders and changes thereto. They also monitor cost and performance of subcontractors through analysis of reports and field trips.

The Subcontract Management Section supervises and directs subcontracted work which is the responsibility of the Subcontract Manager. Each Subcontract Manager is the Grumman counterpart of the Subcontractor's Program Manager, just as the Grumman Purchasing Buyer is the opposite number of the Subcontractor's Contract Administrator. Each Subcontractor Manager is responsible for the administration of resident representatives stationed at subcontractor facilities regardless of the Grumman department represented. He is also responsible for the surveillance of subcontractor progress and cost reports prepared by engineering and purchasing representatives. This information is contained in periodic subcontract reports submitted to Program and Corporate Management. The Subcontractor Managers coordinate and maintain communications among Engineering, Purchasing, and Program Management, and sign all correspondence to subcontractors, except official contractual communications which are signed by the Grumman Director of Procurement or his designee (analogous to those signed by the Contracting Officer for the Government).

The Subcontract Manager supervises and directs Source Evaluation and Selection Procedures including the preparation of Source Selection Documentation, and acts as Executive Secretary of the Preliminary Source Selection Committee.

TABLE OF "BUY" ITEMS

ITEM	SUBCONTRACTOR	GO-AHEAD ISSUED
Propulsion Descent Engine	Rocketdyne	Yes-Development
Propulsion Descent Engine	Space Tech Labs	Yes-Development
Propulsion Ascent Engine	Bell Aero Systems	Yes
Descent Stage Propellant Tanks	Allison	Yes
Ascent Tanks	Aerojet	Yes
S&C - Gimbal Drive Actuator (GDA)	AiResearch	Yes
- Rate Gyro (RGA)	Kearfott	Yes
- Attitude Reference (ARA)	---	-
- Abort Programmer (APA)	---	-
- Attitude & Translation Controller	RCA	Yes
- Descent Engine Controller (DECA)	RCA	No
- Guidance Coupler	RCA	No
- Guidance Timer	---	-
- Guidance Decoder	---	-
- In-Flight Monitor (IFMA)	RCA	No
RCS - Propellant & Thrust Chamber	Marquardt	Yes
- Propellant Tanks	Bell	Yes
- Quan. Gauging	---	-
ECS - Sect. 1, 2, 3, 4	Hamilton Standard	Yes

TABLE OF "BUY" ITEMS (Cont'd)

ITEM	SUBCONTRACTOR	GO-AHEAD ISSUED
Instrumentation - PCMTEA	Radiation	Yes
- SCEA	---	-
- DSEA	Leach	No
- OBCEA	---	-
- C&WEA	---	-
N&G - Rendezvous & Landing Radars	RCA	Yes
Communications		
- Components & Subsystem Integration	RCA	Yes
- VHF Switch & S-Band Switch	---	-
- VHF Diplexer	Rantec	Yes
EPS - Fuel Cell	Pratt & Whitney	Yes
- Cryogenic Tanks	Ai Research	Yes
GSE - Digital & Analog Section	Beckman	Yes
- Signal Conditioning	Astrodata	Yes
- Potentiometric Recorder	Esterline Angus	Yes
- Handling & Trans. - Actuation Sub	Western Gear	Yes
- Fluid Sys. - IES	---	-
- Fluid Sys. - Fuel Cell Test Bench	---	-
- Training Equip. - Ext. Visual Display	Farrand Optical	Yes
- Training Equip. - Mission Tr. Simul	---	-
Displays - Attitude Indicator	---	-
- D'Arsonal Meters	---	-

2.2.2 Test and Support

The Test and Support Manager supervises five Sections: AMR Operations - Planning and Analysis, Field Support & Spares, Manager WSMR, Manager MSC, and Training (figure 2-4).

The AMR Operations - Planning and Analysis Section plans the testing of all flight vehicles, including prelaunch check-out, and in-flight tests and also defines vehicle configuration and crew tasks. This section writes the detail test plans for each flight vehicle and contributes to program plans, support manuals, and and facility requirements reports. (Note: The Systems Test Section, under the Engineering Manager, performs the test planning function for all ground test vehicles, for subsystem verification, qualification and integration tests, and also implements the tests on LTA's at Grumman's home facilities.)

This Section also defines field base requirements for testing a given flight vehicle; i.e., facilities, GSE, procedures, etc., plans the implementation of flight vehicle field tests, maintains liaison with the launch sites and defines general support requirements.

Field operations support personnel will conduct all testing at field bases and operate such bases under the supervision of the base manager. (Note: Testing at Grumman's home facilities, however, is the responsibility of the Systems Test Section, under the direction of the Engineering Manager.)

Test and Support, through the Manager WSMR Section, will supervise the conduct of Grumman-LEM operations at WSMR-PSDF. This PSDF organization provides the necessary operational and analytical support in the areas of test, data systems - instrumentation and data handling, developmental engineering, technical services, support technicians and Q.C. Detailed daily operation of the WSMR facilities will be administered by this section, but it must be recognized that testing teams will have a strong technical tie to other engineering and test areas in the project. All facilities and test personnel at WSMR are directly responsible to this section.

Test and Support, through the Manager, MSC, will supervise the conduct of Grumman - LEM operations at MSC. When established, the organization for MSC operations will provide supporting skills for SESL test operations similar to those at PSDF. Requirements in other areas, such as training, are not yet defined.

The Field Support and Spares Section will provide timely and adequate support of all test sites, particularly for

support manuals, material logistics, maintenance requirements, spares provisioning and spares accountability.

The contractual requirements for support manuals covering vehicles and GSE will be satisfied by this Section. To operate efficiently with several widely separated test sites a centralized logistics agency is necessary. The Field Support and Spares Sections will define logistic requirements, schedule the flow of material and monitor the implementation of the plans. Actual movement of material will be under the immediate jurisdiction of cognizant corporate departments. Maintenance requirements and/or capability and spares provisioning must be consistent for any given site. Similarly, spares provisioning and accountability within the several using activities: manufacturing, developmental tests and field tests, will logically be managed under a common system. Continuity will be achieved from the initial requirement planning through hardware usage. Management will be effected via the necessary maintenance analysis and coordination of affected agencies, such as: design, test, manufacturing, field operations, GSE, etc.

The Training Section is responsible for the following:

- Training of NASA personnel via sub-system oriented courses.
- Support of crew training activities in FCSD, including both planning and equipment support.
- Training of GAEC personnel.

A detailed description of these responsibilities follows. A requirement to train NASA personnel at MSC, WSMR and AMR is anticipated. All efforts to define the necessary courses, develop the course material, and to deliver formal courses oriented to the LEM sub-systems, will be directed by the Training Section. Support of crew training activities within FCSD is expected to include Grumman personnel on site to provide LEM sub-system intelligence and participate in the planning and documentary efforts preceding crew training. This support will be extended on a less definite basis to include maintenance and operations of actual mission simulators. Liaison will be necessary to keep such equipment current with LEM development and operating in the most efficient manner. These efforts will be supported as necessary by the LEM Engineering Group. All requirements for training Grumman personnel are being coordinated by this section. Timely and proper training will be realized via planning to utilize Grumman activities, purchased training from major vendors and training provided by the Principal Contractor for common use GSE. Such efforts are directed and/or monitored to provide the necessary capability.

2.2.3 Manufacturing

The following three functions are the responsibility of the LEM Manufacturing Group, consisting of three sections, although the actual work is accomplished by a corporate operating department. The control of manufacturing expenditures in these three sections is the responsibility of a project man in each section.

The LEM Project Manufacturing Engineer is responsible for developing, providing, and maintaining all tooling necessary for production of the LEM, as well as coordinating with LEM engineering to assure that the end-items are producible. This responsibility includes establishing and maintaining proper tool planning schedules and adequate production facility arrangements, fabricating and maintaining handling equipment, and providing optical measurement support for tests and alignment of hardware.

The LEM Test Equipment and Process Project Engineer is responsible for developing, providing, and maintaining the manufacturing equipment, as well as the process systems necessary for production of the LEM. He also has the responsibility of establishing and maintaining proper manufacturing, test equipment, and process schedules, as well as fabricating and maintaining test and support equipment used at Grumman, and converting engineering information into processes for producing hardware.

The Shop Project Manager is responsible for converting LEM engineering information into parts, subassemblies, final assemblies, and follow-up through LEM acceptance testing and field operations. He establishes internal and external lead times in accordance with schedules and budgets, establishes and maintains proper production planning schedules, and coordinates with LEM engineering to assure compatibility of manufacturing plans with engineering progress. He also has the responsibility of providing technicians for field support activities, controlling spares, both in-house and in-the-field, the shipping of hardware and completed LEM assemblies, and the supervision of procurement planning and controls.

2.2.4 Quality Control

The function of the LEM Quality Control Group is the assurance of end-item (i.e., part, subsystem, or process) conformance with contract quality requirements. LEM Quality Control, through its operating sections, Quality Assurance and Inspection, is responsible for the performance of all LEM Quality Control tasks, with support from the Corporate Quality Control Department.

LEM Quality Control organization, staff, functions, and procedural methods are described in detail in the LEM Quality Control Plan (LPL-81-1).

The LEM Quality Assurance Section is responsible for assuring inclusion of the necessary quality provisions in areas of design procurement, and test that result in the required end-item quality. Specific LEM quality assurance tasks include, but are not limited to, the following:

- LEM subsystem vendor control by assignment of resident or itinerant Quality Control Representatives.
- Quality participation in the establishment of LEM requirements, i.e., specifications, drawings, reports, etc.
- Control of LEM procurement quality requirements.
- Coordination of data reporting and corrective action programs.
- Preparation and maintenance of the LEM Quality Control Plan.

The LEM Inspection Section is responsible for assuring attainment of the required measurable characteristics and conditions. Specific LEM inspection tasks include, but are not limited to, the following:

- Monitoring and control of quality effort during all phases of the Grumman manufacturing program, from material receipt to mission performance.
- Establishment of inspection teams responsible for all inspection efforts on each deliverable module, commencing at the subassembly and terminating at mission accomplishment.
- Control and coordination of inspection efforts for off-site tasks by assignment of resident inspection representatives at WSMR and AMR.

2.2.5 Engineering

The engineering organization consists of three major divisions: Systems, Subsystems, and Ground Support Equipment, each headed by a Project Engineer. This reflects the importance of Systems Engineering and Ground Support Equipment to the LEM program. The LEM design and mission are such that the predominant design and development effort cannot be centered on the flight subsystems alone, but must be shared with Systems Engineering and GSE Engineering. In addition, engineering staff functions have been created as required to satisfy specific needs.

2.2.5.1 LEM Systems Engineering

The principal responsibilities of Systems Engineering are the systems design, integration, reliability and systems test of the LEM spacecraft and all associated equipment. Systems Engineering evolves the overall

systems requirements, defines the desired compromises, the desired performance and provides a coherent overall program. Systems Engineering with the cooperation of the Subsystem Engineers defines the subsystem requirements, reviews and approves the subsystems specifications. Design progress and test results are reviewed by Systems Engineering to assess the validity of the specified requirements and environments, and technical changes, which affect subsystem interfaces, are approved with particular concern for side effects, system tradeoffs, and effects on the developmental test plan.

To accomplish these tasks, Systems Engineering organization is comprised of three sections having broad functional interests, Systems, Reliability and Systems Test and seven more specialized sections as shown in figure 2-2. The specialized sections have been selected to provide the technical support required by the LEM Project while utilizing the internal organization of the Engineering Department.

Systems

The Systems Section is the focal point of the Systems Engineering effort. The principal tasks are:

- Mission Analysis including the determination of the detailed LEM design missions, the minimum successful mission and the detailed flight missions. The purpose of the analysis is to define the mission parameters, develop the mission plans and formulate detailed operating procedures.
- Systems Analysis including establishing the overall systems performance requirements and determining the necessary subsystems performance and tolerance levels. The capabilities of the other specialized Systems Sections and Subsystems Engineering will be utilized by generating study requirements and ground rules and having the majority of the detailed analytical effort performed by these groups.
- Systems Integration including the responsibility of assuring functional compatibility between LEM subsystems and between LEM and other parts of the Apollo spacecraft. This task includes the generation of the LEM systems functional diagrams and subsystems functional descriptions and requirements.
- Systems Coordination in order to assure physical, electrical, mechanical and thermal compatibility between LEM subsystems and between LEM and other parts of the Apollo spacecraft and GSE. This task includes coordination and approval of all Interface Control Documents and Specifications and

primary engineering responsibility for configuration control.

- Space and Lunar Surface Environment Evaluation including radiation, micrometeorite and thermal environment and lunar surface features which affect LEM operation.

Reliability

The Reliability Section formulates and implements the Reliability Program Plan to assure that the delivered LEM meets the reliability objectives specified by NASA with the highest possible confidence level. The Systems Reliability Engineer reports weekly to the LEM Managers on the progress and status of the reliability program and approves specifications, drawings and purchase orders.

This section:

- Estimates and apportions Systems and Subsystems reliability with respect to mission success and crew safety.
- Coordinates with Quality Control in establishing process standards.
- Establishes requirements for and monitors vendor reliability programs.
- Conducts system and subsystem studies including configuration and circuit analysis, failure effect analysis, maintainability analysis and evaluation of of checkout procedures.
- Establishes acceptable parts list (in cooperation with Subsystems Engineering) including component part review, component part specification approval, and review of component parts test plans.
- Establishes a reliability assurance program encompassing all developmental, qualification, acceptance, ground and flight test programs.
- Establishes a data control program to cover component and part data, test data and failure data.

Electronic Integration

Primarily the Electronic Integration Section plans and implements the electronic integration tests on the bench (prototype) electronic system and maintains a bench integration system with which to debug system problems arising from the vehicle ground test program. This section also supports System Test in vehicle-level electronic system testing. Compatibility tests of the electronic systems and the GSE should be performed concurrently.

In addition this section is to:

- Review and verify the detailed electrical and power interfaces between the various subsystems including voltage levels and impedances from pin-to-pin in all connectors.

- Determine those requirements for GSE which are unique to bench testing of the complete electronic systems.
- Generate the electromagnetic interference (EMI) requirements for all LEM equipment and perform EMI testing on all LTA and LEM vehicles.
- Evaluate the interaction of all antennas.
- Evaluate system tradeoffs affecting interconnecting cabling and installation design.

System Test

The Systems Test Section is to establish an integrated ground test plan. This plan is to coordinate all design verification tests, qualification of the subsystems, integration of the subsystems into the vehicle, and to culminate in the demonstration and acceptance of a LEM vehicle in which a high degree of confidence has been developed. It includes all tests which contribute to the reliability assurance program. The plan is to be coordinated to support the flight test and operations requirements.

In addition these specific tasks are to be performed:

- Review and approve all qualification test plans.
- Plan and implement the test program on all LTA ground test vehicles including integration, design verification and ground test vehicle qualification.
- Direct the factory checkout and end item acceptance test of all LEMs and associated equipment.
- For all other environmental tests at Grumman, perform the detail test planning to meet the subsystems requirements and implement according to the test plan. These will include all structural, vibration, thermodynamic and vacuum tests.

Thermodynamics

The principal responsibilities of the Thermodynamics Section are the analysis of the thermal environment heat transfer, thermal balance and fluid dynamic aspects of the LEM spacecraft and associated equipment.

Other tasks performed include analysis of:

- Heating rates for the structure and thermal shield.
- Insulation requirements and evaluation of insulation material.
- Temperature of critical parts of the spacecraft including radiation characteristics of coatings, surfaces and conduction and radiation of vehicle parts.
- Window heat loads and jet impingement, such as RCS, on vehicle structure, and descent engine on landing gear.
- Thermal tradeoffs and constraints which affect mission operations.

In addition, this section will determine vendor thermal design requirements and evaluate vendor thermal design and tests.

Dynamics

Principal responsibilities of the Dynamics Section are the mathematical formulation and the analysis of the lunar trajectories, rigid body dynamics, guidance and control of the LEM spacecraft. In this capacity this section will perform the detailed studies required by the other sections such as Systems, Flight Controls and System Simulation.

The tasks performed by this section include:

- Trajectory tradeoff and optimization studies and calculation of ΔV requirements.
- The formulation and analysis of guidance and control techniques for achieving the desired trajectories. Particular emphasis will be placed on abort and flight safety considerations.
- Detailed performance and error analyses of Guidance and Control configurations from which subsystem requirements may be determined.
- Detailed analysis and optimization of the required trajectories for each LEM flight test and mission plan.

Mass Property Control

The Mass Property Control Section establishes the LEM spacecraft mass property characteristics and the evaluation and control procedures necessary to insure that these characteristics are attained.

Other tasks include:

- Establishment of the minimum practical vehicle weight based on system configuration studies, reliability and performance requirements.
- Establishment of target weights for all vehicle subsystems.
- Calculation and evaluation of the up-dated status of the vehicle weight, balance and moments of inertia.
- Analysis and evaluation of possible corrective action for elimination of deficiencies in the mass properties.
- Development of computer program for rapid evaluation of mass property status.

Crew Systems

The principal responsibility of the Crew Systems Section is the analysis, integration and evaluation of the man-machine relationship of the crew and the spacecraft.

The tasks performed by this section include:

- Analysis of the crew operations for all LEM missions including normal, degraded and abort phases.
- Establishing requirements for controls and displays, panel layout, workplace layout, seat and restraint, crew mobility and visibility as affected by flight crew capabilities.
- Evaluating in-flight capability of the crew.
- Establishing the requirements, designing the experiments, and evaluating the results of the crew performance phases of the flight simulation programs.
- Evaluating and establishing the crew's physiological requirements including respiratory, thermal, contamination, waste management and physiological monitoring.
- Analysis of training requirements, and assisting NASA in establishing a training plan.

Structures

The principal responsibility of the Structures Section is the structural integrity of the LEM spacecraft and all associated equipment.

Tasks include:

- The determination of LEM design criteria and design environments. These shall be maintained up-to-date for project-wide use.
- The establishment of the design loads for all structure.
- Detailed landing impact and stability studies.
- Detailed stress analysis of all structure, including approval of design drawings.
- Detailed shock and vibration analysis of the entire spacecraft.
- Evaluation of all materials used in the spacecraft and assistance to the design groups in the selection of applicable materials.
- Determination of the critical test conditions of load, shock, vibration and temperature for the spacecraft structure.

System Simulation

The Systems Simulation Section is to plan and implement an integrated simulation program which will fulfill the requirements of all the system and subsystem sections. The Flight Controls Subsystems Section, Crew Systems Section and Systems Section will be the heaviest participators. System Simulation shall utilize the analytical capability of the Dynamics Section to aid in developing the mathematical equations.

In addition these specific tasks are to be performed:

- Design and supervise the construction of engineering simulation equipment.

- Formulate specifications for the procurement of related engineering simulation equipment not built by Grumman.
- Determine the analog and digital computer requirements and assure the availability of the required equipment in accordance with the Simulation Plan.
- Participate in the formulation of the mathematical models and program the computers and any analog-digital links.
- Coordinate all out-of-house simulations and act as GAEC liaison with NASA and other organizations involved in the Apollo simulation effort.

2.2.5.2 LEM Subsystem Engineering

In general, each Subsystem Engineering section is responsible for the planning, analysis, design, procurement, testing and delivery of a specific functional grouping of LEM hardware. Each Subsystem section is further charged with the responsibility of insuring that the hardware for which it is responsible meets all established requirements throughout the life of the LEM Program and that all hardware interfaces are properly resolved.

Wherever vended or subcontracted equipment is involved, Subsystems Engineering is responsible for preparing the design control specification and other engineering inputs to the purchase order (such documents to include appropriate Systems Engineering inputs); and for directing and monitoring the subcontractor or vendor performance. The Subsystems Engineer is responsible for the technical, cost, and schedule performance of his subcontractors. He supports and is assisted by the LEM Business office in evaluating subcontractor cost and schedule performance. Contractual dealings with subcontractors are handled by the LEM Business office in accordance with standard Grumman procedures. Engineering handling of subcontractors is coordinated by the LEM Subcontract Engineer.

Subsystems Engineering is also responsible for implementing common usage of flight equipment in accordance with NASA direction.

Propulsion

The Propulsion Subsystem Section is responsible for the main propulsion systems for the LEM ascent and descent stages. Each stage system consists of a liquid rocket engine, a propellant storage and feed section, and a pressurization section.

Specific tasks include: establishing the requirements and analysis for testing of propulsion mock-ups, test models,

test rigs, and flight test models, followed by subsystem support of systems ground testing and flight operations. Analytical tasks include propulsion performance, analysis of test results, responsibility for development tests on both ascent and descent stages, and review of vendor prepared analytical reports. Propulsion Subsystem testing responsibilities require the coordination of test facilities requirements in-house, at the vendor plants and at government installations.

Vehicle Design Integration

The Vehicle Design Integration Subsystem Section is responsible for the detailed structural design of the complete LEM vehicle, and for the coordination and optimization of all structural interfaces with all other LEM subsystems, the Apollo Principal Contractor and the G&N Associate Contractor. Design responsibilities include the detailed design of all primary structure (except the landing gear) and all secondary structure, including equipment support structure, and vehicle mock-ups and propulsion test rigs.

Responsibility for the overall integration of all mock-ups, test models and operational vehicles lies with the VDI Subsystem. This includes maintaining updated drawings covering vehicle configuration and internal arrangement. Design tasks include layout and design of vehicle structure, the routing of equipment lines, provisions for the installation of the thermal insulation, design of the micrometeoroid protection, sealing of the pressurized crew compartment and equipment tunnel, allocation of volume for equipment, and approval of all flight hardware specification control drawings.

Flight Controls

The Flight Controls Subsystem Section is responsible for directing activities in the performance of analyses and design studies to establish detailed requirements for FCS operation during all phases of the LEM mission, functional integration of the SCS and RCS subsystems and for the interfaces between these subsystems and the primary navigation and guidance equipment, ascent engine, descent engine, controls and displays, and the astronauts. Specific tasks include the analysis of nominal and back-up modes, back-up navigation and guidance concepts; directing FCS development, integration and evaluation testing; providing field and flight test engineering services as needed for spacecraft integration, field validation, pre-flight and post-flight test operations support; establishment of handling qualities requirements, FCS operation, display and control requirements, and the detailed analysis of dynamic response of the flight control system.

In order to accomplish these tasks, the FCS group will direct the design, development and operation of the FCS laboratory for development and integration testing; participate in the design, development and operation of the engineering development full mission simulator; and participate directly in all part task simulation programs and LTA and LEM test vehicles wherein FCS equipment is included.

Stabilization and Control

The S&C Subsystem Section is responsible for all stabilization and control hardware as follows: control electronics section consisting of the guidance coupler assembly, attitude translation and control assembly, descent engine control assembly and gimbal actuators, rate gyro assembly and hand controllers, in-flight monitor assembly, and the back-up guidance section consisting of the back-up attitude reference assembly and back-up programmer. An additional task includes responsibility for the development of the special S&C hardware for unmanned flight vehicles, and field support of test programs utilizing S&C hardware.

Reaction Control

The Reaction Control Subsystem Section is responsible for the reaction jet control hardware consisting of reaction jet engines, the RCS propellant storage and feed section and the RCS pressurization section. Development testing of this subsystem requires integrated testing with S&C hardware and concurrent testing with propulsion hardware. Facility liaison in-plant, at vendor facilities, and at government installations is also required.

Mechanical Design

The Mechanical Design Subsystem Section is responsible for the LEM landing gear, docking devices, adapter separation devices, the ascent-descent stage separation devices and other special mechanical devices such as hatch mechanisms, antenna deployment hardware, pyrotechnic mechanisms, etc. A special task includes responsibility for design coordination of the entire ascent-descent stage interface. Close liaison with the Vehicle Design Integration Subsystem Section and the Electrical Power Subsystem Section is inherent in this section's responsibilities.

An Electro-Explosive Devices (EED) group within Mechanical Design is responsible for the detailed implementation of EED design, development and integration for the entire project.

Environmental Control

The Environmental Control Subsystem Section is responsible for all life support and environmental control

hardware i. e., the atmosphere revitalization section, heat transport section including provisions for cold plate design for electronic equipment cooling and cryogenic fluid warming heat exchangers, the crew oxygen supply and cabin pressure control section; and the water management section including potable water storage. Specific tasks include the internal thermal analysis of environmental control hardware and the design and operation of the man-rated internal environment simulator, ECS liquid testing and ECS oxygen supply simulator. Close coordination with the Electrical Power Subsystem Section is required to insure proper design of the combined cryogenic oxygen storage system.

This section also is responsible for establishing ECS requirements for design of the Internal Environment Simulator and for the planning and operation of IES testing.

Crew Provisions

The Crew Provisions Subsystem Section is responsible for crew station study and design including display and control arrangement, mechanical assembly and installation, space vehicle lighting, crew support and restraint, visibility, ingress and egress provisions, GFE crew equipment provisions, and cabin equipment arrangement, location, rationale and installation provisions. Close coordination with the Crew Systems Section is required to insure that man-machine interfaces are properly handled.

Displays

The Displays Subsystem Section is responsible for establishment of design requirements for all contractor-furnished displays and controls and for interface documentation of government-furnished displays and controls. This group is also responsible for the procurement and the electrical integration of these items into the crew station design. Display requirements of all other subsystems are continuously monitored by this section. Standardization of the indicator designs and indicator lighting provisions as well as responsibility for insuring that common usage displays are identical from a crew operation viewpoint to those in the Command Module is this section's responsibility.

Instrumentation

The Instrumentation Subsystem Section is responsible for all vehicle instrumentation including Operational Instrumentation, R&D Instrumentation and Scientific Instrumentation (GFE). Operational Instrumentation includes responsibility for the PCM Telemetry/Central Timing Equipment, Data Storage Equipment*, On-Board

*If required.

Checkout Equipment*, Caution and Warning Equipment, and all sensors and signal conditioning equipment required for data gathering. Sensors will either be obtained directly by LEM Instrumentation Subsystem, or may be procured by the cognizant subsystem subject to design approval by the LEM Instrumentation Subsystem. Responsibility also includes the establishment and publication of all vehicle measurement lists, EDP Measurement Data Handling System, and telemetry channel assignment lists involving both operational and R&D measurements. The R&D and Scientific Instrumentation includes responsibility for liaison with NASA on all GFE requirements, hardware and installation or storage provisions. Coordination with all subsystems groups requiring vehicle instrumentation, with the Systems Test Section and Test and Support Group are an important and continuing responsibility of this subsystem section.

Navigation and Guidance

The Navigation and Guidance Subsystem Section is responsible for the design and procurement of the landing and rendezvous radar equipment and for liaison with the Apollo G&N Associate Contractor including cognizance over interface control documentation for all primary navigation and guidance hardware. Specific tasks include the planning and performance of navigation and guidance subsystem testing as well as support of systems integration testing of the primary navigation and guidance equipment. GFE equipment in this category includes the Inertial Measurement Unit (IMU), Alignment Optical Telescope (AOT), Power and Servo Assembly (PSA), Coupling and Display Units (CDU), LEM Guidance Computer (LGC), cabling and junction boxes.

*If Required

Communications

The Communications Subsystem Section is responsible for all internal and external LEM communication equipment, to provide contact between the LEM and Command Module, Earth, and extra-vehicular astronauts. The subsystem provides two-way voice communications, television, processing and transmission of telemetry data and aid in tracking and ranging.

This responsibility requires definition of communication design requirements and procurement of components for a properly integrated and qualified subsystem. Antenna placement and design coordination is handled by the Antenna Group within LEM Communications Subsystem.

Electrical Power

The Electrical Power Subsystem Section is responsible for the generation conversion and distribution of all LEM vehicle electrical power.

Power Generation responsibilities include the design, development, procurement and qualification of a Power Generation Section consisting of fuel cell assemblies, cryogenic hydrogen and oxygen tankage assemblies, and fuel cell reactant feed components and assemblies. Close coordination with the Environmental Control Subsystem is required to insure the proper design of the common oxygen supply system.

Power Distribution responsibilities include the design of DC and AC power distribution and control circuitry for all subsystems, the electrical circuit design for the EPS, ECS, and Propulsion subsystems, vehicle lighting, engineering support of installation of all vehicle wiring, cabling and electrical assemblies, the preparation and up-dating of all vehicle wiring diagrams and schematics, preparation of a detailed electrical load analysis, and the development and monitoring of an electrical power and energy budget for all subsystems. Also the design, procurement and test of auxiliary batteries, inverters, battery charger, lighting power conditioners and electrical components.

2.2.5.3 Ground Support Engineering

Organization

The GSE Project is organized in five principal subsystems: Instrumentation, Electronics Support, Handling and Transportation, Fluid Systems Support and Training Equipment. Several GSE staff groups also support the GSE Project Engineer and the GSE Subsystems Engineers. These groups are: Administration, Specifications, Structural Analysis, Requirements, Facility Coordination and Activation, and Planning and Controls.

General Responsibility

Each Subsystem, for their particular equipment involved, is responsible to the Project Engineer for the following activities:

- Perform the engineering functions necessary to implement requirements (1) for design, develop, procure, test, and deliver CFE to support LEM testing, checkout, handling, transportation, servicing, and maintenance, and to provide equipment for training ground and flight crews in operation and maintenance procedures. To implement the requirements for (1) and perform tasks necessary to insure that Government Furnished

Equipment GSE is available at the proper time and capable of performing its intended tasks.

- Perform studies as necessary to implement the maintenance and checkout requirements for the LEM and its associated equipment, in coordination with other LEM organizations (1). Contribute to detail test procedures for those tests which are of a checkout or maintenance nature in accordance with the test plans produced by the various LEM organizations (2).
- Review and approve the Special Test Equipment (STE) proposed by LEM subcontractors.

NOTES:

(1) "Implement requirements" - GSE functional and performance requirements are established by the cognizant flight subsystem, subject to general checkout criteria established by Systems Analysis and Integration. GSE Engineering establishes general GSE design requirements, and interprets the functional and performance requirements established by the flight subsystems for GSE implementations.

(2) Test procedures will be prepared and issued by System Test for in-house GAEC testing, and by Test and Support for off-site testing, based on inputs from the LEM sections involved, including GSE. Test plans will be prepared by the cognizant LEM subsystem, defining in detail the test requirements and the capabilities of the equipment under test. The test procedures will generally be derived from the detailed test plans.

- Review and approve the checkout and maintenance sections of all LEM support publications and in addition review and approve the complete GSE publications.
- Perform systems design for the installation of GSE at all test sites including certain specific areas at GAEC. This effort includes the location of the GSE, definition and description of GSE/facility interfaces (via ICD's prepared by GSE and submitted via Systems Integration), the functional operation of the installation and the final checkout procedure of the installation. Assist the LEM Facilities Group in site activation.
- Functional analysis of test operations for purposes of determining support equipment requirements and quantities, and facility compatibility.
- Perform evaluation tests on GSE and STE where necessary to insure that this equipment will have the compatibility to perform the function for which it was designed.

- Preparation of required documentation (data sheets, planning and requirement lists, flow diagrams, schedules, etc.).
- Establishing and maintaining PERT for each item of support equipment.
- Conduct common usage support equipment studies with NAA.
- Provide design, procurement and test specifications for support equipment.
- Provide functional block diagrams of the GSE, and its external interfaces.
- Attend regularly scheduled and special meetings with the NASA, NAA, MIT and subsystem vendors in order to establish direction and integrated efforts.

Instrumentation Support

This GSE subsystem section contains the following groups: a) Data Acquisition, b) Data Reduction, c) Measurements, and d) Data Design, whose responsibilities are to:

- Support the Electronic Support, Fluid Support, Handling and Transportation, and Training Equipment Subsystems in areas relating to measuring devices and systems, and to data acquisition and processing equipment.
- Provide the data acquisition, recording and processing equipment for WSMR LEM propulsion systems development tests.
- Provide the special data processing equipment required at Grumman to support tests at all LEM and LTA sites.

Electronics Support

The groups constituting this GSE subsystem are: a) Support Requirements, b) Checkout, c) Assembly and Integration, d) Propulsion (Ascent Engine, Descent Engine, RCS), e) Vehicular Facilities (EPS, ECS) and Intelligence (Communication, Instrumentation), f) Fluid Controls (S&C, N&G, Displays and Controls, Electro-Explosive Devices, g) Electrical Design, and h) Mechanical Design. Their specific responsibilities are to:

- Perform studies, analysis and liaison with other LEM groups for the purpose of establishing systems requirements, measurements lists, test point minimization, etc.
- Supply the flight equipment subsystems with the equipment required for use in the performance of development/evaluation tests and Flight Control integration tests.

- Supply the equipment required for use in the performance of manufacturing tests, vehicle checkout, environmental tests.
- Supply the equipment required for use in the performance of developmental system integration tests.
- Supply NASA with the equipment required for use in performance of vehicle checkout, maintenance and development tests.
- Establish support equipment design criteria in the areas of electromagnetic control and environment.

Handling and Transportation

The primary groups comprising this subsystem are: a) Support Requirements, b) Mechanical and Structural Equipment and Packaging, and c) Support Equipment Propulsion Test. Specific responsibilities are to:

- Provide design criteria with respect to transportation size and weight restrictions, transporation environment, packaging, and preservation requirements of all end items to be delivered to test sites.
- Determine optimum method of shipment of all end items.
- Design all special transporation and packaging equipment.
- Determine suitability of all proposed Government Furnished Transportation Equipment.
- Provide all mobile equipment required to house GSE (STE) spare parts and personnel.
- Provide special equipment required for the local movement, positioning, lifting, mating and assembling of the LEM, and its GSE.
- Provide special tools, protection devices, safety equipment and mechanical test and maintenance equipment.
- Provide necessary work stands and platforms.

Fluid Systems Support

This Subsystem consists primarily of: a) Support and Design Requirements, b) Propulsion Subsystem Support, c) ECS Support, d) EPS Support, e) RCS Support, f) Structural Design, and g) Drafting. Their specific responsibilities are to:

- Provide all fluid servicing equipment, and ancillary devices and plumbing.
- Provide special equipment and ground test rigs to support the LEM fluid systems.
- Coordinate the supply of fluids necessary to support testing.

Training Equipment

The first level of the Training Equipment Subsystem is divided into three functional areas: a) Trainer Requirements and Interfaces, b) Electronic Design, and c) Mechanical Design, whose responsibilities are to:

- Design, procure and test all training equipment to be used by NASA for the training of LEM flight and ground crews; in addition, cover all interfaces between the LEM training units, the Apollo Mission Simulator and IMCC. The list of training devices includes: LEM Mission Training Simulator, LEM Part Task Trainer, Operations Trainer, and other training devices which may subsequently be required.
- Prepare and deliver math models for computer implementation and an analysis of the interface requirements.
- Provide technical information for Training Equipment Manuals and support of the Training Program.

2.2.5.4 Engineering Staff Functions

Administrative Services and Facilities: Provides those administrative services necessary for proper functioning of the project, which are not covered by other supporting groups particularly involved with secretarial services, office space planning and allocation, travel, security and other administrative functions as required.

Consulting Pilot: Provides essential point of contact between the LEM project and the NASA astronauts. Participates in and evaluates simulation and mock-up activities and consults with Crew Provisions, Crew Systems, Flight Controls, and other sections involved with the man-machine interface as required.

Staff Assistant: The Staff Assistant's responsibilities mainly involve coordination of LEM engineering requirements for facilities and the expediting of purchase requisitions through LEM engineering. He also serves on special assignments as directed by the Engineering Manager.

Subcontract Engineer: The extent and diversity of subcontracting on the LEM program, and the major responsibilities for subcontractor direction and performance review vested in the LEM Subsystem Engineer, lead to a high degree of engineering involvement in subcontract matters. The LEM Subcontract Engineer reviews and reports upon LEM Engineering's performance in the area of subcontracts, and coordinates

engineering activities involving procurement and subcontracts to the extent necessary to assure reasonable consistency of approach throughout the Project. He also assists the LEM Subsystem Engineers and other LEM departments upon request in resolving special problems in the subcontract area. In this application, the LEM Subsystem Engineer refers to both flight subsystems and GSE.

Technical Data Control: Technical Data Control is a supporting service organization of the engineering department. It consists of three groups: Specifications, Data Requirements Control, and Standards, which support the entire LEM program. Elements from the Technical Data Control section have been assigned full time to LEM. The duties of the Technical Data Control groups are generally as follows:

- Data Requirements Control (DRC) - has company-wide responsibility for defining and interpreting contractural data requirements and minimizing the duplication of preparation and procurement of data. This is accomplished by coordinating with all affected departments and groups. If it is necessary for Grumman to request a contractual change to more clearly definitize requirements, such action is the responsibility of DRC via the Business Office. In addition, DRC prepares subcontract documentation requirements in coordination with all departments concerned.
- Specifications Group - responsible for the preparation of control documents for purchased equipment and services, e.g., Specifications and VR's. In addition, the Specifications Group prepares Grumman "in-house" control documents and is responsible for the review of specification and source control drawings. Engineering inputs to these documents are the responsibility of the cognizant engineer.
- Standards - responsible for the issuance and usage coordination of all engineering product design standards information including NASA and military standard specs. Also maintains catalogue files for many vended items.

Vehicle Coordinator: The Vehicle Coordinator coordinates and expedites the engineering design effort associated with particular vehicles (TM, LTA, or LEM) and represents LEM engineering in resolving with other departments, problems which affect these vehicles. He is responsible for providing the LEM Engineering Project Office with recommendations for actions required to resolve special schedule and technical problems. He also provides liaison with Manufacturing and other departments during design, fabrication,

and assembly. In general, his principal responsibility for a vehicle will cease when it is turned over to the test activity which will use it (LEM Systems Test or LEM Test and Support), although he will subsequently support the test activity as required.

Configuration Management Representative: Represents the Engineering Project Office in Configuration Management. Assigned full-time to the Configuration Management organization.

Engineering Planning and Controls: Responsible for the preparation and evaluation of all Engineering manhour estimates, task descriptions, and justifications for the LEM contract and any changes that may result. Manpower loadings (APR's), time expenditures, overtime budgets, job-shopper budgets and statistical manhour information is also compiled by this group.

The System and Subsystem Planning Engineers support the Chief Planning Engineer in the efforts noted above.

Component Scheduling is responsible for preparing drawing release schedules, drawing priority guides and isometric drawings which are required to identify major assemblies built at GAEC. This group is also responsible for Engineering drawing accountability.

2.3 PROGRAM CONTROLS

Control procedures used by the Program Manager and his delegated representatives are summarized in the following paragraphs.

2.3.1 Schedule

The Program Schedule, issued by the Program Manager through his Program Planning staff, provides the calendar time basis against which program performance is measured. This schedule is updated as needed after review of the actual performance to date, PERT estimates and contract changes. The LEM management team utilizes PERT networks to plan detailed execution of vehicle and subsystem design, development, manufacture, installation, checkout and testing. Time estimates for each network are used to monitor these plans as compared to the basic schedule. PERT networks are updated bi-weekly, and the critical paths and corrective action are summarized in a narrative report issued by Program Management in combination with the cognizant Engineering section.

2.3.2 Companion Cost

Companion cost personnel collect the costs of labor and materials in accordance with a detailed hardware orientated

program breakdown. These costs are compared to the estimated rates of expenditures prepared by the Operating Departments. The resultant cost performance is matched with schedule performance employing the similar PERT/Time work breakdown and reported to MSC on the required 533 Form.

LEM Management utilizes this cost performance as a primary aid in maintaining and, when necessary, revising budgets and allocations of resources for the accomplishment of program objectives.

2.3.3 Cost

To fulfill the cost control responsibility, which requires the interaction of proper uniform procedures of reporting and analysis of expenditures, and progress with the budget-conscious management of tasks on the operating level, the Business Manager uses personnel from his three sections to maintain the following functions:

- Coordination and review of Subsystem Engineering or Functional Management estimates for all tasks.
- Assignment of budgets to the above two units.
- Review and supervision of the subdivision of these budgets among Grumman functional departments and subcontractors.
- Review and supervision of plans made by the Subsystem Engineers or Functional Managers for the accomplishment of their tasks efficiently and economically, including supervision of subcontractors.
- Monitoring of expenditures and comparison of progress being made in conjunction with the Program Manager's PERT/Companion Cost Staff.
- Consultation with Subsystem Engineers, Grumman functional departments and subcontractors to achieve cost reductions.

The detailed applications of cost control techniques are handled by the responsible operating groups that are familiar with the trade-offs available between cost on one hand and performance/schedules on the other. Accordingly, each Subsystem Engineer or Functional Manager is charged with the responsibility to minimize costs to the greatest extent consistent with meeting his portion of the overall LEM schedule and performance requirements. To effectively do this, a realistic initial budget for each task, continued updating of this budget to reflect changes in requirements and experience, a comparison of actual expenditures with the budget, and a comparison of progress with schedules, are employed by the Subsystem Engineer or Functional Manager.

The Program Manager's Staff regularly monitors the cost performance on each subsystem and, when routine cost management appears to be ineffective, reviews the

situation and attempts to identify remedies. In instances where no remedy can be found, action will be initiated by the Business Manager to provide additional funding.

All data and information developed in this manner are compiled on a regular basis by the Program and Business Offices into reports for Grumman LEM and Corporate Management and for NASA. Among these reports are the required Financial Management Report and the Man Loading Graphical Summary Report.

2.3.4 Subcontract

Grumman affords a deliberate and detached negotiation effort with major subcontractors. This approach, together with incentive/penalty provisions and the application of the procedures outlined herein, is used to provide a well-managed and well-controlled program.

Grumman defines subcontractor tasks in great detail by means of the Vendor Requirements Document prior to negotiation to avoid cost quotations that later may be found not to cover the complete subcontracted job.

Routine procedures for subcontract administration include: 1) manhour and dollar expenditure vs. contract plan accompanied by revisions to the three month projection; 2) percent of task remaining to completion vs. percent of funds remaining; 3) justification for deviations from forecast and plan; and 4) forecast of progress to match projection of (1) above. Monthly meetings for formal review of subcontractor progress problems, and proposed solutions at both the management and working levels, the immediate reporting of all subcontractor difficulties, subcontractor change proposals with sufficient background data, and resident Grumman representatives, aid in the administration of subcontracted effort. These meetings together with review of the Subcontractor's periodic PERT reports enable Grumman to oversee and control, if necessary, the efforts of the Subcontractor.

Grumman LEM Management and Subsystem Engineering bi-weekly reviews of the subcontractor progress and pending design changes, based on informal reporting, result in Action Items Lists to Subsystem Engineers and resident representatives. Should circumstances warrant, direct and immediate contact with the subcontractor is taken.

Management contact and supervision as required assures that the LEM subcontract is receiving top priority within the subcontractor's operation.

2.3.5 Change

Any change to the contract document that would affect the mission as described, schedule, estimated cost, or any contract requirement, will be handled generally in accordance with the NASA Contract Change Procedure. This procedure is to be followed whether the change is Contractor-initiated or MCS-directed.

In the event of a Contractor - initiated change, the Contractor will notify the procuring Contracting Officer by TWX or letter of the proposed change requesting a Contract Change Authorization. The MSC Contract Change Procedure calls for the submission of a Preliminary Contract Change Proposal (PCCP) within ten (10) working days of receipt of the Contract Change Authorization, and submission of a final Contract Change Proposal (CCP) within sixty (60) days of date of the Contract Change Authorization. The Contractor will endeavor, as a working objective, to submit proposals within the time period specified; however, it is understood that these dates are not binding and that technical and/or administrative circumstances may require a longer time interval between receipt of a Contract Change Authorization and submission of proposals. The final Contract Change Proposal will be the basis for negotiation of a Supplemental Agreement to the Contract.

This same procedure will be followed should the Contractor receive MSC direction to incorporate a change by means other than a Contract Change Authorization or a Supplemental Agreement.

The Contractor maintains a Contract Change Authorization Summary listing all authorizations by number and descriptive title that have been processed and those being actively considered for possible incorporation into the contract. This summary includes applicable Contractor authority references, procuring activity serial number, effectivity, status, and disposition. The list is submitted on a monthly basis to MSC.

2.3.6 Liaison

To maintain vital lines of communication with MSC, Grumman has established a liaison office at Houston.

This office is kept current by Grumman on all aspects of the LEM Program, and is primary information channel between the two organizations.

In like manner, permanent representative offices have been established at AMR, WSMR, NAA, MIT, Rocketdyne, STL, Bell Aerosystems, Marquardt, Hamilton-Standard, Pratt & Whitney, RCA, AiResearch and Marquardt for control, monitoring, coordination and/or contractual matters.

Grumman feels that this method of liaison is essential to the successful operation and implementation of the entire LEM Program, as well as providing an atmosphere conducive to satisfactory business relationships and the interchange of common data.

2.3.7 Configuration

LEM Configuration Management is being implemented and will be effected through a set of procedures by which the configuration of deliverable end items is identified, controlled, and documented. Configuration Management procedures are scheduled for a pilot run on LTA-2. The entire system is designed to assure that:

- All delivered end items are configured in accordance with the latest released information.
- All delivered end items are accurately and completely described by readily available documentation.
- For approved changes in an end item configuration, corresponding changes are made in all related support elements; i.e., test equipment, spares, manuals, tooling, training equipment, documentation, etc. All changes to end items will be controlled by a Change Control Board.
- The specific location and status of each "controlled item" of equipment, by part number and serial number is known at all times.

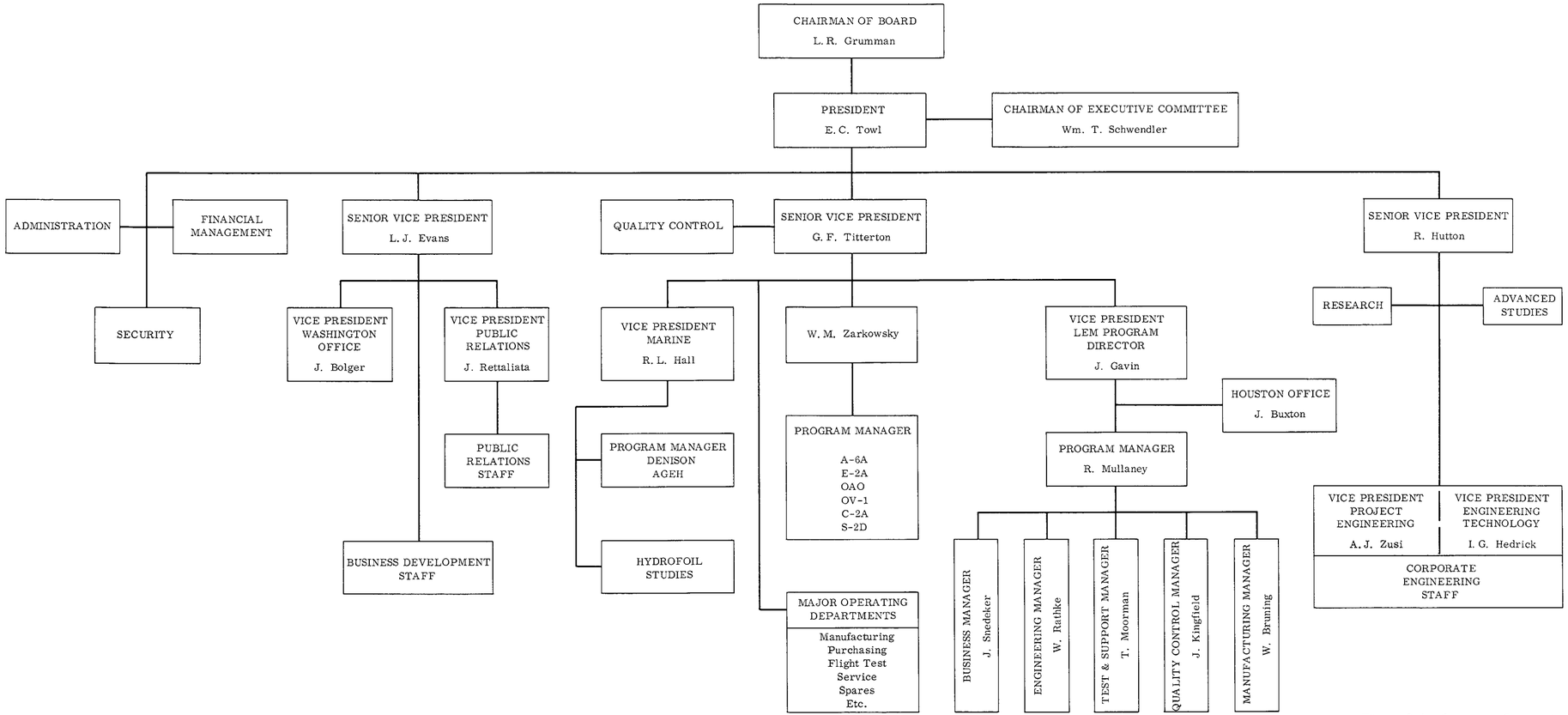


Figure 2-1. Grumman Corporate Organization

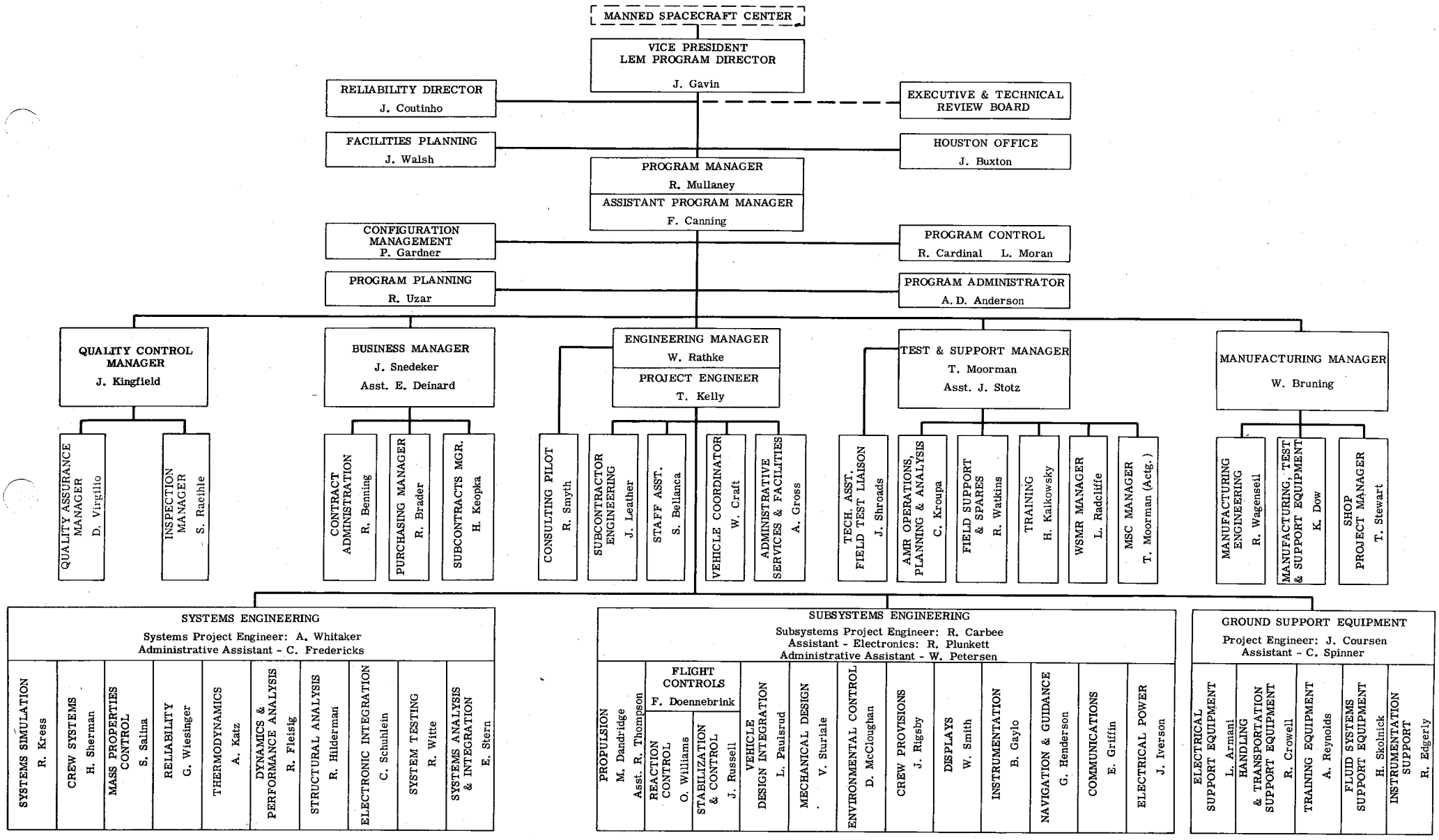


Figure 2-2. GAEC-LEM Organization Chart

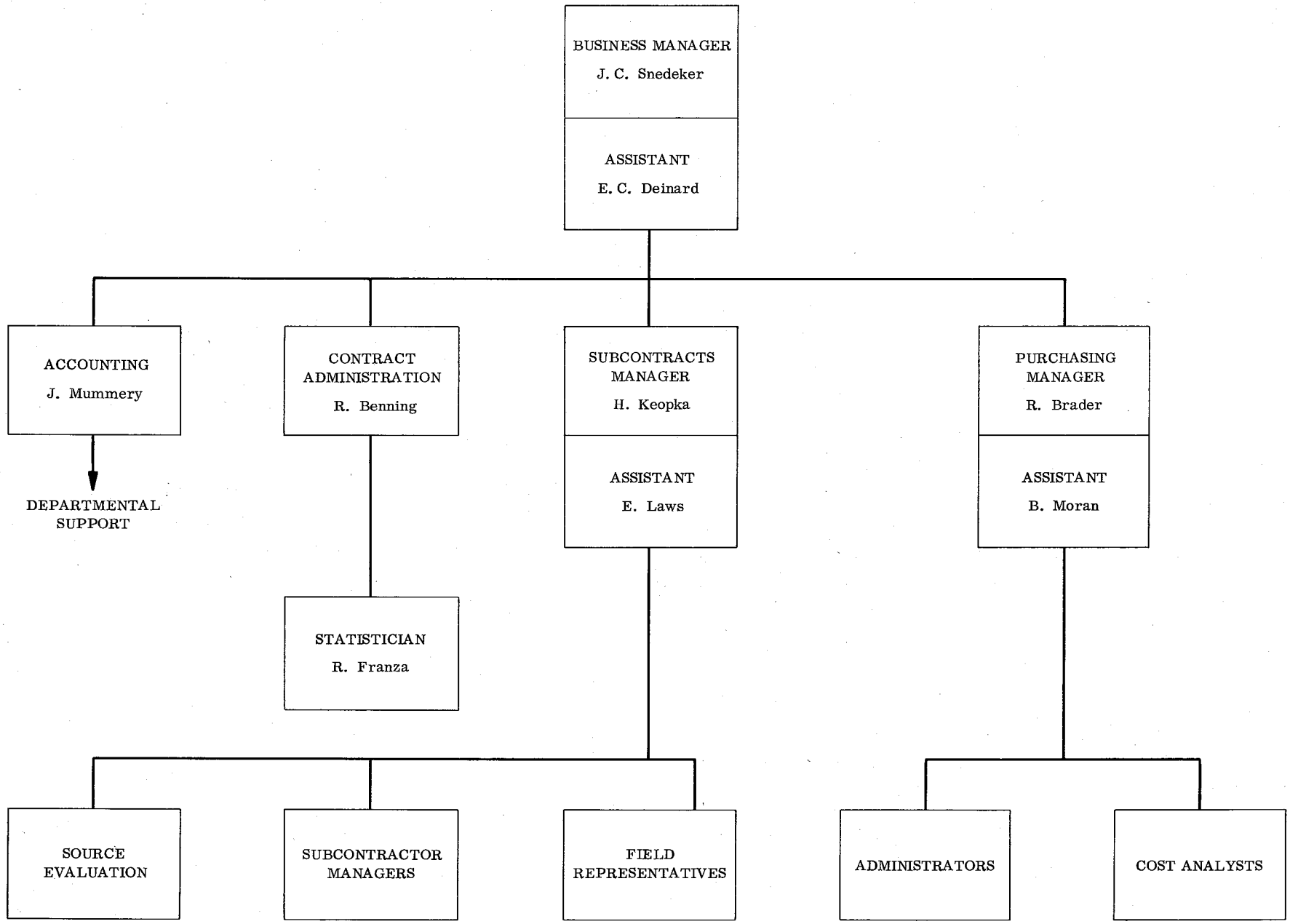


Figure 2-3. LEM Business Management Group

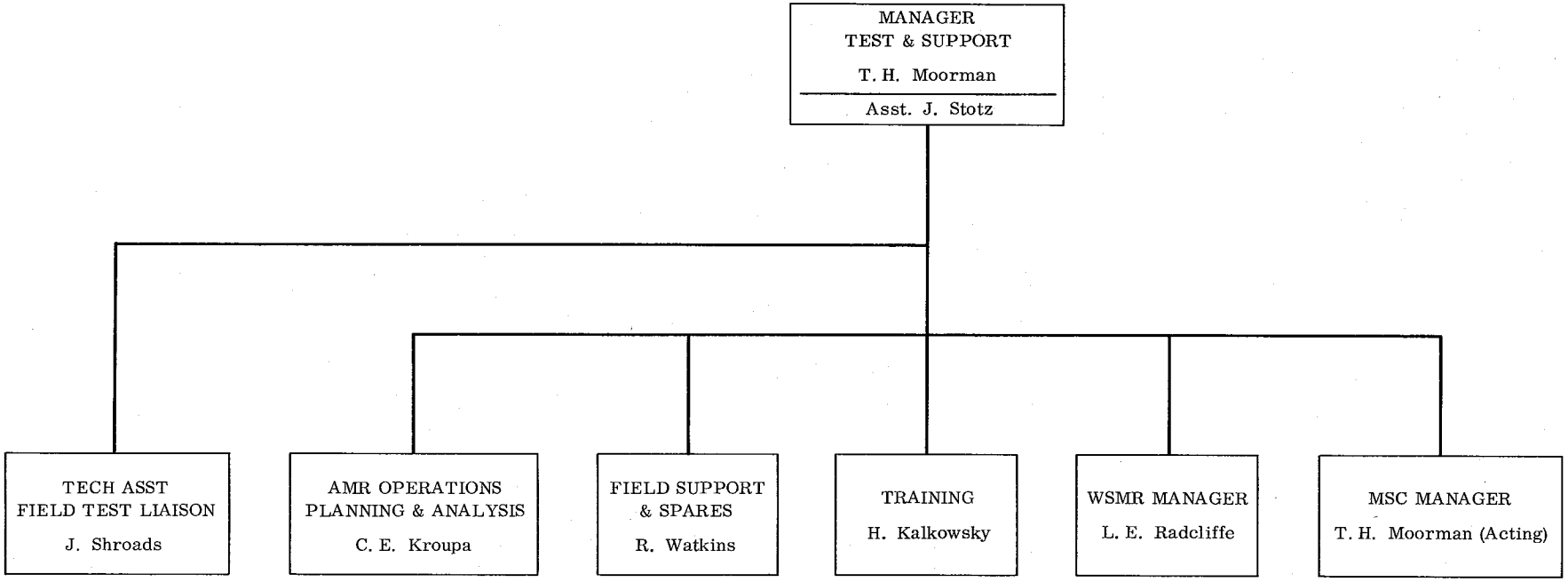


Figure 2-4. LEM Test and Support Organization

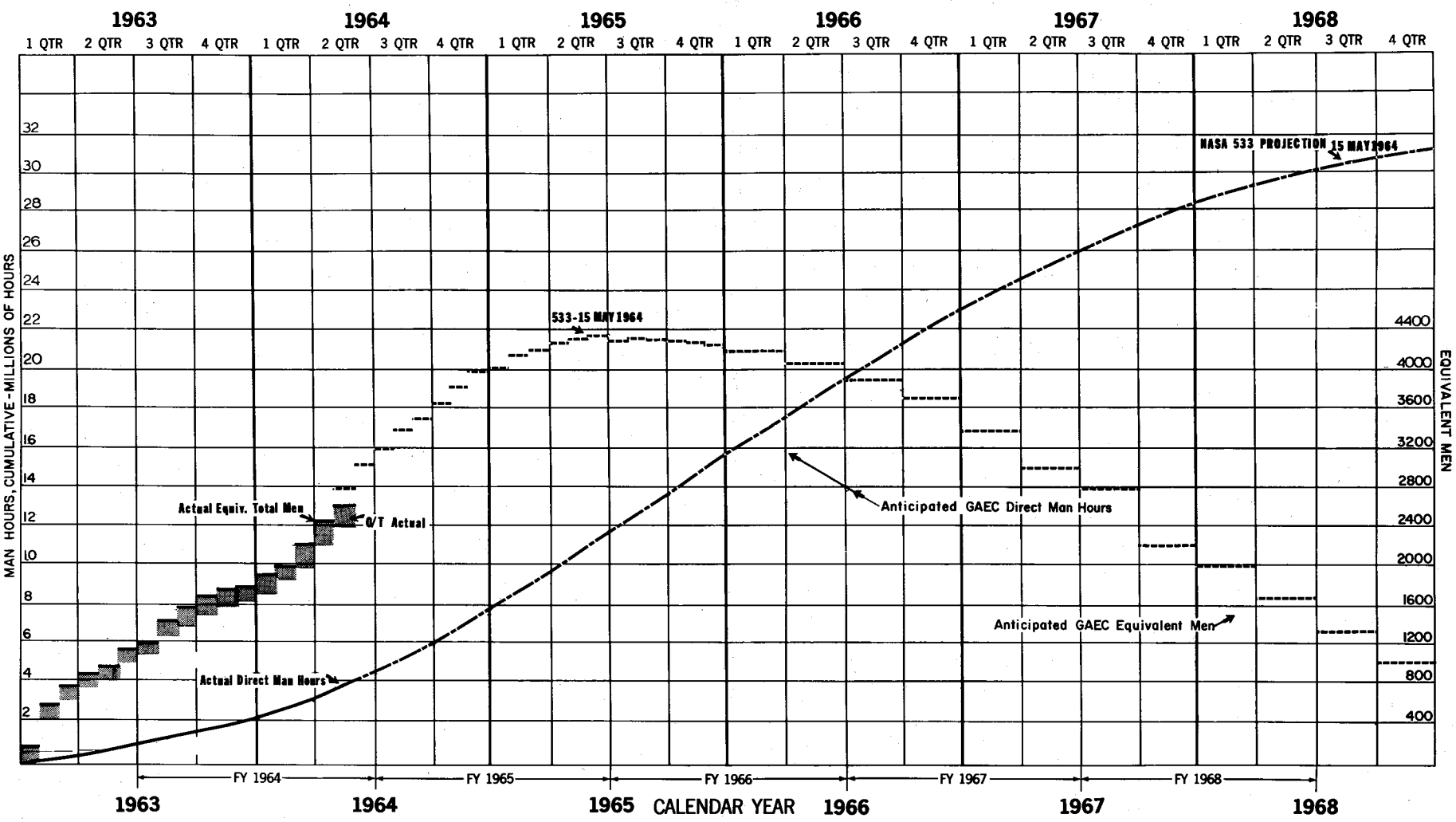
SECTION 3
MANPOWER CHARTS

The actual vs. anticipated manpower required for the LEM Program is presented in the charts which comprise this section. Subcontractors' manpower is not included.

- Total Labor (total of charts 2 through 6)
- Engineering (including Flight Test and Service) Manpower Required
- Tooling (including Manufacturing Engineering, and Test Equipment and Process Engineering) Manpower Required
- Manufacturing (including Quality Control) Manpower Required
- WSMR Manpower Required (included in charts 1 and 2)
- AMR Manpower Required (included in charts 1 and 2)

LEM PROGRAM

TOTAL LABOR



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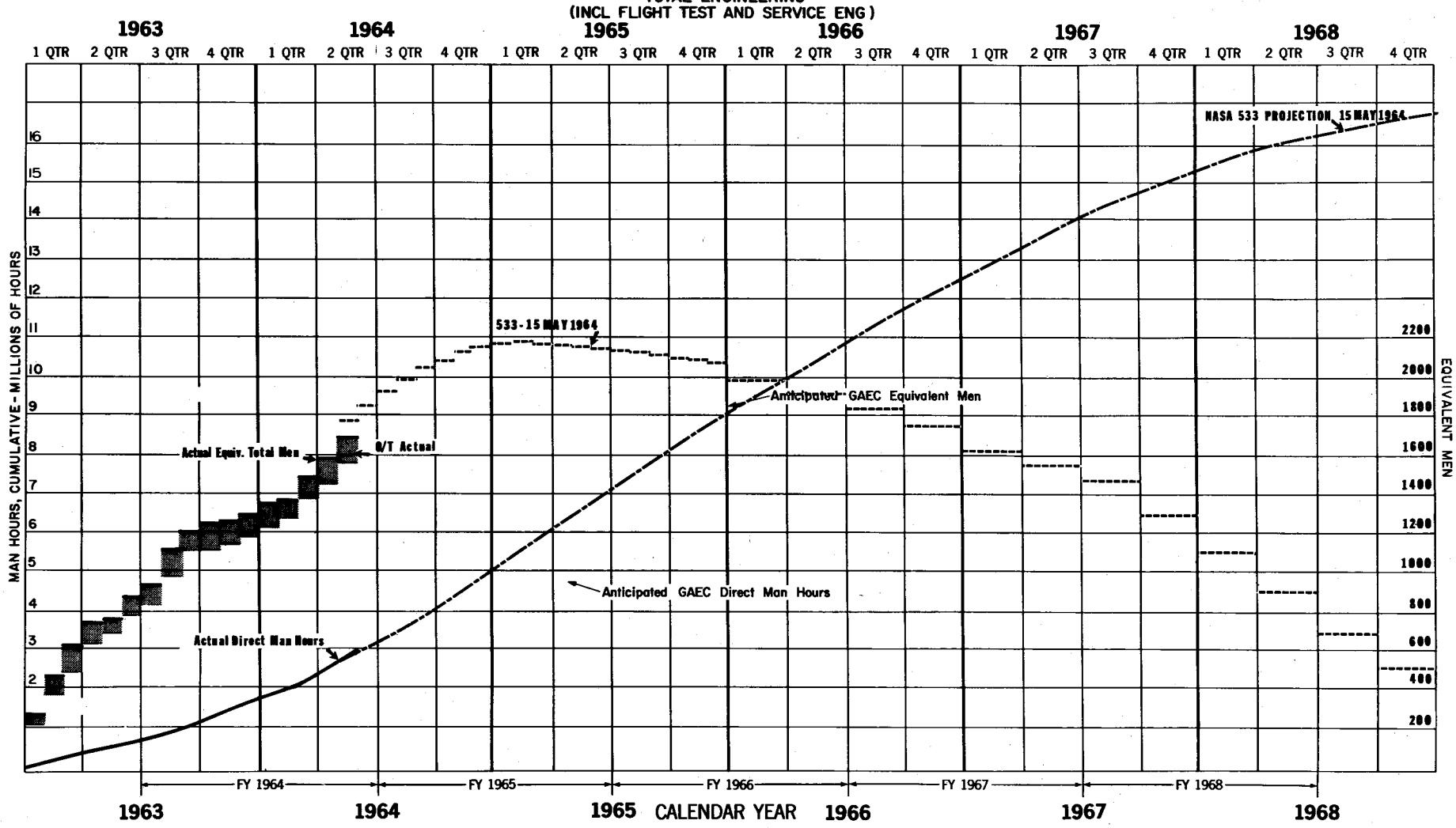
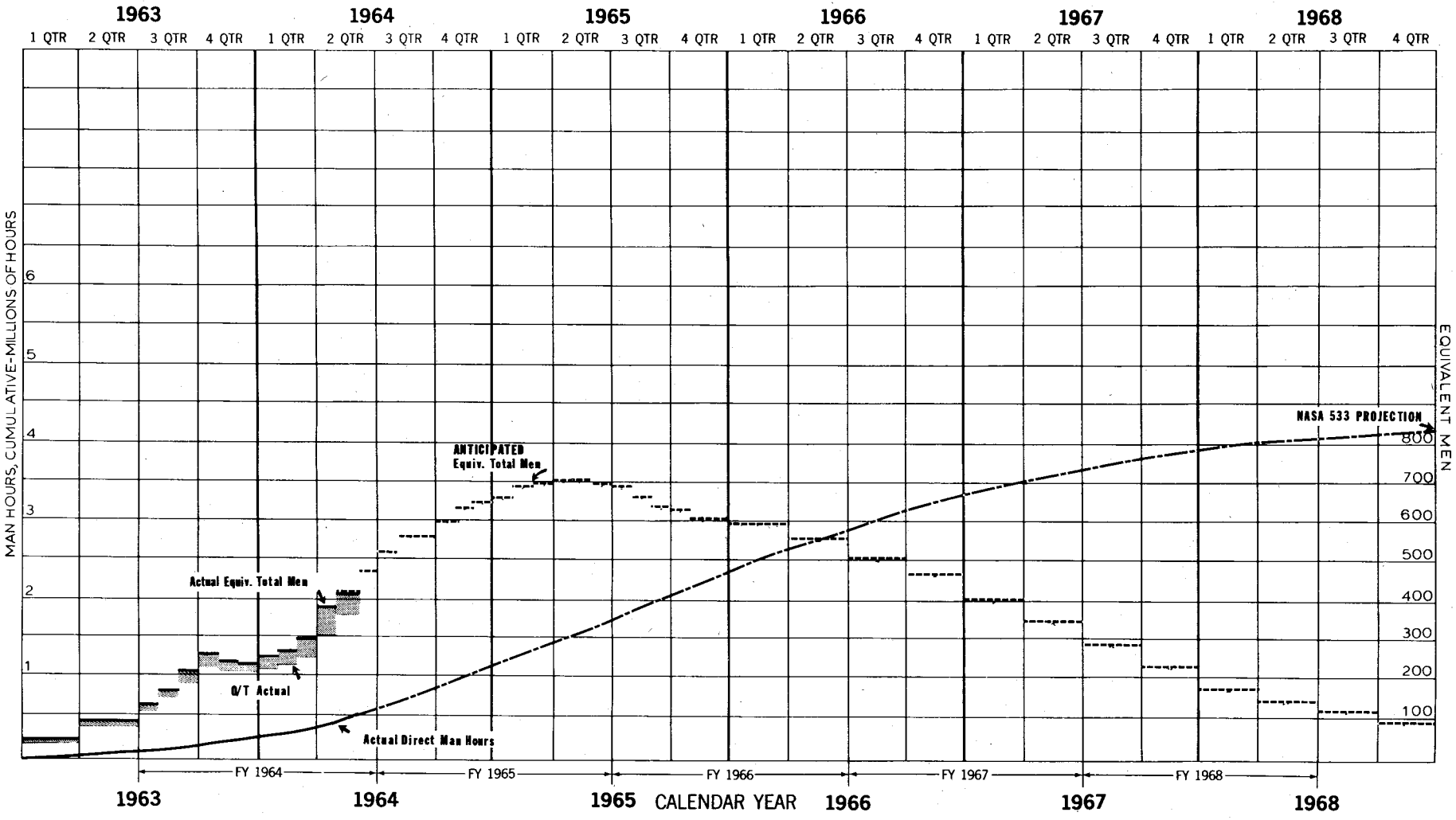
LEM PROGRAM

TOTAL ENGINEERING
(INCL FLIGHT TEST AND SERVICE ENG)



LEM PROGRAM

TOOLING



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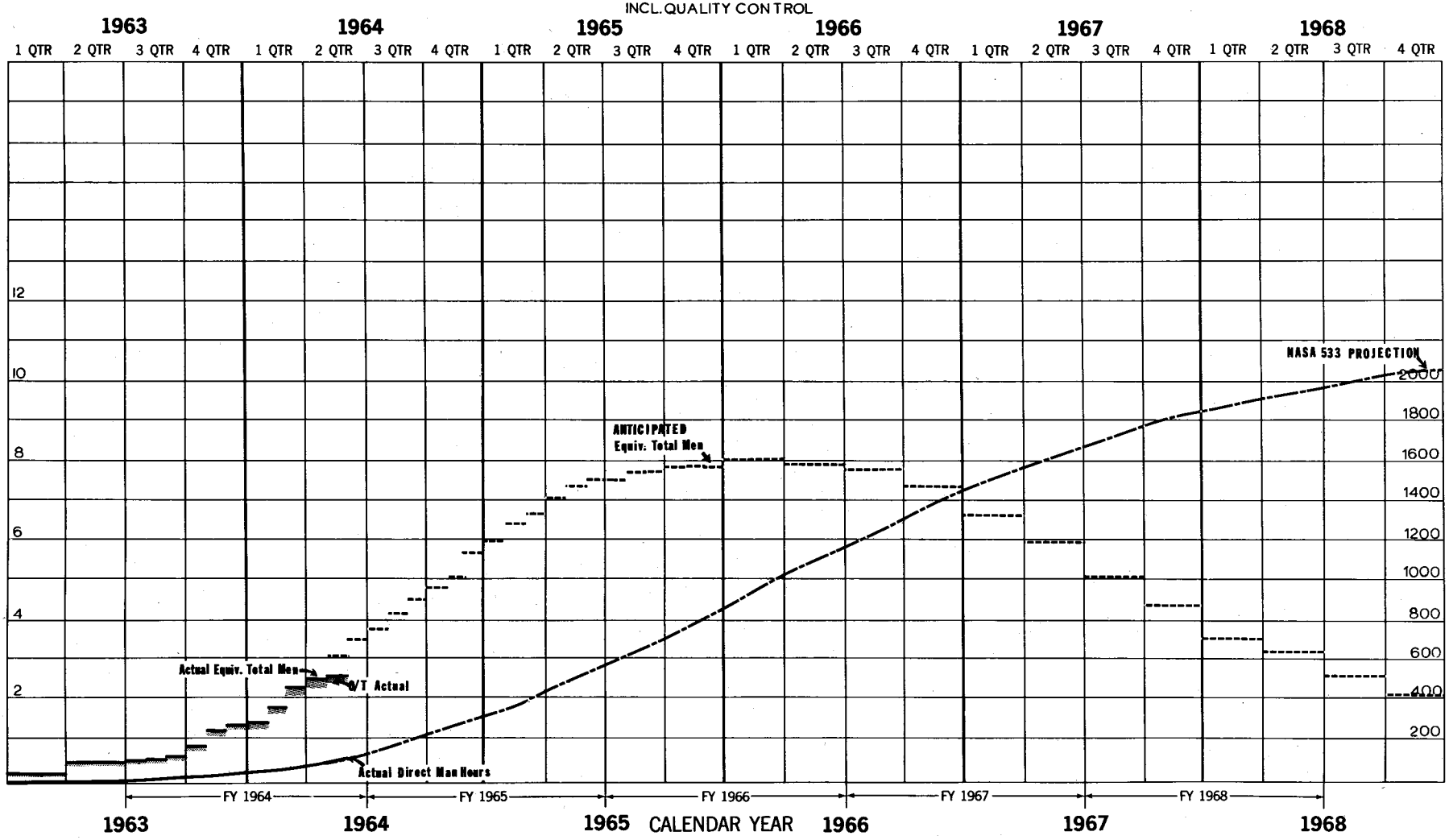
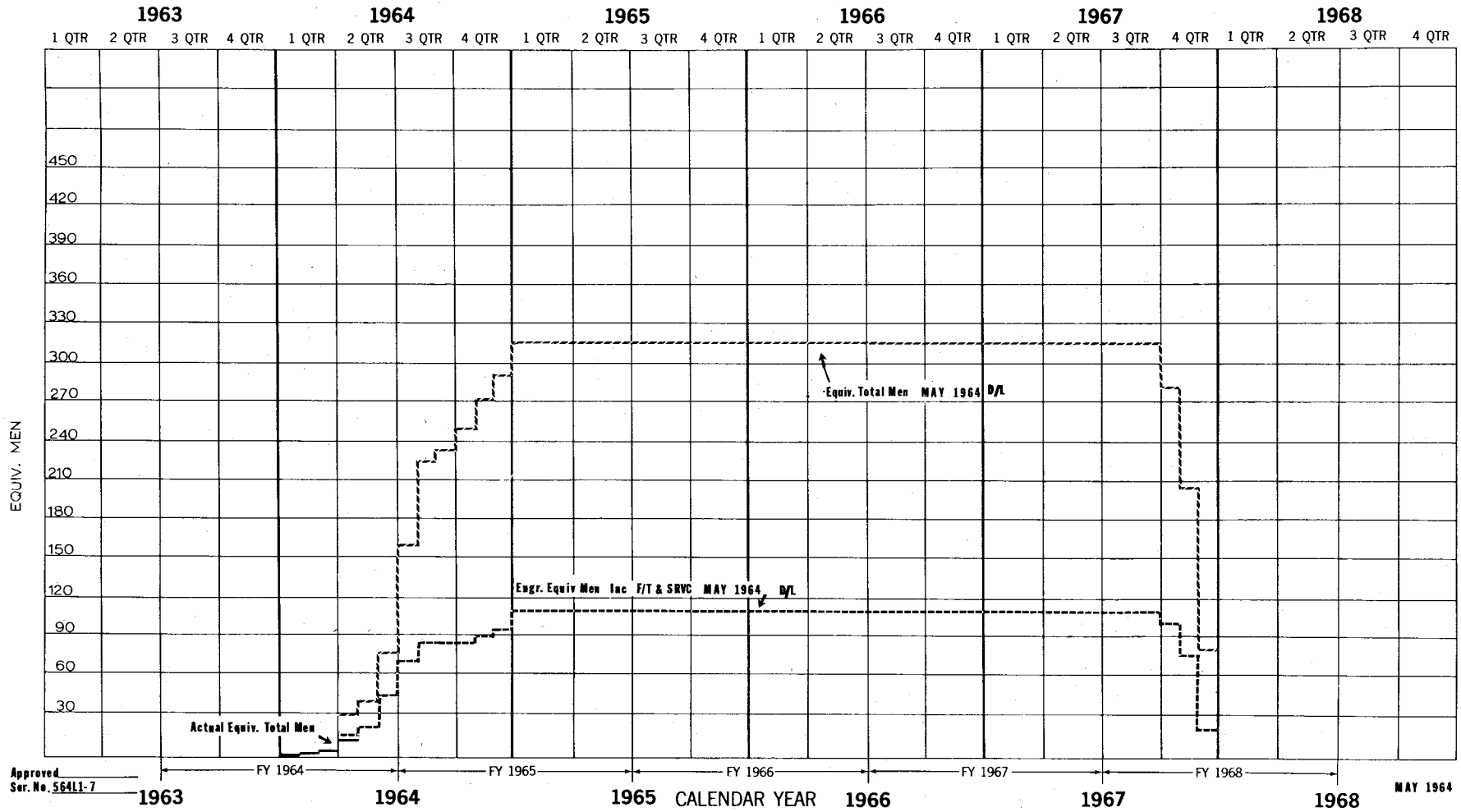
LEM PROGRAM

MANUFACTURING
INCL. QUALITY CONTROL



LEM PROGRAM

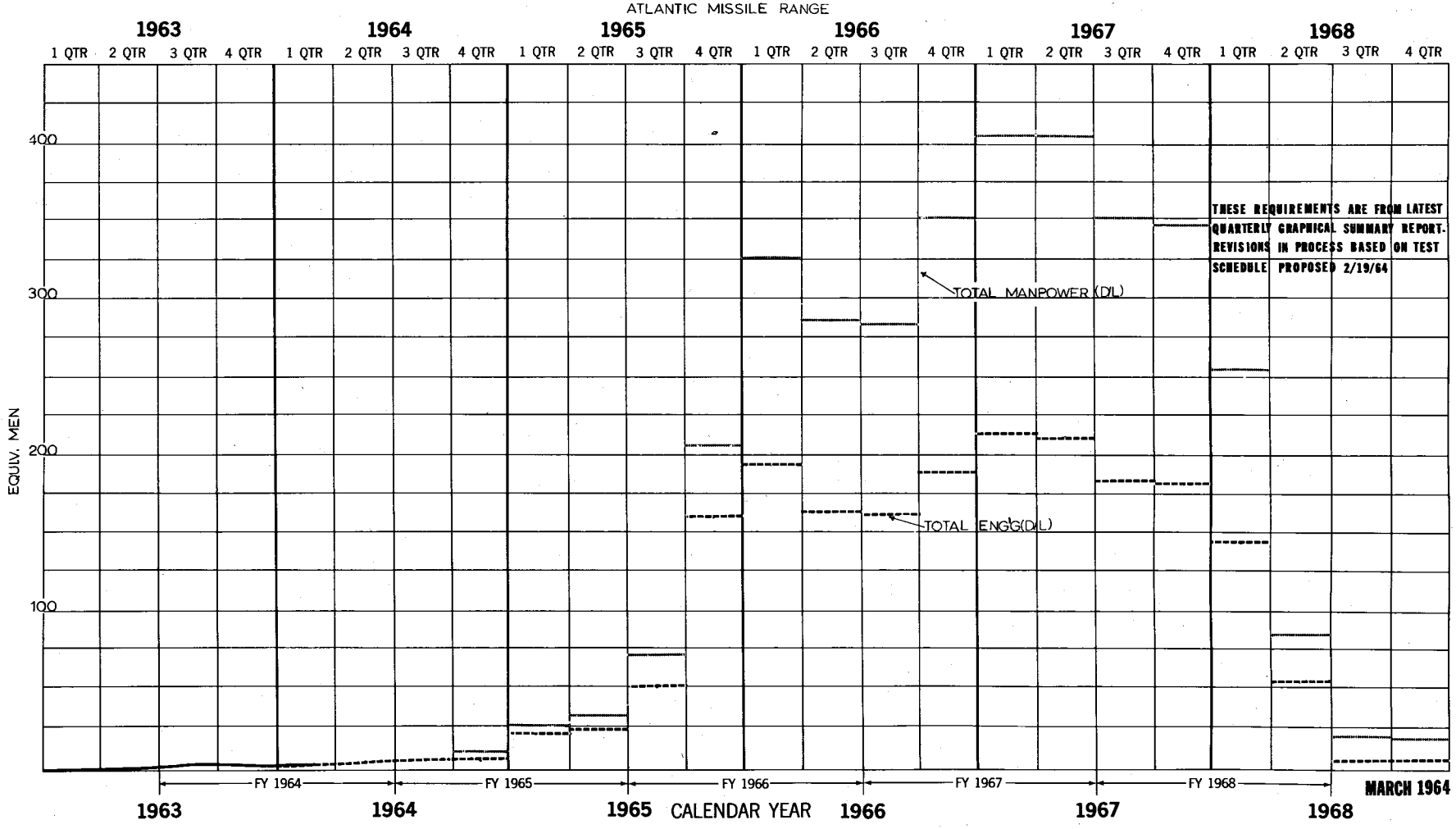
WHITE SANDS MISSILE RANGE



LPL 13-1A
Revised 1 July 1964

LEM PROGRAM

ATLANTIC MISSILE RANGE



SECTION 4
MISSION AND MODULE DESCRIPTION

4.1 INTRODUCTION

As a part of project Apollo, the Lunar Excursion Module (LEM) will be the manned landing vehicle that will make the ultimate descent to the surface of the moon. To accomplish this mission, the LEM will be injected into a descent trajectory from the orbiting Command and Service Modules, land on the lunar surface, serve as a communications and support center for the crew during exploration periods, and launch itself for rendezvous with the Command and Service Modules. System redundancies will provide adequate safety factors in the event of critical system failures during any phase of the mission. Since the LEM will be launched into an intercept orbit and rendezvous with the Command Module in lunar orbit, the overall mission concept is known as the Lunar Orbit Rendezvous (LOR) technique. A functional block diagram of the LEM is shown in figure 4-1.

4.2 LUNAR ORBITAL RENDEZVOUS (LOR) MISSION

The LEM will be launched on its lunar mission from the Launch Operations Center of the NASA complex at Cape Canaveral, Florida. Prior to launch, the LEM will be subject to a series of rigorous checkout exercises designed to assure complete mission reliability and maximum crew safety. System acceptance and functional tests, integrated equipment tests, and launch pad tests will allow constant monitoring of the LEM status. ACE-S/C (Acceptance Checkout Equipment - Space Craft), an integrated data acquisition, processing, and display system, shall be used to monitor all checkout operations and facilitate isolating malfunctions.

At launch, the LEM will be stowed along the longitudinal centerline on top of the S-IVB stage of the Saturn V

launch vehicle. The Apollo Command/Service Modules, containing a three-man crew, will be attached to the LEM and S-IVB stage by an adapter to form the nose of the Saturn. The Saturn vehicle will inject the payload consisting of the Saturn S-IVB stage, LEM, and the Command/Service Modules into an earth orbit. During earth orbit, the astronauts will complete subsystem checkouts in preparation for escape from earth orbit. Certain in-flight maintenance operations may be performed, if necessary. Mission abort may be executed at any time during the mission. Upon completion of earth orbit, the S-IVB propulsion system will inject the LEM, and Command/Service Modules into an earth-moon trajectory (translunar injection). Following the initial coast of translunar flight, the Command/Service Modules, containing the three astronauts, will detach as a unit from the LEM and S-IVB stage, rotate 180° in free flight and dock with its nose on the top hatch of the LEM (transposition). Immediately following transposition, the spent S-IVB stage and the lower part of the LEM adapter will be jettisoned. When the jettisoned S-IVB stage is clear, the CSM and LEM will be oriented for the translunar coast period.

Approximately 70 hours after launch, the LEM and the Command/Service Modules will enter an eighty-nautical-mile lunar orbit. Upon completion of the first portion of the lunar orbit, the LEM will be pressurized from the Command module and two astronauts will enter the LEM through the top docking hatch to check out each subsystem. They will then align the Navigation and Guidance Subsystem. At a predetermined point in lunar orbit, the Reaction Control Subsystem (RCS) will separate the LEM from the CSM. The descent stage engine will then inject the LEM into an elliptical descent transfer orbit and shut off. The transfer orbit will have its pericynthion (point nearest moon) at an altitude of 50,000 feet, in the vicinity of the proposed landing site. The descent transfer orbit allows passive rendezvous with the Command/Service Modules in the event of an abort decision prior to restarting the descent engine. At the pericynthion, the descent engine is again fired and the powered descent phase initiated. This phase terminates at about 1000 feet altitude near the intended landing site. Final descent will be performed under manual control from the 1000-foot altitude at a flight path angle that affords the maximum visibility of the landing site. If necessary, an abort can be executed at any point up to the moment of lunar touchdown by means of powered ascent and rendezvous with the orbiting CSM.

Following lunar touchdown, a subsystems checkout will be made and the LEM prepared for astronaut egress

One astronaut will leave the LEM through the forward hatch for scientific exploration of the lunar surface. During exploration, the LEM will serve as a scientific support and communications relay center. After approximately three hours of exploration, the astronaut must return to the LEM to replenish his life support pack, if further exploration is necessary. Life support stores permit six refills of the portable life support pack. After exploration is completed, a pre-launch check will be made, and certain repair operations may be performed if required. The LEM Navigation and Guidance Subsystem will be aligned with respect to the lunar vertical, with the proper azimuth orientation for take off determined via celestial sightings. Nominal launch time will occur when the Command/Service Modules are slightly downrange of their zenith position over the LEM. Launch at this time allows a single-thrust phase of the ascent engine into an ascent transfer orbit.

The LEM descent stage will be used as a launch platform and will be left on the moon. The ascent trajectory begins with an initial vertical rise, followed by two pitchover phases, one at a high pitch rate, and a final one at a comparatively low pitch rate, with burnout occurring at 50,000 feet. At this point the LEM is in the ascent transfer orbit. Ascent guidance is performed in an inertial mode, with a backup mode available. Both modes are capable of assuring satisfactory conditions for orbital transfer at burnout. Transfer from the 50,000-foot altitude to the 80-nautical-mile Command/Service Module orbit is made by coasting in orbit, with capability for mid-course correction if necessary, by means of the LEM Reaction Control Subsystem.

At a range of approximately 20 nautical miles, rendezvous begins, using radar tracking. Course corrections may be made in either automatic of manual mode, using the reaction control system, to bring the LEM within 500 feet of the orbiting Command/Service Modules at a relative velocity of 5 to 10 fps. The astronaut will then manually maneuver the LEM to a docking attitude and adjust the rate of closure until complete docking is accomplished. The Command/Service Modules will normally remain passive during the rendezvous operation, although capable of maneuvering for rendezvous if necessary. The LEM will dock with its forward hatch on the nose of the Apollo Command Module. After men, equipment, and scientific samples are transferred through the docking hatch to the Command Module, the LEM will be jettisoned and the Apollo Service Module engines will be started for the return to earth.

4.3 LUNAR EXCURSION MODULE

4.3.1 General

The LEM is a two-stage vehicle, consisting of a lower (descent) stage and an upper (ascent) stage. The complete LEM contains all the required operational subsystems necessary to land two men on the lunar surface from lunar orbit, support them during the period of lunar exploration, and bring them safely back to the Command Module.

Both stages operate together as a LEM unit during lunar orbit, descent, touchdown and lunar stay. At lunar launch, the stages are separated and the ascent stage, alone, is launched for rendezvous and docking with the Command Module.

4.3.2 Descent Stage

The descent stage contains the means for safely landing on the lunar surface and provides a stable platform for launching the ascent stage after completion of the lunar exploration phase.

The descent stage houses the descent propulsion stage, the lunar landing gear, scientifie equipment, and tankage for the staged water, oxygen, and hydrogen used by the Environmental Control and Electrical Power Subsystems. The primary structure of the descent stage consists of 2 pairs of beams arranged in a cruciform with upper and lower bulkhead closures. The descent engine is mounted in the central compartment created by the intersection of the beams. The main propellant tanks are mounted on the lower bulkhead between the beams outboard of the engine compartment. There are four landing gear legs, attached to outriggers extending from the ends of each pair of beams. These outriggers are also used to support LEM in the spacecraft adapter. The scientific equipment and the auxiliary tankage are located in the quandrants adjacent to the propellant tankage compartments. Thermal protection is provided by an exterior shield supported off the primary structure.

4.3.3 Ascent Stage

The ascent stage is comprised of the pressurized crew and equipment compartment, and the aft equipment bay, the tankage sections, windows, hatches and the ascent propulsion stage.

The pressurized crew and equipment compartment is a welded aluminum alloy structure. Two triangular windows are located in the forward face of the crew

compartment and one window over the flight commander's position to provide visibility for the lunar landing and the lunar orbit rendezvous and docking phase of the mission. Attached at the rear of the crew compartment is a smaller cylindrical section containing the engine hatch, docking hatch, and equipment stowage requiring crew access. The forward hatch is located at the lower front of the crew compartment. Additional equipment for the environmental control and electrical power subsystems is located in unpressurized areas of the stage. The ascent stage is insulated and thermal protection is provided by the exterior shield.

4.4 LEM SUBSYSTEMS

4.4.1 Stabilization and Control

The Stabilization and Control Subsystems, based upon crew and navigation and guidance inputs, develops outputs that initiate three types of control: attitude stabilization and control, translational control, and main engine thrust control.

Attitude Stabilization and Control is divided into four basic attitude control modes: Automatic, Attitude Hold, Rate Command, and Direct.

The Automatic Mode normally provides fully automatic attitude control during all phases of the mission except however, landing, and docking. This mode provides rapid responses to navigation and guidance inputs, resulting in a close-to-nominal flight path and fuel conservation. It also relieves the crew of repetitive tasks and tedious routine operations.

In the Automatic Mode, navigation and guidance error signals are combined with rate gyro damping signals. The resultant output controls the firing of the Reaction Control Subsystem reaction jets and provides automatic trim control of the gimbaled descent engine.

The Attitude Hold Mode is the primary attitude control mode for the hover, landing, and docking phases. It also is used whenever the pilot wishes to control vehicle attitude during coasting flight. The Attitude Hold Mode is a semi-automatic mode in which the pilot commands an angular rate proportional to the displacement of the attitude controller. When the controller is in the neutral position, the vehicle will hold attitude in accordance with the attitude reference outputs established by the Primary or Backup inertial platforms.

The Rate Command Mode is basically similar to the Attitude Hold Mode except that it does not contain the attitude hold feature. In this mode, as in the Attitude Hold Mode, the pilot commands angular rates proportional to the displacements of the attitude controller. In case of open-type rate gyro failures in one or more axes, this mode provides open-loop acceleration command capability.

The Direct Attitude Mode provides the pilot with open-loop type acceleration control, selectable on an individual axis basis. Two types of acceleration control are provided: low-frequency pulse-control and on-off control. Low-frequency pulse-control is routed through the system electronics, while on-off control is connected directly to the emergency coils of the reaction jet solenoids.

Translational Control, via the Reaction Control Subsystem jets, is provided in both automatic and manual modes. Automatic control for X-axis translation is generated in the automatic guidance equipment, while control for ullage requirements is generated in the Control Electronics Section of the Stabilization and Control Subsystem upon receiving a signal from either the Apollo Guidance Computer or the astronaut. Manual Translation Control is provided in all three axes for docking and possibly for vernier corrections during hover and landing.

Thrust Control is provided for both the ascent and descent engines of the Propulsion Subsystem. Commands from the Primary Navigation and Guidance Subsystem generate automatic on-off control of both engines, with manual override always possible. Automatic thrust vector trim control for the descent engine is derived from the Control Electronics Section attitude error channels in the form of gimbal actuation signals.

The Stabilization and Control Subsystems also contains a backup guidance section that can be utilized if a malfunction occurs in the Primary Navigation and Guidance Subsystem. With the Primary Navigation and Guidance Subsystem functioning properly, signals are routed to the guidance coupler and to the attitude and translation control circuits in the Stabilization and Control Subsystem during Automatic Mode operation; these signals are then routed to the thruster fuel-control solenoids in the Reaction Control Subsystem, to the descent engine gimbal motors, and to the ascent and descent engines. Should the Primary Navigation and Guidance Subsystem fail, the Backup Guidance Section of the Stabilization and Control Subsystem will supply backup programmed guidance signals to the guidance coupler for the attitude

and translation control circuits for abort or nominal ascent to a clear pericynthion orbit; these signals are routed as described for normal operation.

4.4.2 Navigation and Guidance (N & G) Subsystem

The N & G Subsystem provides the measuring and data processing capabilities and control functions necessary to accomplish lunar landing and ascent, and rendezvous and docking with the Command/Service Modules. The N & G Subsystem comprises the landing radar, a rendezvous radar/transponder, the alignment optical telescope, the inertial measurement unit, the LEM guidance computer, the power and servo assembly, and three coupling display units.

The N & G Subsystem is primarily an aided inertial system whose principal aids are the landing radar, the rendezvous radar/transponder, and the alignment optical telescope. The inertial measurement unit is aligned to an inertial reference by star tracking with the alignment optical telescope. During descent to the lunar surface, altitude and velocity information from the landing radar are used to update inertially-derived data. During the coasting descent, lunar stay, and rendezvous phases of the mission, the rendezvous radar tracks its transponder on the Command Module to provide range, range rate, and angle rate measurements with respect to inertial space. A brief functional description of each of the major components of the N & G Subsystem is contained in the following paragraphs.

The landing radar is an X-band doppler altimeter and velocity radar that provides the LEM guidance computer with velocity data along each of the three beams, with range data along the altitude beam, and with data on the position of the landing radar antenna.

The rendezvous radar is an X-band, interrupted-constant-wave, amplitude comparison, monopulse radar that can acquire and accurately track its transponder in the Command module at any range between 400 nautical miles and 5 feet. (An identical transponder on the LEM is tracked by the Command module.) Range-rate measurements are provided at any LEM rate of closure or opening (with respect to the Command module) between 4900 feet per second and 1 foot per second.

The radar/computer interface unit, a part of the rendezvous radar package, provides the interfaces between the landing and rendezvous radars and the LEM guidance computer. Radar output signals are processed into the format required by the LEM guidance computer

and selected sequentially for transfer by coded strobe signals generated by the computer.

The LEM guidance computer is the central data-processing device of the N & G Subsystem. It is a paralle, fixed point, ones' complement digital computer with a fixed rope core memory and an erasable ferrite core memory. Inputs to the LEM guidance computer are received from the landing and rendezvous radars through the radar/computer interface unit, from the inertial measurement unit, and from the navigator via the data entry keyboard on the LGC control panel. Using these data, the LEM guidance computer computes flight control commands and transfers them to the Stabilization and Control Subsystem and to the LEM guidance computer display panel.

The alignment optical telescope is a non-articulating, unity power, 55-degree field-of-view telescope used for aligning the inertial measurement unit. The telescope optics mechanism has three distinct viewing positions and a stowage position.

The inertial measurement unit is the primary inertial sensing device of the LEM. Three accelerometers and three gyroscopes are mounted on the innermost gimbal of a three-degree-of-freedom gimbal system. The innermost gimbal is held non-rotating with respect to inertial space. Outside forces acting upon the LEM are sensed by the accelerometers, which produce signals representing incremental changes in velocity. Signals proportional to changes in the attitude of the LEM are generated by the inner, middle, and outer gimbal angle resolvers. The outputs of the accelerometers and resolvers are transferred to the LEM guidance computer.

The power and servo assembly consists of the following subassemblies: gimbal servo amplifiers, gyro accelerometer amplifiers, coupling and display unit electronics, power diodes and signal conditioners, and power supplies.

The coupling and display units (CDU's) transfer angular information between the major elements of the Navigation and Guidance Subsystem, the Stabilization and Control Subsystem, and the crew displays. The N & G Subsystem uses three CDU's, one for each gimbal of the IMU. The digital-CDU principle is based upon the use of a-c analog computing techniques to derive error voltages from analog resolver angle signals. Digital circuitry continuously alters the analog computational scaling factor to null the error

voltages. When this null occurs, the state of the digital memory drive circuit exactly corresponds to the resolver position.

4.4.3 Crew Provisions

Provisions for the LEM flight crew include space suits, portable life support systems (PLSS), support and restraint facilities, drinking water, food, waste storage, first-aid equipment, and a radiation dosimeter. The crew consists of a flight commander and a systems engineer, with crew station design consisting of a side-by-side seating arrangement that permits LEM piloting from either station. The flight commander is seated on the left; the systems engineer on the right. A large center instrument panel permits the flight crew to share displays and controls. Additional control and displays are provided through instrument panels and circuit breaker panels located throughout the LEM compartment. Ingress and egress to the crew station can be accomplished through either the forward hatch under the central panel, or the aft overhead hatch.

A space suit is worn by each crew member. Normally, a crewman at his station is umbilically connected to the vehicle for suit environmental control and communication. During lunar excursions, the suit functions through the independent portable life support system. The crew wears cotton under garments to absorb perspiration and guard against irritation to the skin from the space suit. A thermal outer garment including insulated gloves and boots is worn over the space suit for extra vehicular operations such as exploring the lunar surface, and to protect against thermal radiation.

Each crew member will be provided with a PLSS, which is stowed when not in use. The PLSS will be utilized by a crew member to permit a maximum of four hours of extra vehicular operation before the batteries must be recharged and other expendables replenished from the Environmental Control Subsystem supplies. Spare parts and a repair kit are provided with the PLSS. Waste management provisions will be integral with the space suit except for final storage of waste products.

The support and restraints are adjustable to position the crewman for maximum visibility, plus display and control utilization. Food will be stored and available for use as well as provisions to supply water for food reconstitution, drinking and PLSS recharge.

4.4.4 Environmental Control

The LEM Environmental Control Subsystem (ECS) performs two primary functions: life support and thermal control. Life support includes the pressurization and ventilation of the cabin and the crew's space suits and controlling of the Portable Life Support System (PLSS). It also provides for the removal of contaminants such as CO_2, odors, excess water vapor and particulate matter from the atmosphere breathed by the crew. Thermal control includes control of the temperature of the electronic equipment and of the ventilating gas for the cabin and the space suits.

During normal operation, both the cabin and the space suits are maintained at 5 psia, permitting the crew to open the face plates and remove the gloves from the suits. With the cabin depressurized, the space suit pressure is reduced to 3.5 psia and the suits must be sealed. The pressurizing gas is 100% oxygen. The major portion of this oxygen is stored cryogenically in two supercritical storage assemblies, but the system also includes a small gaseous oxygen accumulator for high-flow demands of short duration. Sufficient oxygen is stored for six cabin repressurizations and two fills and four refills of the portable life support system (PLSS) primary oxygen tanks, in addition to normal crew consumption and vehicle and suit leakage.

The thermal control function employs an ethylene glycol-water mixture as a heat transport fuild, circulated through a closed loop. Waste heat from this loop is rejected to a water evaporator, which discharges steam to the surrounding vacuum.

A positive expulsion tank is used tor storage of water required for evaporation and for supplying the metabolic needs of the crew. The tank also stores sufficient water for two fills and four refills of the PLSS water tanks.

4.4.5 Instrumentation

The Instrumentation subsystem equipment provides for the collection of critical information for transmission to earth, for the detection and isolation of malfunctions, and for the evaluation and display of vital information concerning the performance of the LEM subsystems.

The subsystem is divided into three parts: operational instrumentation, scientific instrumentation, and research and development instrumentation.

The operational instrumentation senses physical data, monitors the LEM subsystems during the unmanned and manned phases of the mission, performs an inflight and lunar surface checkout, prepares LEM status data for transmission to earth, provides timing frequency

for the LEM subsystems, and stores data when the LEM is unable to transmit to earth. The operational instrumentation group consists of sensors, signal conditioner equipment (SCE), caution and warning equipment (CWE), on-board checkout equipment (OBCE), pulse code modulation and timing equipment (PCMTE), and data storage equipment (DSE).

The sensors and SCE provide the capability for gathering the various physical parameters in the LEM subsystems and modifying them into a form compatible with the instrumentation subsystem equipment.

The CWE provides the crew with a rapid check of LEM status during the manned phase of the mission by continuously monitoring all LEM subsystems.

The OBCE provides the crew with a central checkout facility for in-flight and lunar surface checkout of the LEM subsystems.

The PCMTE converts the data from the signal conditioning unit (SCU) into coded digital signals that are used by the pre-modulation processor (PMP) equipment of the Communications Subsystem and, on the ground, by the acceptance checkout equipment (ACE). The PCMTE also provides timing frequencies to synchronize LEM equipment and furnishes coded time information for display and telemetering.

The DSE provides magnetic tape storage for PCMTE data, selected analog sensor signals, and a voice channel when the LEM is unable to transmit to earth.

Scientific instrumentation will be devoted primarily to selenogolical research. The following experiments are some that are considered typical: radioactivity survey; temperature measurements; surface and rock formation detail, survey, core samples, analysis, and soil density; communications experiment; seismological studies; gravity; magnetic field strength measurements, and residual atmosphere studies.

The research and development instrumentation equipment includes instrumentation required for spacecraft development flight tests in excess of that provided by the Operational Instrumentation System. This equipment will utilize flight-proved components where possible. The following are typical examples of this equipment: FM/FM telemetry modulation package; telemetry RF package; signal conditioning package;

transducers; tape recorder; and radar tracking transponders.

4.4.6 Electrical Power

The prime electrical power for the LEM is supplied by a power generation system, consisting of three hydrogen-oxygen fuel cell assemblies and a reactant storage and supply section. The fuel cells convert chemical energy into electrical energy by reacting gaseous hydrogen and oxygen in stoichiometric ratios under controlled conditions. Since the reaction is not 100 percent efficient, heat and water are produced as by-products. Waste heat and product water are removed by passing a stream of cool dry hydrogen through the hydrogen gas space in the cell.

The reactant storage and supply section consists of cryogenic tanks containing supercritical hydrogen and oxygen; internal electrical heaters that maintain the proper pressure in the tanks; heat exchangers to bring the reactants up to the required fuel cell operating temperatures; supply lines and manifolds; and valves and pressure regulators.

Integral sensors and controls automatically shut down the supply of reactant fluids and isolate the fuel cells from the electrical system if a malfunction occurs. Manual shutdown from the cockpit will also be provided.

Distribution of the generated power is accomplished via a system of essential and non-essential DC busses from which the various LEM subsystems are energized. AC power is obtained via the use of a solid state inverter.

Silver-zinc batteries are presently being considered as a source of emergency power for powering pyrotechnic devices.

A battery charger is utilized to recharge the astronaut back-packs.

4.4.7 Propulsion

LEM Propulsion is divided into separate ascent and descent stages. Each stage is complete in itself, consisting of a liquid propellant rocket engine and its tankage, valving and pressurization sections. A throttleable, gimbaled engine is used in the descent stage; the ascent stage contains a constant-thrust, non-gimballed engine for lunar launch. The propellant is a 50-50 blend of hydrazine (N_2H_4) and unsymmetrical dimethylhydrazine (UDMH), with nitrogen tetroxide (N_2O_4) as the oxidizer. This same hypergolic propellant combination is also used in the Apollo Service Module and LEM Reaction Control Subsystem.

In both ascent and descent stages, the propellant is supplied from baffled tanks, with helium as the tank

pressurizing gas. Propellant is supplied at a nominal temperature of 70°F; the mixture ratio by weight of oxidizer to fuel is 1.6 to 1. Each stage contains its own redundancies and is completely independent of the other. The tankage section in the ascent stage, however, contains provisions for propellant crossfeed to the Reaction Control Subsystem, as a backup for the latter.

Both the ascent and descent engine incorporate sensors for measuring fuel and oxidizer inlet pressures and temperatures, injector inlet pressures, thrust chamber pressure, valve positions, vibration and exterior surface temperatures.

In the descent stage, the propellant tanks are pressurized by helium that is stored in two, interconnected spheres. These spheres are manifolded together and connect to parallel regulation lines with two regulators in series on each side. Either line will deliver total system demand during normal operation through one of the four regulators. Downstream of the regulators, the helium line divides and passes through quad check valves to the fuel and oxidizer tanks. The propellants then flow to the engines through burst discs, which rupture as the tanks are pressurized.

The descent engine is deep throttling, with a thrust range of 10:1; developing 10,500 pounds thrust in a vacuum at full throttle and 1050 pounds at minimum thrust. The engine can be gimballed ±6° by means of vehicle-mounted gimbal actuators to provide trim control in pitch and roll axes during powered descent (with yaw provided by the LEM RCS).

The throttling and injection technique to be employed in the descent engine is currently the subject of parallel development efforts in which a mechanical throttling engine is being tested and evaluated in competition with an engine that uses gaseous injection throttling. Research in this area concerns itself with the problems of preventing spray pattern deterioration and chuffing instability at low thrust settings.

The gaseous injection throttling concept involves the injection of helium at low thrust settings (below 50%) to sustain propellant flow at approximately the same volumetric flow rate as would be obtained with propellant alone at maximum thrust. Throttling is accomplished by varying flow through upstream bipropellant valves. These valves are arranged in a redundant manner to ensure continued or subsequent engine operation should a valve fail closed and to prevent propellant loss if a valve fails open.

This engine uses a fixed-area, fixed orifice injector, with fuel and oxidizer orifices arranged alternately in a series of concentric rings on the injector face. These orifices are fed from a system of inlet manifolds arranged in segments on top of the injector. Helium is introduced by direct injection into these inlet manifolds.

In the mechanical throttling engine, thrust control is obtained by using a variable-area, concentric tube injector, with redundant flow control valves. The injector has a movable sleeve; oxidizer flows through the center of the sleeve and is sprayed into the chamber through ports whose area increase with sleeve motion. The orifice for the fuel is an annular opening between the sleeve and injector face. This annular orifice is contoured so that as the sleeve moves upward (away from the injector tip), the fuel passages enlarge. This action permits increased propellant flow while maintaining optimum velocity and impingement angles. In the full down position, the sleeve closes off the propellant openings.

At maximum thrust, the mechanically throttled engine operates as a conventional, calibrated, pressure-fed engine. At reduced thrust, however, propellant flow rate must be made insensitive to downstream pressure variations at the injector. This is accomplished through dual-throat, variable-area, cavitating venturi valves, one for fuel and one for oxidizer. As the engine is cut back, injector orifice areas are decreased and, at the same time, the flow control area of the venturi valves are decreased so that the pressure drop across the valves balances out the difference between the engine inlet pressure and the injector inlet pressure. At approximately 70% of maximum thrust, cavitation commences in the venturi valve throats. From this level down to minimum thrust, cavitation continues in the venturis and the propellant flow is controlled by the throat area of the valves. Engine startup and shutdown is controlled through propellant shutoff valve solenoids.

In the ascent stage, the helium pressurization and propellant feed sections are functionally similar to those in the descent stage. Only two propellant tanks are used, however. Pressurization is obtained from two completely separate helium storage spheres that supply separate regulation branches. The two branches connect to a common manifold, and helium then flows through quad check valves and squib valves to each of the tanks. Propellant flow from the tanks then ruptures burst discs in the lines and passes through trim orifices to the engine valving.

The ascent engine is a 3400-pound-thrust, restartable rocket engine with an all ablative combustion chamber, throat, and nozzle extension. Fuel and oxidizer enter the engine through inlet lines located near the engine mount at the throat and then flow through quadruple shutoff valves at the head of the engine and finally into the injector. Each of the propellant lines divides to provide two flow paths to the injector and each flow path has two main propellant valves in series. These valves are on-off valves, with the upstream valve serving as an isolation valve; the bipropellant valve is downstream. Each valve assembly consists of a pair; one oxidizer and one fuel valve. They are controlled by hydraulic actuators that use fuel as the actuating medium. The application of pressure to the actuators is controlled through solenoid valves, with each pair of fuel and oxidizer valves being controlled by a single actuator. Valves in the parallel lines are thus opened and closed simultaneously at start and cutoff.

4.4.8 Reaction Control Subsystem

The LEM Reaction Control Subsystem (RCS) provides rocket thrust impulses that stabilize the vehicle during lunar descent and ascent and control the vehicle attitude and translation about or along all axes during hover, rendezvous, and docking maneuvers. The RCS consists of two separate and independent propellant feed sections, each with its own helium pressurization section, and 16 thrust chambers. The thrust chambers are mounted in clusters of four on outriggers arranged diametrically opposite and equally spaced around the vehicle ascent stage. In each cluster, two thrust chambers are mounted on a vertical axis, facing in opposite directions; the remaining two are 90 degrees apart, parallel to the vehicle's y and z axes. Two of the thrust chambers in each cluster are fed by one propellant feed section; the other two are fed by the other independent feed section. Normally, both sections are in simultaneous operation. Should one section fail, however, full control in all axes is still possible.

The propellant is a 50-50 mixture of hydrazine and unsymmetrical dimethylhydrazine, with nitrogen tetroxide as the oxidizer. The mixture ratio of oxidizer to fuel is 2 to 1, by weight.

Each propellant feed section has two cylindrical tanks, one for fuel and one for oxidizer. The propellants are stored in positive expulsion bladders that are supported by standpipes running lengthwise through each tank. Tanks are pressurized by a common supply of helium, which acts upon the bladders to force feed the propellants. The helium is sealed in a spherical tank by two parallel, explosively operated squib valves. Downstream of the squib valves, the helium passes through

a filter and the line splits into duplicate lines, each containing a two-stage pressure regulator. Only one regulator line is open at a time, however; should the normally open line malfunction, it can be shut off and the duplicate line opened. The helium line then splits into oxidizer tank and fuel tank pressurization lines, with a quadruple check valve in each. There is a relief valve near the helium inlet to each propellant tank to prevent system overpressurization if the pressure regulator assembly fails completely. Even with such failure, however, the relief pressure (approximately 250 psi) permits continued tank pressurization for normal operation of the RCS.

When the helium supply squib valves are fired for the initial RCS start, the propellant tanks are pressurized and a burst disk downstream of each tank ruptures as the propellant pressure reaches approximately 150 psi. The fuel and oxidizer from each feed section flow into a manifold that supplies eight of the 16 thrust chambers. Normally-open, solenoid shutoff valves in the outlet line of each propellant tank may be closed to isolate the feed section in the event of a malfunction. If one feed section must remain isolated, normally-closed squib valves in a crossfeed piping arrangement between the two manifolds may be fired to provide propellant flow from the other feed section to all 16 thrust chambers. In addition, there are normally-closed solenoid valves in the system piping between the RCS and the ascent propulsion tanks for the transfer of residual ascent engine propellant to the RCS, if necessary.

Each thrust chamber is a small rocket engine capable of either pulse mode or steady state operation, and produces 100 pounds of thrust. The engine consists basically of a combustion chamber and nozzle, an injector assembly, and fuel and oxidizer solenoid valves. Fuel and oxidizer are piped through the cores of the solenoid valves, the armatures of which are seated on the injector inlets to prevent flow to the combustion chamber. The "engine-on" signal energizes both solenoids simultaneously, lifting the armatures and permitting flow to the injector orifices. These orifices are arranged in two concentric circles on the face of the injector, and are drilled in doublets at angles to each other so that the emerging fuel and oxidizer streams impinge. Normally-open solenoid shutoff valves in the propellant manifolds just upstream of each thrust chamber may be closed to isolate the engines should the cluster malfunction or be damaged.

The RCS is initially fired for LEM separation from the Command/Service module and may be operated by the astronauts at any time thereafter. Either fully automatic

semiautomatic, or manual mode of operation may be used. In the fully automatic mode, control commands originate in the primary Navigation and Guidance Subsystem and follow a pre-programmed plan. Semiautomatic mode operation combines automatic attitude hold with manual control about each axis through the astronaut's hand controller. During lunar descent and ascent, use of the semiautomatic mode permits the astronaut to manually control the LEM attitude. In the full manual mode, all RCS control commands originate from the hand controller, including manual control of the duration of thrust. The RCS control commands are processed through a pulse modulator and jet logic network, which establishes which of the 16 thrust chambers are to be fired, when, and for how long. Outputs from the pulse modulator and jet logic network are timed voltage pulses that actuate the propellant solenoid valves on the appropriate thrust chamber.

4.4.9 Communication

The LEM Communications Subsystem provides voice communications, processes and transmits telemetry data and television signals, and aids in tracking and ranging. Voice communications provide LEM-earth contact, LEM-Command Module contact, LEM-man contact and intercom provisions for the crew members within the LEM. For LEM-earth communications, S-band is used; VHF is used for LEM-Command Module and LEM-man communications. The Subsystem components include: intercom set, VHF transceiver, S-band transceivers, telemetry, television and antennas. The Subsystem also includes a LEM-earth tracking and ranging link.

The LEM-earth communications link provides for transmission of voice, telemetry and television on S-band frequencies through an S-band transceiver, operating in conjunction with a premodulation processor (PMP) and audio centers. Only voice is received from earth; reception is obtained on S-band frequencies during line-of-sight phases of the mission.

Voice signals from the LEM crew are processed by the PMP and audio centers and are coupled to either the S-band transceiver of VHP transceiver (depending upon the mode of operation) for transmission to earth. An emergency code keying system is provided for transfer of priority information in the event of a voice transmission failure. Biomedical signals from the astronauts are also processed by the PMP before being transmitted to earth for monitoring.

Two-way voice communications between the LEM and the Command Module are accomplished through the

VHF channel during line-of-sight phases of the mission at distances up to 320 nautical miles. During non-line-of-sight phases, the S-band transceiver is used to extend the range of the LEM-Command Module voice link by using the earth station as a relay. A LEM-Command Module intercom is connected through an umbilical during docking phases.

Telemetry data originates in the Operational and Instrumentation Subsystem and is processed by the pulse code modulator before being transmitted by the S-band transceiver to earth.

Television data is provided by a portable TV camera that is carried in the Command Module from launch to lunar orbit. During lunar orbit, the camera is transferred to the LEM and stowed until landing, after which it is connected by means of an umbilical, carried from the LEM, and used to televise the lunar terrain. The television signals are processed by the PMP and transmitted via the S-band transceiver to earth.

The LEM-man communications link utilizes a VHF radio link between the LEM and the roving astronaut on the lunar surface. This channel also transmits information concerning the physiological functions of the astronaut and the operation of his Portable Life Support System while he is on foot exploration. This information is monitored by the remaining astronaut in the LEM and is also transmitted via the S-band to earth monitors. Voice reception is made on VHF at distances up to three nautical miles. While the television camera is being used outside the LEM, an alternate voice channel is provided through the camera umbilical. A closed-circuit intercom system provides the voice communications link when both astronauts are aboard the LEM.

The LEM-earth tracking and ranging link provides the LEM with the capability to receive and re-transmit a random noise coded signal to enable earth observation stations to track the LEM during deep space phases of the mission.

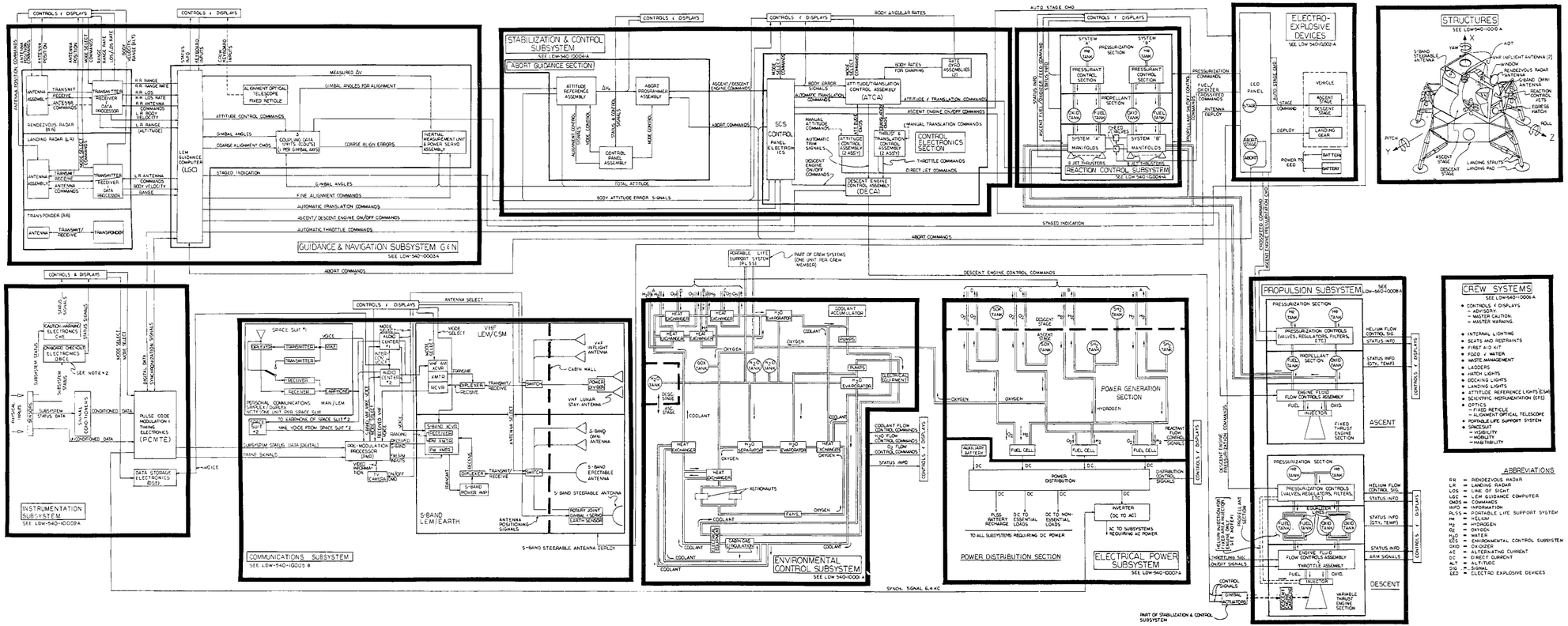


Figure 4-1. LEM Functional Diagram

SECTION 5
PHASING CHARTS

The charts contained herein reflect CCA's 28, 34, 38, 39, 43, 45, 46, 47 and 48.

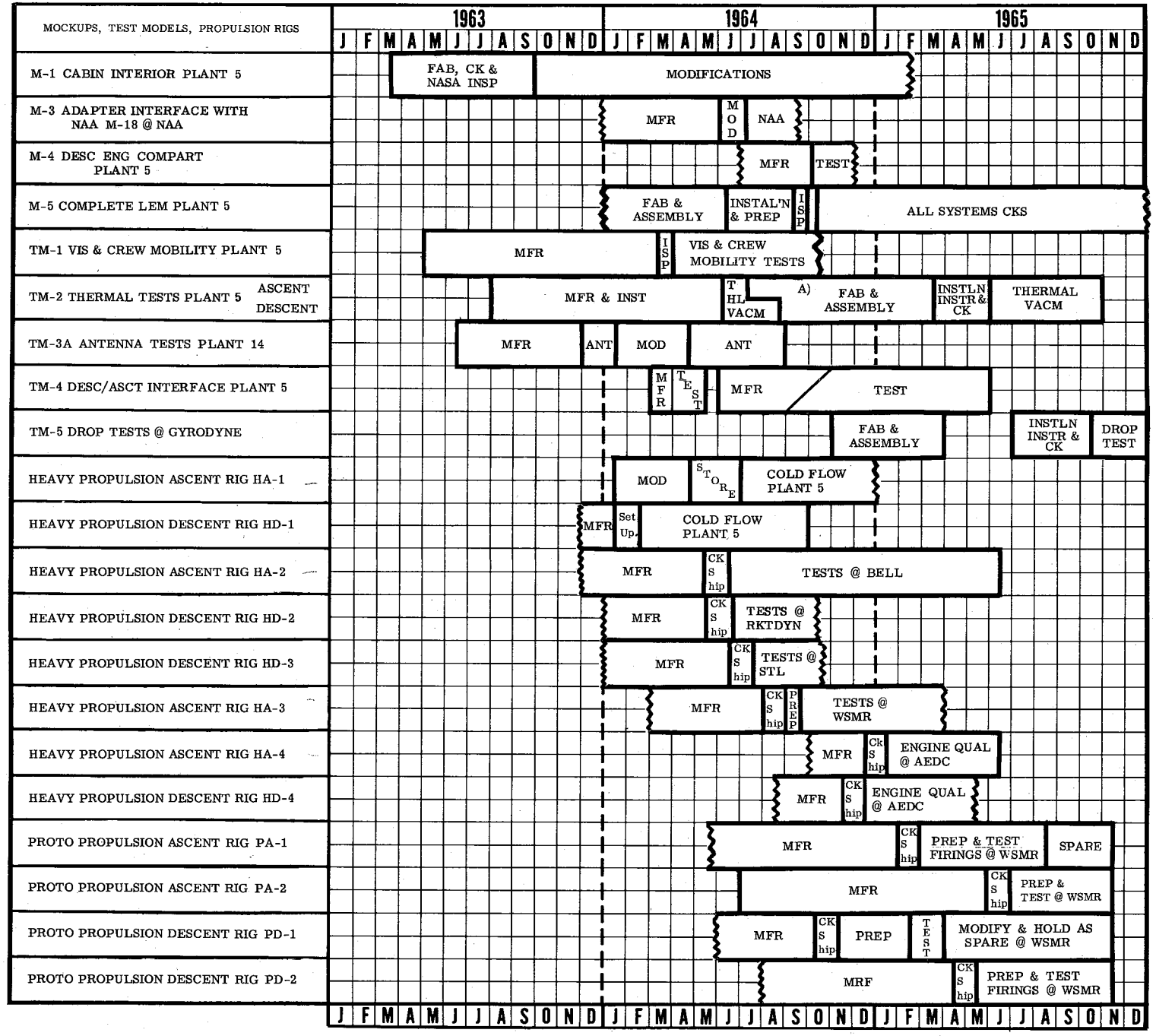
The subsystem phasing charts show scheduled dates of equipment availability for installation. Some installations constitute only those portions of the subsystem which are required for the test or mission assigned.

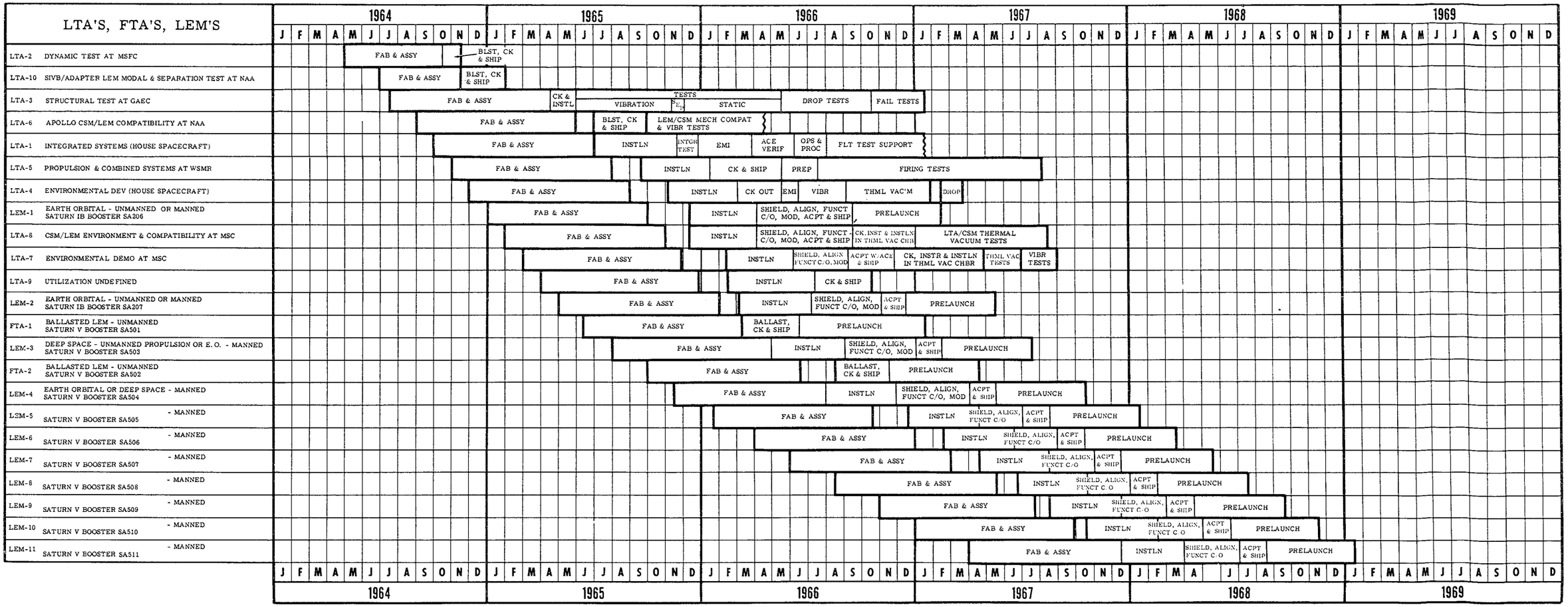
The model classifications listed on the charts are based on the subsystem section/s with the lowest classification planned for installation in that particular vehicle.

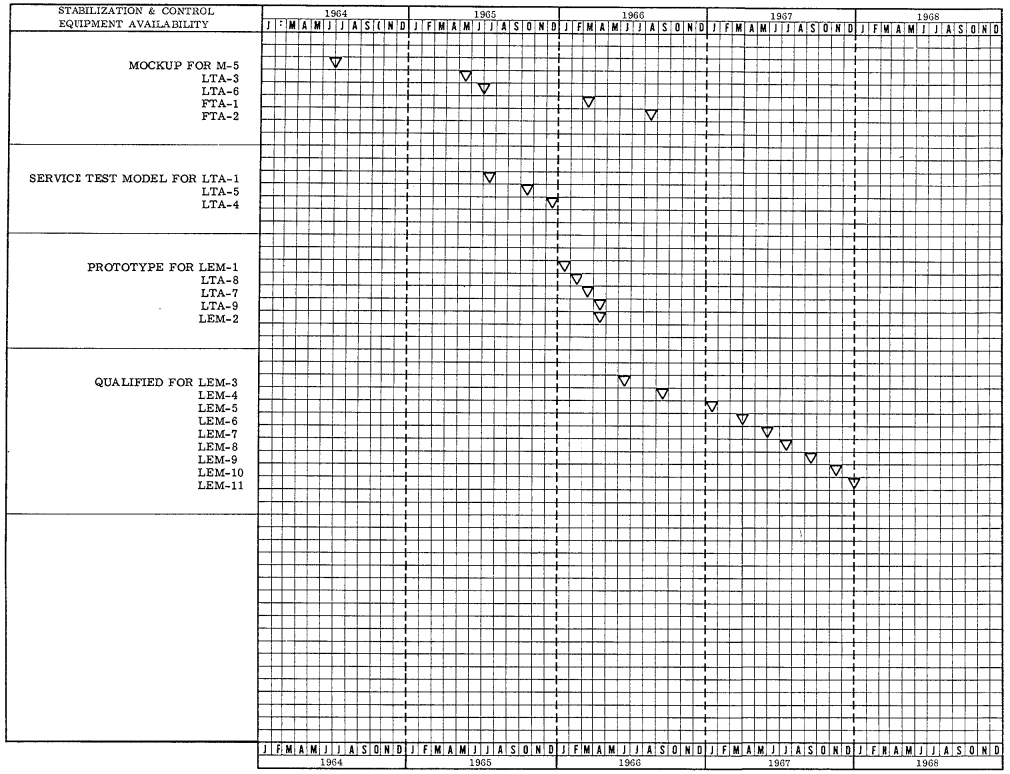
Model classifications are defined as follows:

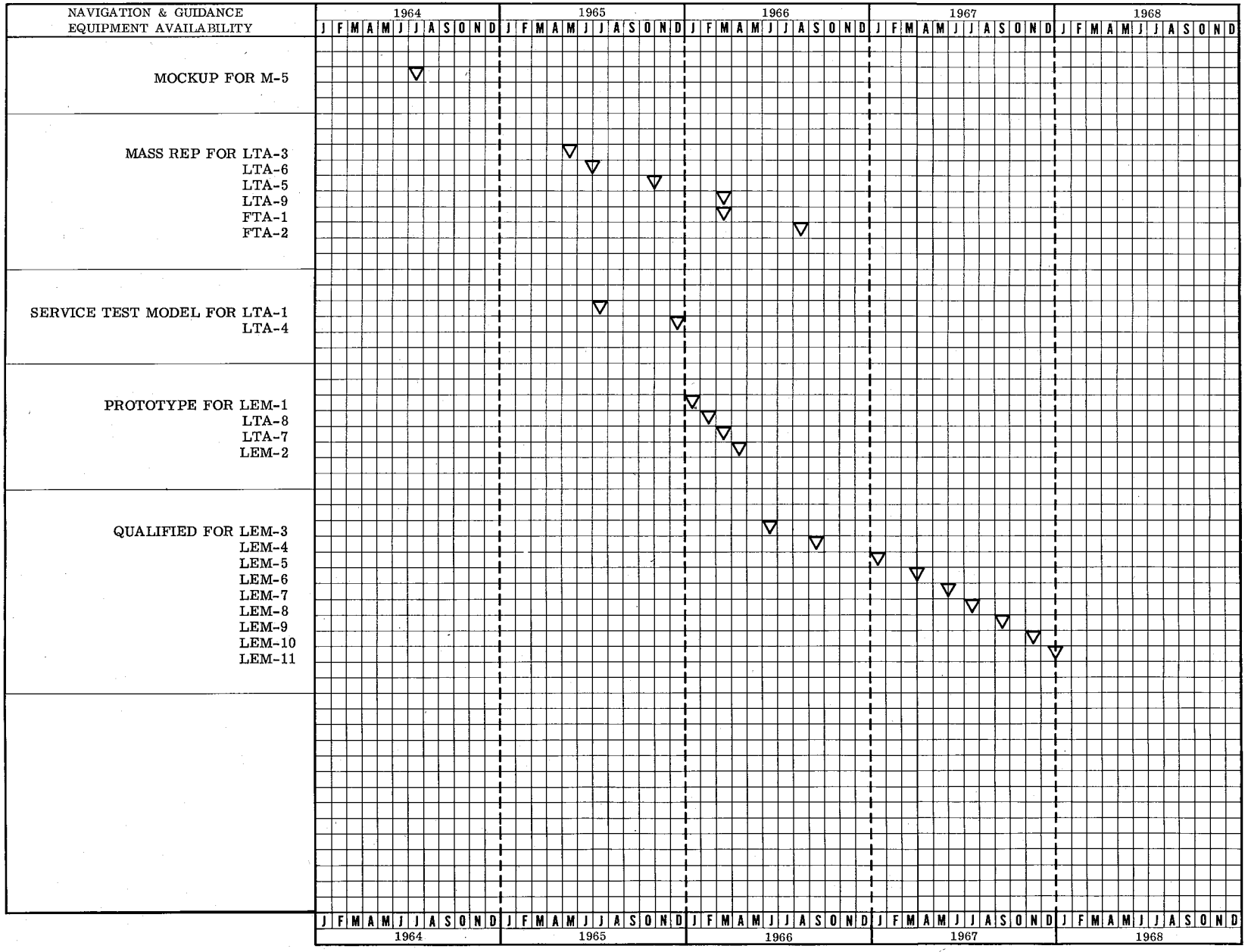
- Mass Representation - The installation has the correct mass, c.g. and moment of inertia.
- Experimental Model - This is a model of the complete equipment constructed to demonstrate the technical soundness of the selected design. This model need not have the required final form factor or contain approved parts.
- Service Test Model - This is a model designed to meet the performance requirements of the specification. This model employs approved parts or their interchangeable equivalents. It should approach the required final form factor and weight It may be used to demonstrate the reproducibility of the equipment design.
- Prototype Model - This is a flightweight model suitable for complete evaluation of all physical and functional characteristics. It is of final structure, form, employs approved parts, and is fabricated with approved tooling and processes. This is the model which is subjected to LEM qualification tests.
- Qualified Model - This is the final flightweight model employing approved parts and fabricated with approved tooling and processes. It shall be identical to the prototype model which has successfully completed its LEM qualification tests.

The GSE phasing charts show scheduled dates of the equipment operational availability. Where more than one unit is needed, only the first date is shown. Dates at WSMR are based on an ambient stand firing scheduled for November 1964. Dates at AMR reflect the shipment of LEM-1; assignment of GSE to individual sites at AMR will determine later schedule dates.


MOCKUPS, TEST MODELS, PROPULSION RIGS
1963
1964
1965
J F M A M J J A S O N D
M-1 CABIN INTERIOR PLANT 5
FAB, CK & NASA INSP
MODIFICATIONS
M-3 ADAPTER INTERFACE WITH NAA M-18 @ NAA
MFR
MOD
NAA
M-4 DESC ENG COMPART PLANT 5
MFR
TEST
M-5 COMPLETE LEM PLANT 5
FAB & ASSEMBLY
INSTAL'N & PREP
ISP
ALL SYSTEMS CKS
TM-1 VIS & CREW MOBILITY PLANT 5
MFR
ISP
VIS & CREW MOBILITY TESTS
TM-2 THERMAL TESTS PLANT 5
ASCENT
DESCENT
MFR & INST
THL VACM
A)
FAB & ASSEMBLY
INSTLN INSTR & CK
THERMAL VACM
TM-3A ANTENNA TESTS PLANT 14
MFR
ANT
MOD
ANT
TM-4 DESC/ASCT INTERFACE PLANT 5
MFR
TEST
MFR
TEST
TM-5 DROP TESTS @ GYRODYNE
FAB & ASSEMBLY
INSTLN INSTR & CK
DROP TEST
HEAVY PROPULSION ASCENT RIG HA-1
MOD
STORE
COLD FLOW PLANT 5
HEAVY PROPULSION DESCENT RIG HD-1
MFR
Set Up
COLD FLOW PLANT 5
HEAVY PROPULSION ASCENT RIG HA-2
MFR
CK S hip
TESTS @ BELL
HEAVY PROPULSION DESCENT RIG HD-2
MFR
CK S hip
TESTS @ RKTDYN
HEAVY PROPULSION DESCENT RIG HD-3
MFR
CK S hip
TESTS @ STL
HEAVY PROPULSION ASCENT RIG HA-3
MFR
CK S hip
PREP
TESTS @ WSMR
HEAVY PROPULSION ASCENT RIG HA-4
MFR
CK S hip
ENGINE QUAL @ AEDC
HEAVY PROPULSION DESCENT RIG HD-4
MFR
CK S hip
ENGINE QUAL @ AEDC
PROTO PROPULSION ASCENT RIG PA-1
MFR
CK S hip
PREP & TEST FIRINGS @ WSMR
SPARE
PROTO PROPULSION ASCENT RIG PA-2
MFR
CK S hip
PREP & TEST @ WSMR
PROTO PROPULSION DESCENT RIG PD-1
MFR
CK S hip
PREP
TEST
MODIFY & HOLD AS SPARE @ WSMR
PROTO PROPULSION DESCENT RIG PD-2
MRF
CK S hip
PREP & TEST FIRINGS @ WSMR


LTA'S, FTA'S, LEM'S
1964
1965
1966
1967
1968
1969
J F M A M J J A S O N D
LTA-2 DYNAMIC TEST AT MSFC
FAB & ASSY
BLST, CK & SHIP
LTA-10 SIVB/ADAPTER LEM MODAL & SEPARATION TEST AT NAA
FAB & ASSY
BLST, CK & SHIP
LTA-3 STRUCTURAL TEST AT GAEC
FAB & ASSY
CK & INSTL
TESTS
VIBRATION
STATIC
DROP TESTS
FAIL TESTS
LTA-6 APOLLO CSM/LEM COMPATIBILITY AT NAA
FAB & ASSY
BLST, CK & SHIP
LEM/CSM MECH COMPAT & VIBR TESTS
LTA-1 INTEGRATED SYSTEMS (HOUSE SPACECRAFT)
FAB & ASSY
INSTLN
EMI
ACE VERIF
OPS & PROC
FLT TEST SUPPORT
LTA-5 PROPULSION & COMBINED SYSTEMS AT WSMR
FAB & ASSY
INSTLN
CK & SHIP
PREP
FIRING TESTS
LTA-4 ENVIRONMENTAL DEV (HOUSE SPACECRAFT)
FAB & ASSY
INSTLN
CK OUT
EMI
VIBR
THML VAC'M
DROP
LEM-1 EARTH ORBITAL - UNMANNED OR MANNED SATURN IB BOOSTER SA206
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C/O, MOD, ACPT & SHIP
PRELAUNCH
LTA-8 CSM/LEM ENVIRONMENT & COMPATIBILITY AT MSC
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT - C/O, MOD, ACPT & SHIP
CK, INST & INSTLN IN THML VAC CHB
LTA/CSM THERMAL VACUUM TESTS
LTA-7 ENVIRONMENTAL DEMO AT MSC
FAB & ASSY
INSTLN
SHIELD, ALIGN FUNCT C/O, MOD
ACPT W/ACE & SHIP
CK, INSTR & INSTLN IN THML VAC CHBR
THML VAC TESTS
VIBR TESTS
LTA-9 UTILIZATION UNDEFINED
FAB & ASSY
INSTLN
CK & SHIP
LEM-2 EARTH ORBITAL - UNMANNED OR MANNED SATURN IB BOOSTER SA207
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C/O, MOD
ACPT & SHIP
PRELAUNCH
FTA-1 BALLASTED LEM - UNMANNED SATURN V BOOSTER SA501
FAB & ASSY
BALLAST, CK & SHIP
PRELAUNCH
LEM-3 DEEP SPACE - UNMANNED PROPULSION OR E. O. - MANNED SATURN V BOOSTER SA503
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C/O, MOD
ACPT & SHIP
PRELAUNCH
FTA-2 BALLASTED LEM - UNMANNED SATURN V BOOSTER SA502
FAB & ASSY
BALLAST, CK & SHIP
PRELAUNCH
LEM-4 EARTH ORBITAL OR DEEP SPACE - MANNED SATURN V BOOSTER SA504
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C/O, MOD
ACPT & SHIP
PRELAUNCH
LEM-5 SATURN V BOOSTER SA505 - MANNED
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C/O
ACPT & SHIP
PRELAUNCH
LEM-6 SATURN V BOOSTER SA506 - MANNED
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C/O
ACPT & SHIP
PRELAUNCH
LEM-7 SATURN V BOOSTER SA507 - MANNED
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C/O
ACPT & SHIP
PRELAUNCH
LEM-8 SATURN V BOOSTER SA508 - MANNED
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C O
ACPT & SHIP
PRELAUNCH
LEM-9 SATURN V BOOSTER SA509 - MANNED
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C O
ACPT & SHIP
PRELAUNCH
LEM-10 SATURN V BOOSTER SA510 - MANNED
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C O
ACPT & SHIP
PRELAUNCH
LEM-11 SATURN V BOOSTER SA511 - MANNED
FAB & ASSY
INSTLN
SHIELD, ALIGN, FUNCT C O
ACPT & SHIP
PRELAUNCH


STABILIZATION & CONTROL EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MOCKUP FOR M-5
LTA-3
LTA-6
FTA-1
FTA-2
SERVICE TEST MODEL FOR LTA-1
LTA-5
LTA-4
PROTOTYPE FOR LEM-1
LTA-8
LTA-7
LTA-9
LEM-2
QUALIFIED FOR LEM-3
LEM-4
LEM-5
LEM-6
LEM-7
LEM-8
LEM-9
LEM-10
LEM-11


NAVIGATION & GUIDANCE EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MOCKUP FOR M-5
MASS REP FOR LTA-3
LTA-6
LTA-5
LTA-9
FTA-1
FTA-2
SERVICE TEST MODEL FOR LTA-1
LTA-4
PROTOTYPE FOR LEM-1
LTA-8
LTA-7
LEM-2
QUALIFIED FOR LEM-3
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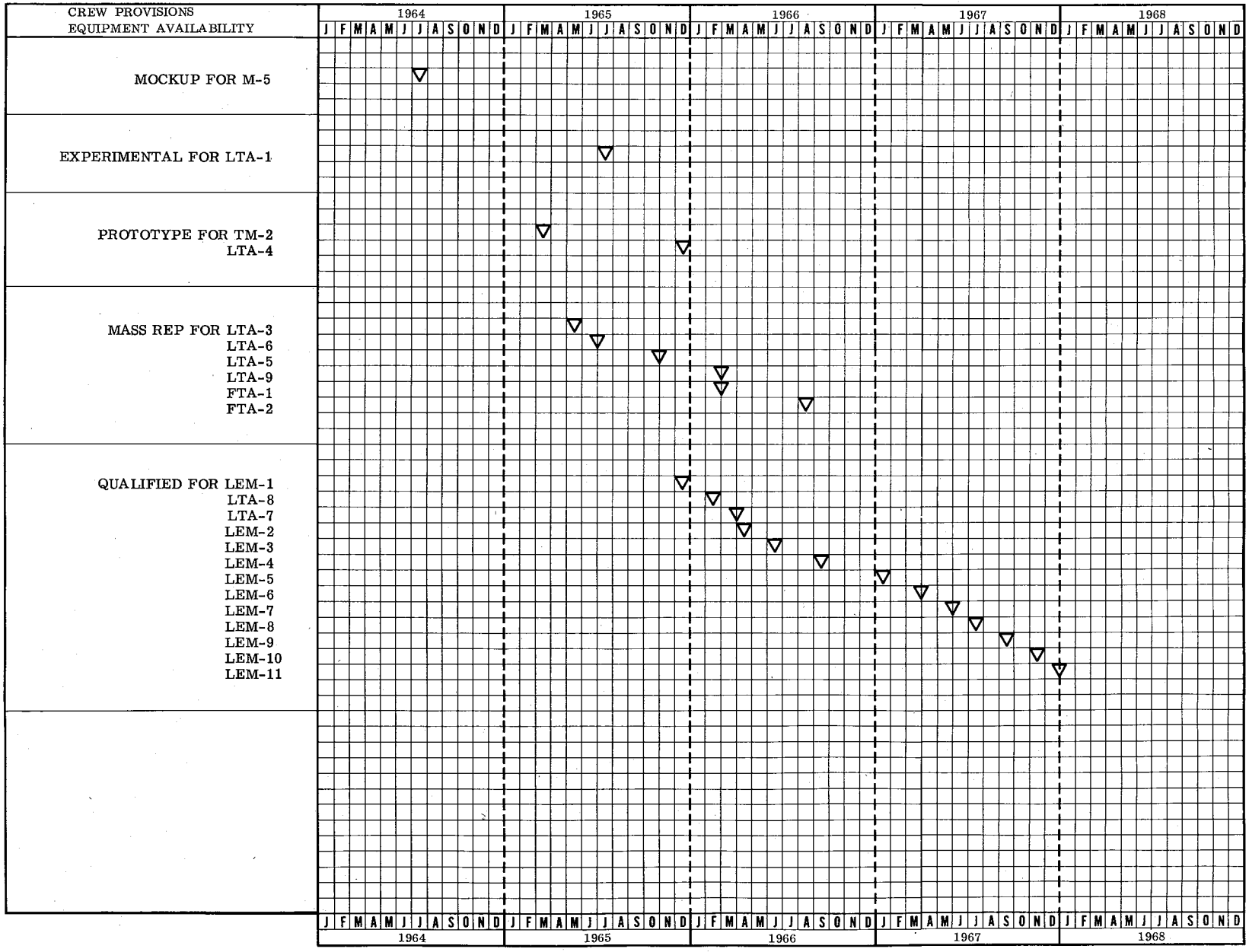
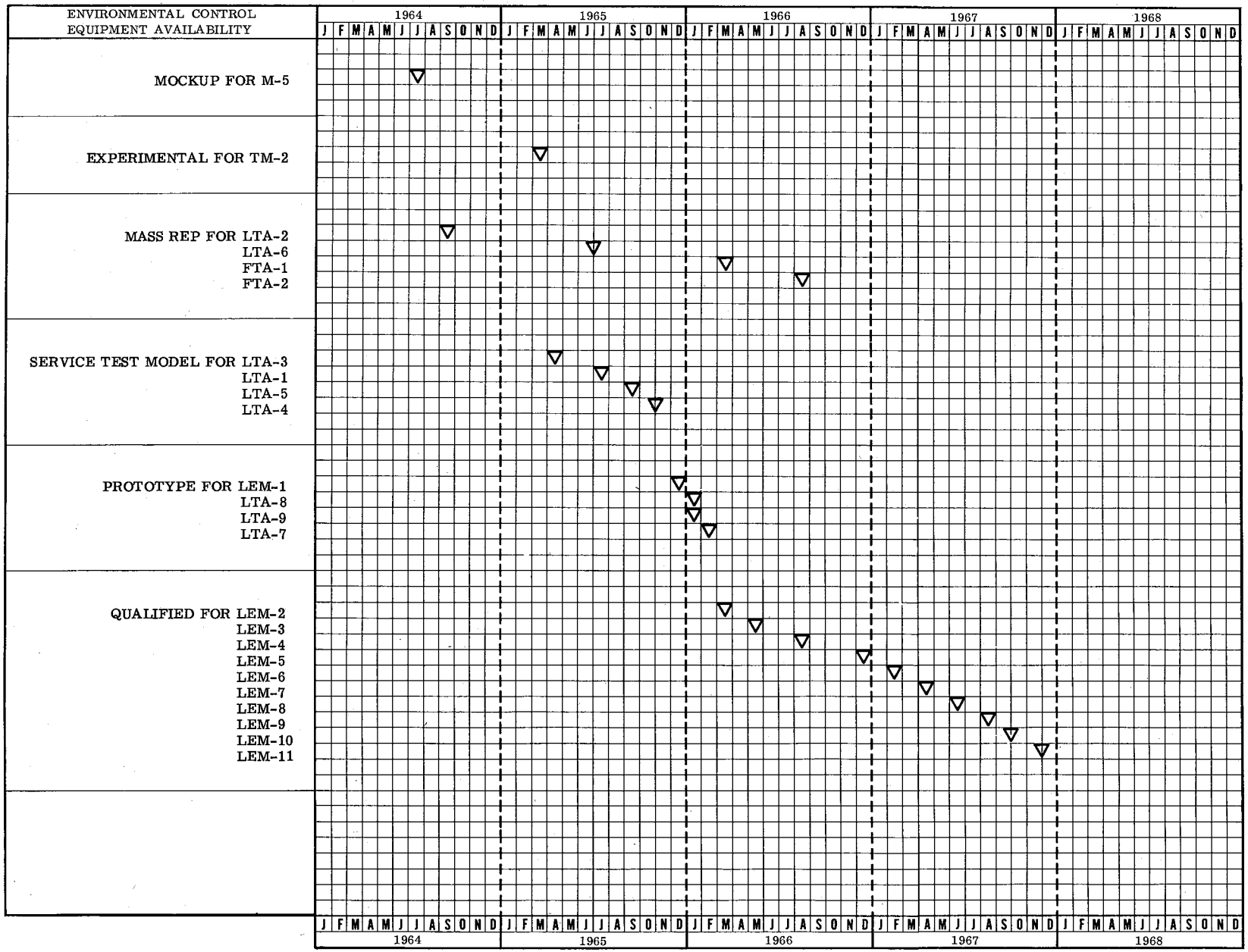
LEM-9
LEM-10
LEM-11


CREW PROVISIONS
EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MOCKUP FOR M-5
EXPERIMENTAL FOR LTA-1
PROTOTYPE FOR TM-2
LTA-4
MASS REP FOR LTA-3
LTA-6
LTA-5
LTA-9
FTA-1
FTA-2
QUALIFIED FOR LEM-1
LTA-8
LTA-7
LEM-2
LEM-3
LEM-4
LEM-5
LEM-6
LEM-7
LEM-8
LEM-9
LEM-10
LEM-11


ENVIRONMENTAL CONTROL EQUIPMENT AVAILABILITY
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1965
1966
1967
1968
J F M A M J J A S O N D
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EXPERIMENTAL FOR TM-2
MASS REP FOR LTA-2
LTA-6
FTA-1
FTA-2
SERVICE TEST MODEL FOR LTA-3
LTA-1
LTA-5
LTA-4
PROTOTYPE FOR LEM-1
LTA-8
LTA-9
LTA-7
QUALIFIED FOR LEM-2
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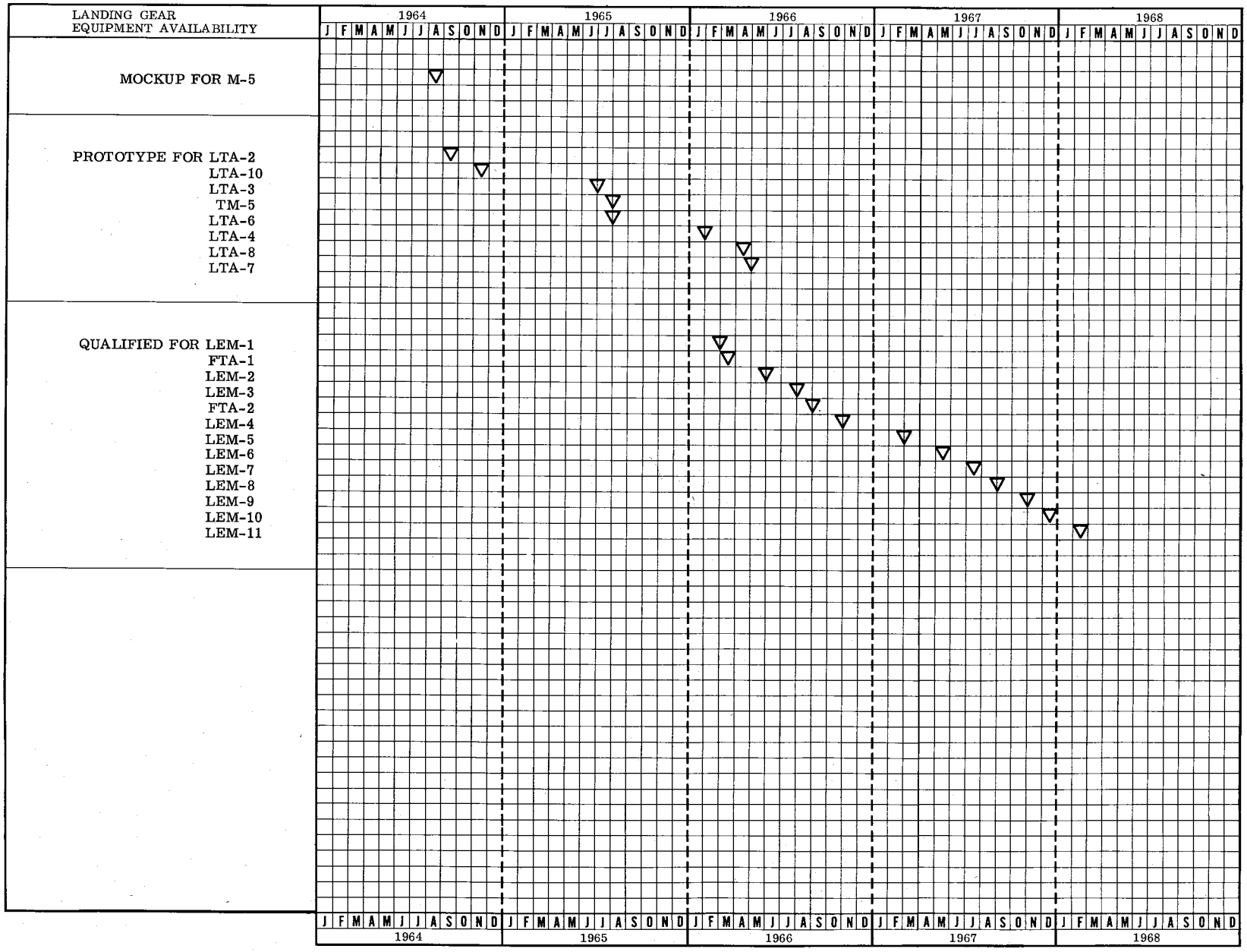
LEM-9
LEM-10
LEM-11


LANDING GEAR
EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MOCKUP FOR M-5
PROTOTYPE FOR LTA-2
LTA-10
LTA-3
TM-5
LTA-6
LTA-4
LTA-8
LTA-7
QUALIFIED FOR LEM-1
FTA-1
LEM-2
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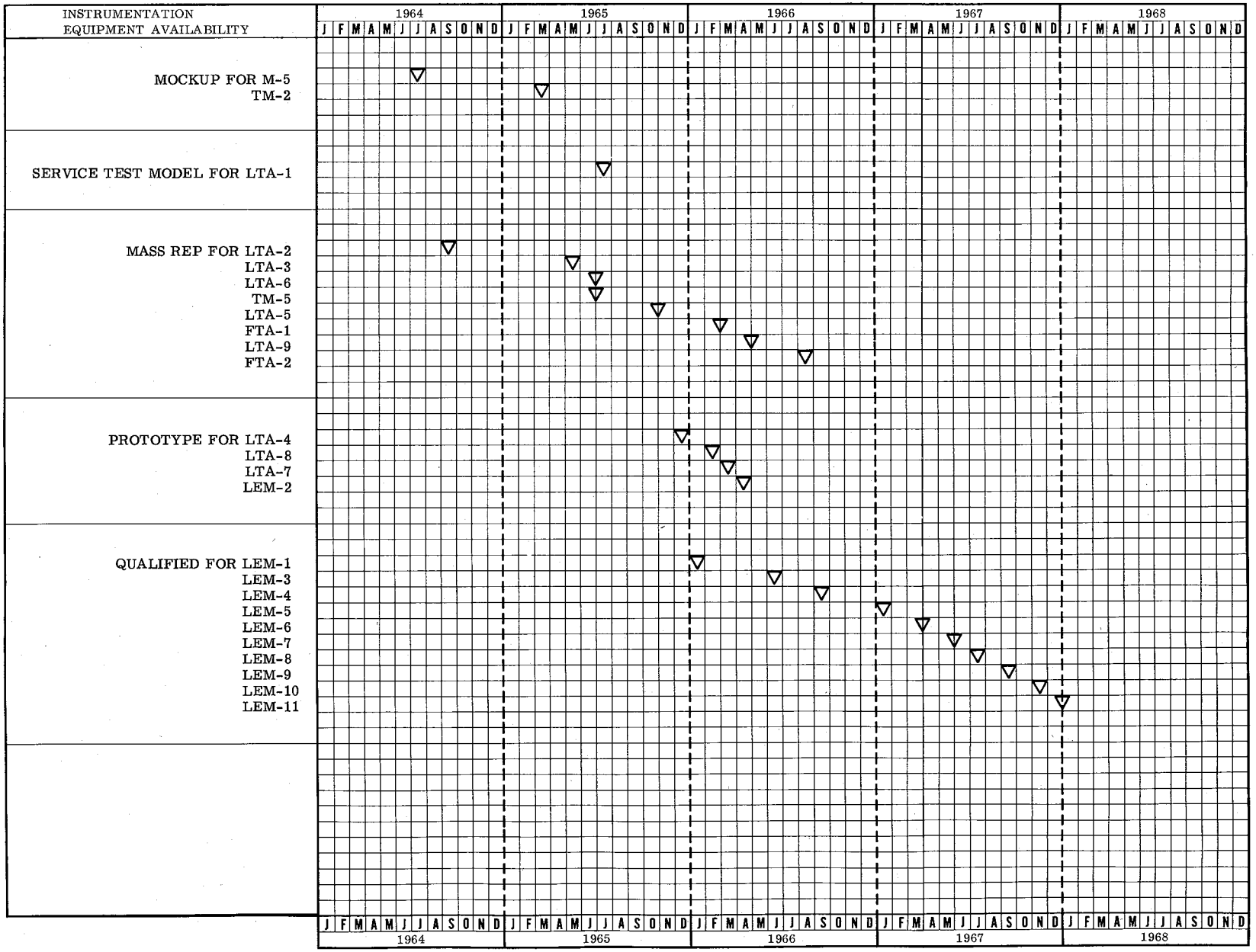
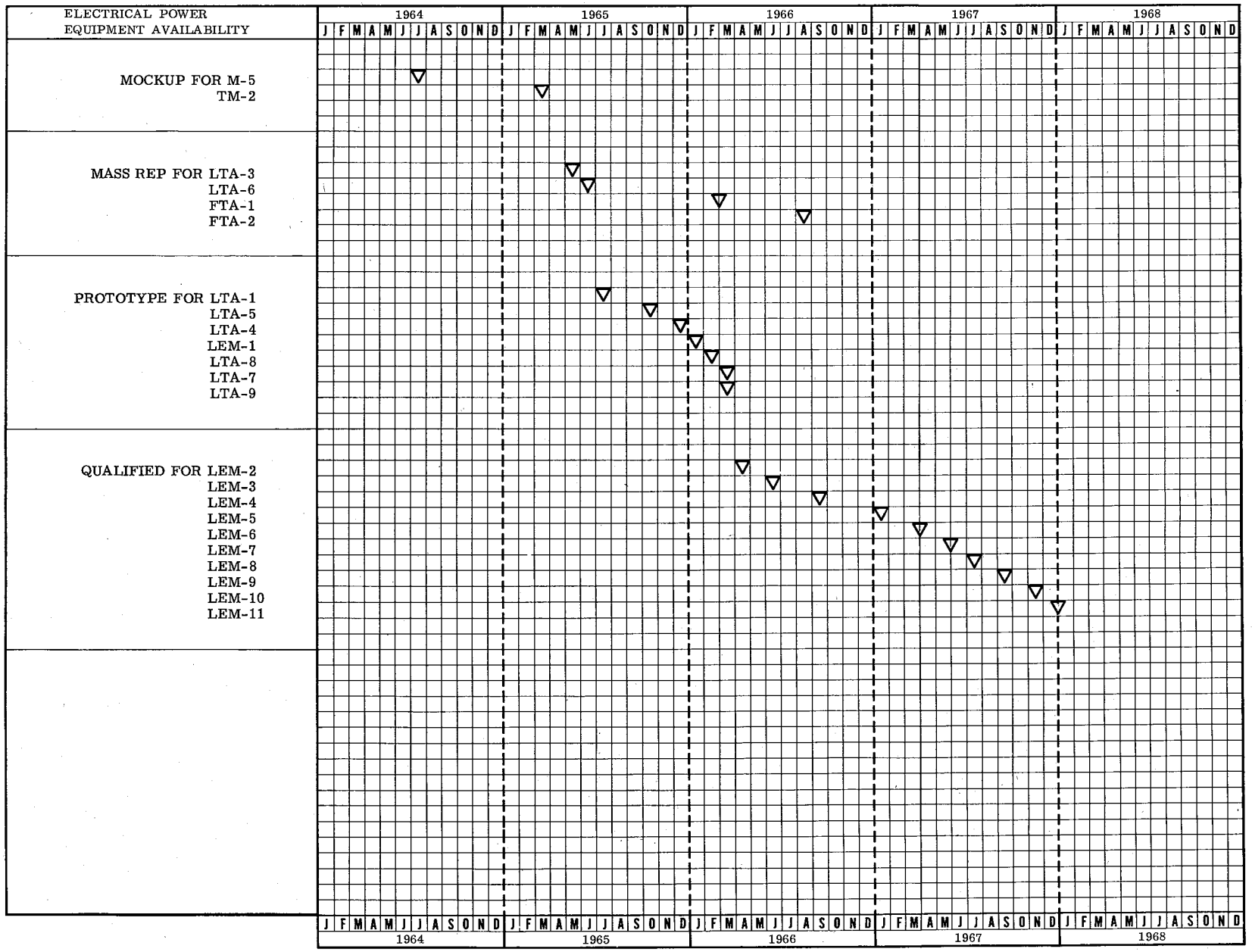
LEM-9
LEM-10
LEM-11


INSTRUMENTATION
EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MOCKUP FOR M-5
TM-2
SERVICE TEST MODEL FOR LTA-1
MASS REP FOR LTA-2
LTA-3
LTA-6
TM-5
LTA-5
FTA-1
LTA-9
FTA-2
PROTOTYPE FOR LTA-4
LTA-8
LTA-7
LEM-2
QUALIFIED FOR LEM-1
LEM-3
LEM-4
LEM-5
LEM-6
LEM-7
LEM-8
LEM-9
LEM-10
LEM-11


ELECTRICAL POWER
EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MOCKUP FOR M-5
TM-2
MASS REP FOR LTA-3
LTA-6
FTA-1
FTA-2
PROTOTYPE FOR LTA-1
LTA-5
LTA-4
LEM-1
LTA-8
LTA-7
LTA-9
QUALIFIED FOR LEM-2
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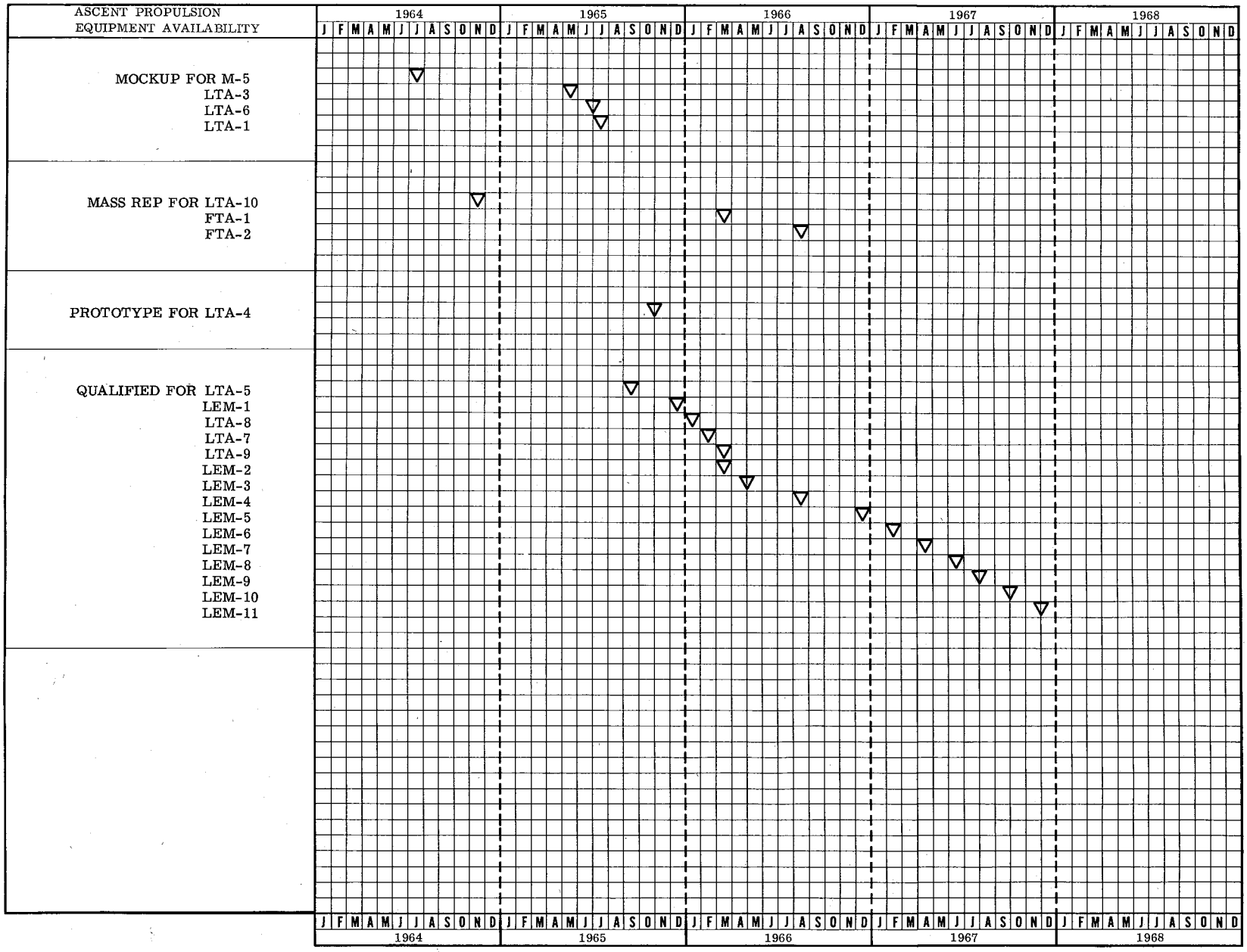
LEM-9
LEM-10
LEM-11


ASCENT PROPULSION
EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MOCKUP FOR M-5
LTA-3
LTA-6
LTA-1
MASS REP FOR LTA-10
FTA-1
FTA-2
PROTOTYPE FOR LTA-4
QUALIFIED FOR LTA-5
LEM-1
LTA-8
LTA-7
LTA-9
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LEM-4
LEM-5
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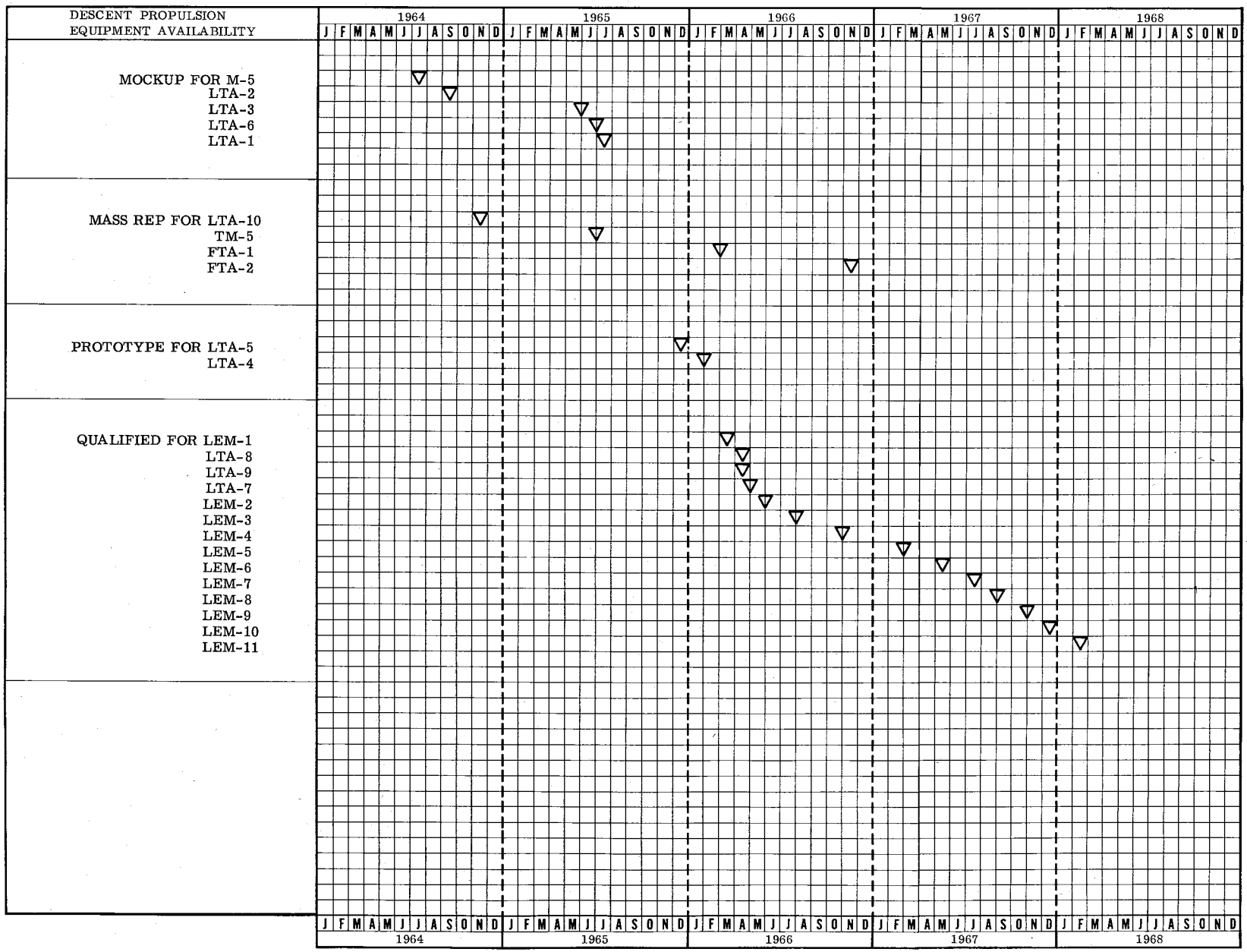
LEM-7
LEM-8
LEM-9
LEM-10
LEM-11


DESCENT PROPULSION
EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MOCKUP FOR M-5
LTA-2
LTA-3
LTA-6
LTA-1
MASS REP FOR LTA-10
TM-5
FTA-1
FTA-2
PROTOTYPE FOR LTA-5
LTA-4
QUALIFIED FOR LEM-1
LTA-8
LTA-9
LTA-7
LEM-2
LEM-3
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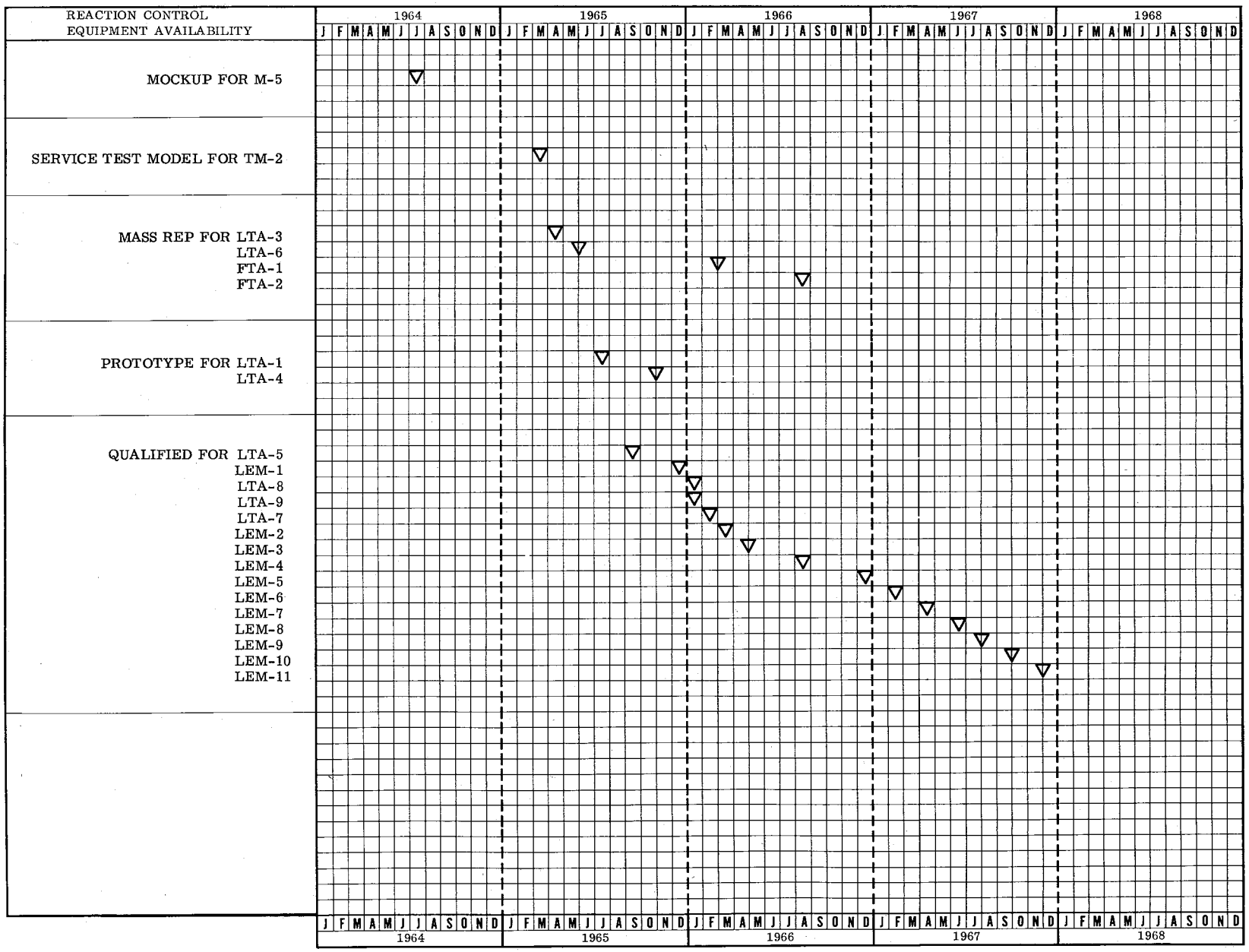
LEM-9
LEM-10
LEM-11


REACTION CONTROL
EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MOCKUP FOR M-5
SERVICE TEST MODEL FOR TM-2
MASS REP FOR LTA-3
LTA-6
FTA-1
FTA-2
PROTOTYPE FOR LTA-1
LTA-4
QUALIFIED FOR LTA-5
LEM-1
LTA-8
LTA-9
LTA-7
LEM-2
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LEM-4
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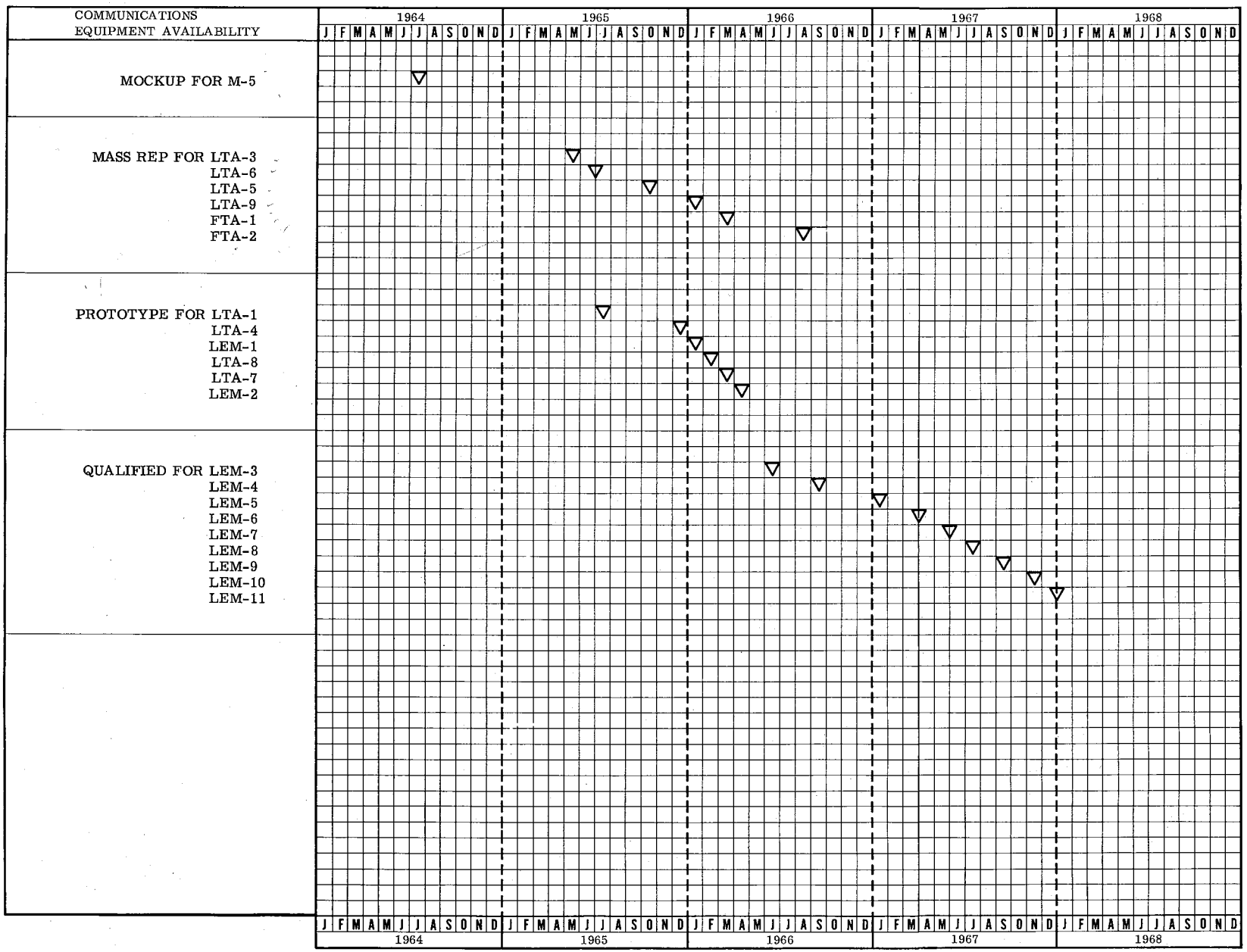
LEM-9
LEM-10
LEM-11


COMMUNICATIONS EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MOCKUP FOR M-5
MASS REP FOR LTA-3
LTA-6
LTA-5
LTA-9
FTA-1
FTA-2
PROTOTYPE FOR LTA-1
LTA-4
LEM-1
LTA-8
LTA-7
LEM-2
QUALIFIED FOR LEM-3
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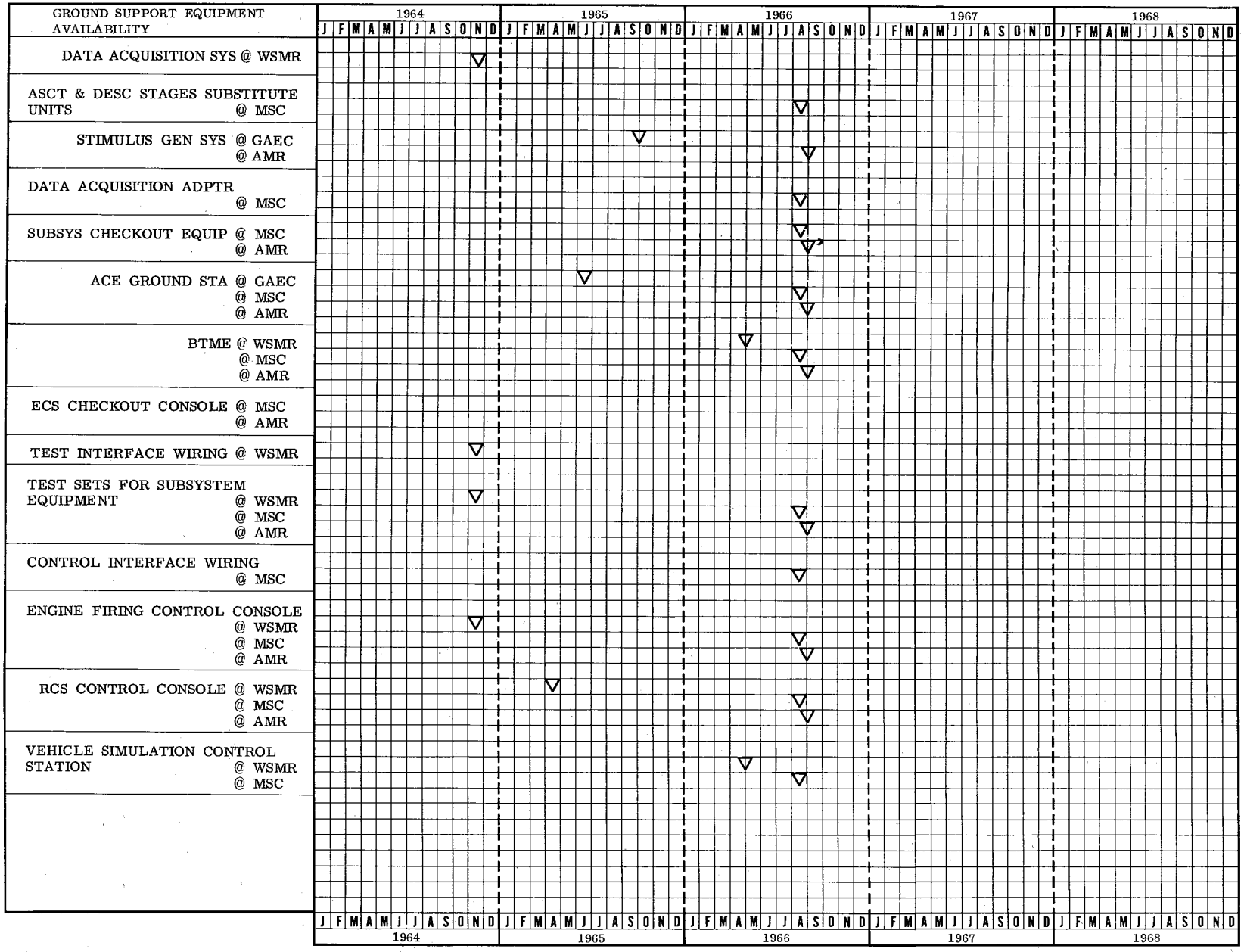
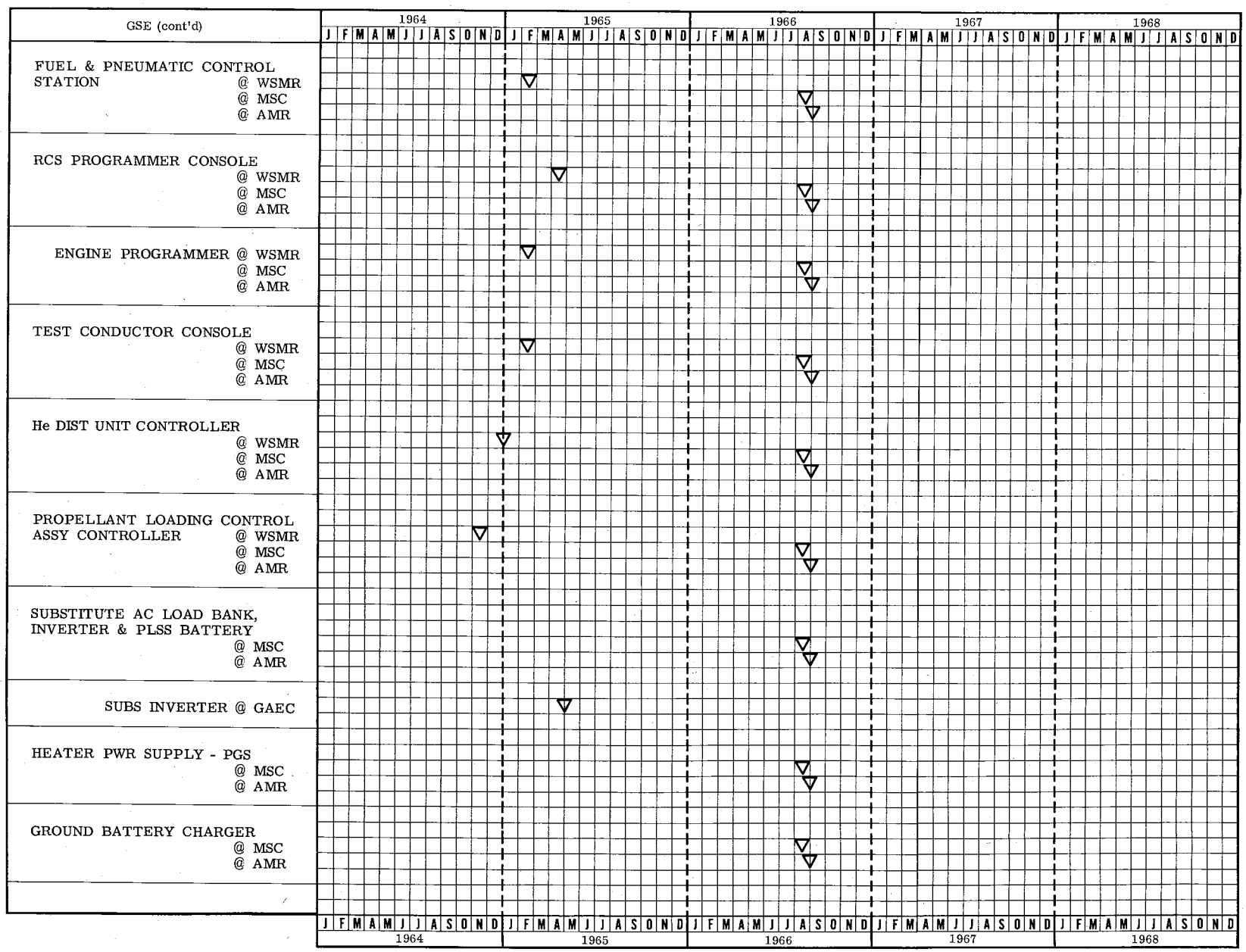
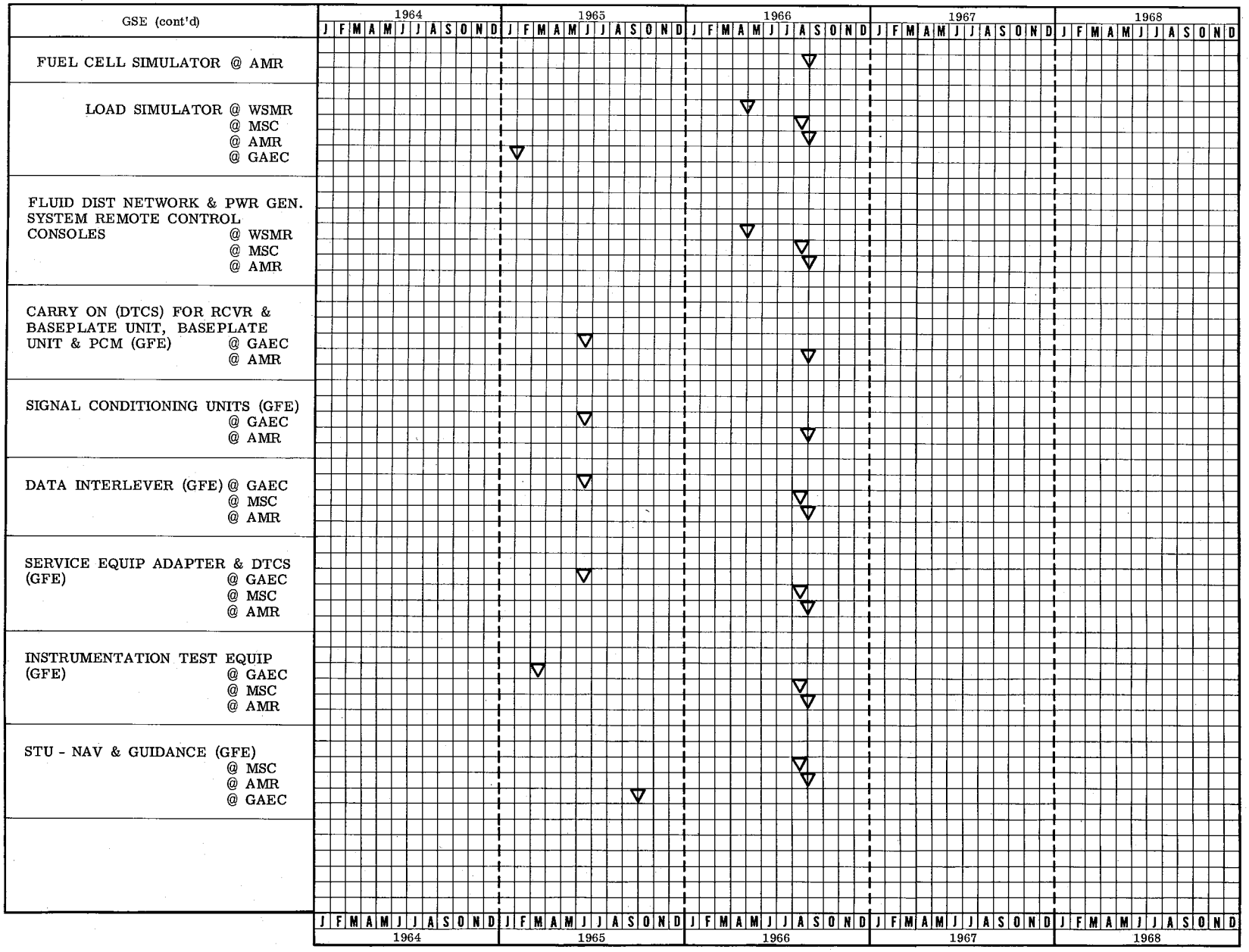
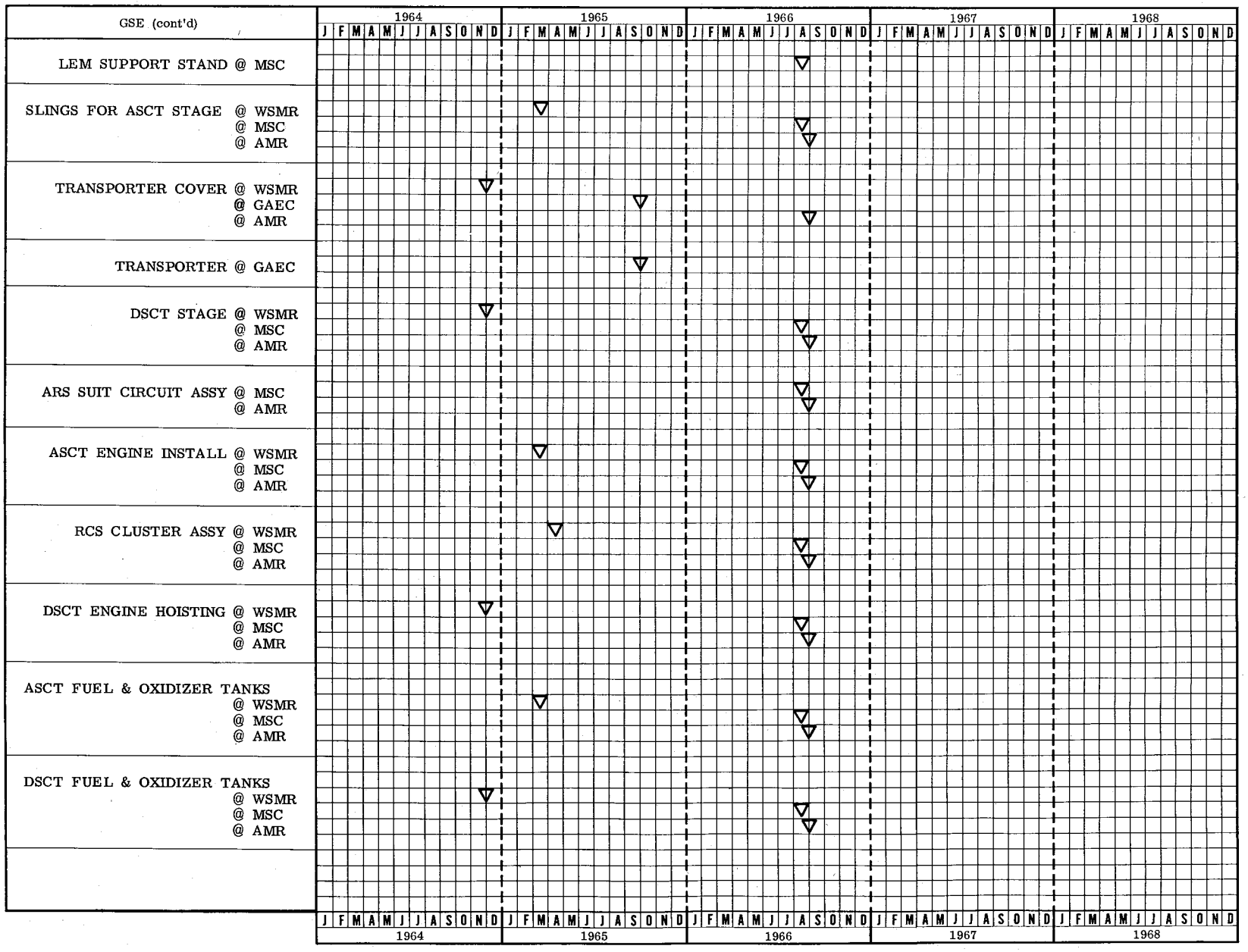
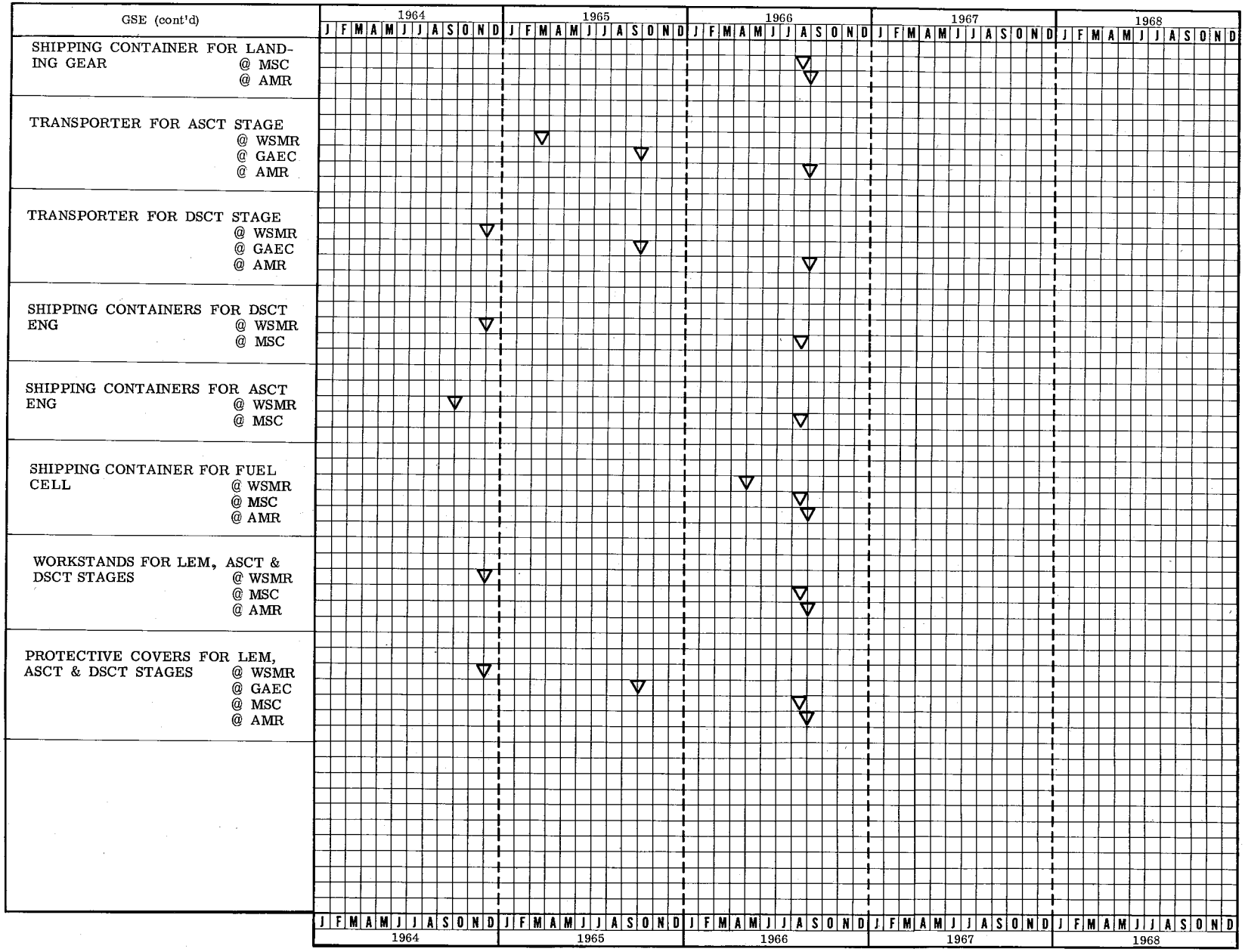
LEM-9
LEM-10
LEM-11


GROUND SUPPORT EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
DATA ACQUISITION SYS @ WSMR
ASCT & DESC STAGES SUBSTITUTE UNITS @ MSC
STIMULUS GEN SYS @ GAEC
@ AMR
DATA ACQUISITION ADPTR @ MSC
SUBSYS CHECKOUT EQUIP @ MSC
@ AMR
ACE GROUND STA @ GAEC
@ MSC
@ AMR
BTME @ WSMR
@ MSC
@ AMR
ECS CHECKOUT CONSOLE @ MSC
@ AMR
TEST INTERFACE WIRING @ WSMR
TEST SETS FOR SUBSYSTEM EQUIPMENT @ WSMR
@ MSC
@ AMR
CONTROL INTERFACE WIRING @ MSC
ENGINE FIRING CONTROL CONSOLE @ WSMR
@ MSC
@ AMR
RCS CONTROL CONSOLE @ WSMR
@ MSC
@ AMR
VEHICLE SIMULATION CONTROL STATION @ WSMR
@ MSC


GSE (cont'd)
1964
1965
1966
1967
1968
J F M A M J J A S O N D
FUEL & PNEUMATIC CONTROL STATION @ WSMR @ MSC @ AMR
RCS PROGRAMMER CONSOLE @ WSMR @ MSC @ AMR
ENGINE PROGRAMMER @ WSMR @ MSC @ AMR
TEST CONDUCTOR CONSOLE @ WSMR @ MSC @ AMR
He DIST UNIT CONTROLLER @ WSMR @ MSC @ AMR
PROPELLANT LOADING CONTROL ASSY CONTROLLER @ WSMR @ MSC @ AMR
SUBSTITUTE AC LOAD BANK, INVERTER & PLSS BATTERY @ MSC @ AMR
SUBS INVERTER @ GAEC
HEATER PWR SUPPLY - PGS @ MSC @ AMR
GROUND BATTERY CHARGER @ MSC @ AMR


GSE (cont'd)
1964
1965
1966
1967
1968
J F M A M J J A S O N D
FUEL CELL SIMULATOR @ AMR
LOAD SIMULATOR @ WSMR
@ MSC
@ AMR
@ GAEC
FLUID DIST NETWORK & PWR GEN. SYSTEM REMOTE CONTROL CONSOLES @ WSMR
@ MSC
@ AMR
CARRY ON (DTCS) FOR RCVR & BASEPLATE UNIT, BASEPLATE UNIT & PCM (GFE) @ GAEC
@ AMR
SIGNAL CONDITIONING UNITS (GFE)
@ GAEC
@ AMR
DATA INTERLEVER (GFE) @ GAEC
@ MSC
@ AMR
SERVICE EQUIP ADAPTER & DTCS (GFE) @ GAEC
@ MSC
@ AMR
INSTRUMENTATION TEST EQUIP (GFE) @ GAEC
@ MSC
@ AMR
STU - NAV & GUIDANCE (GFE)
@ MSC
@ AMR
@ GAEC

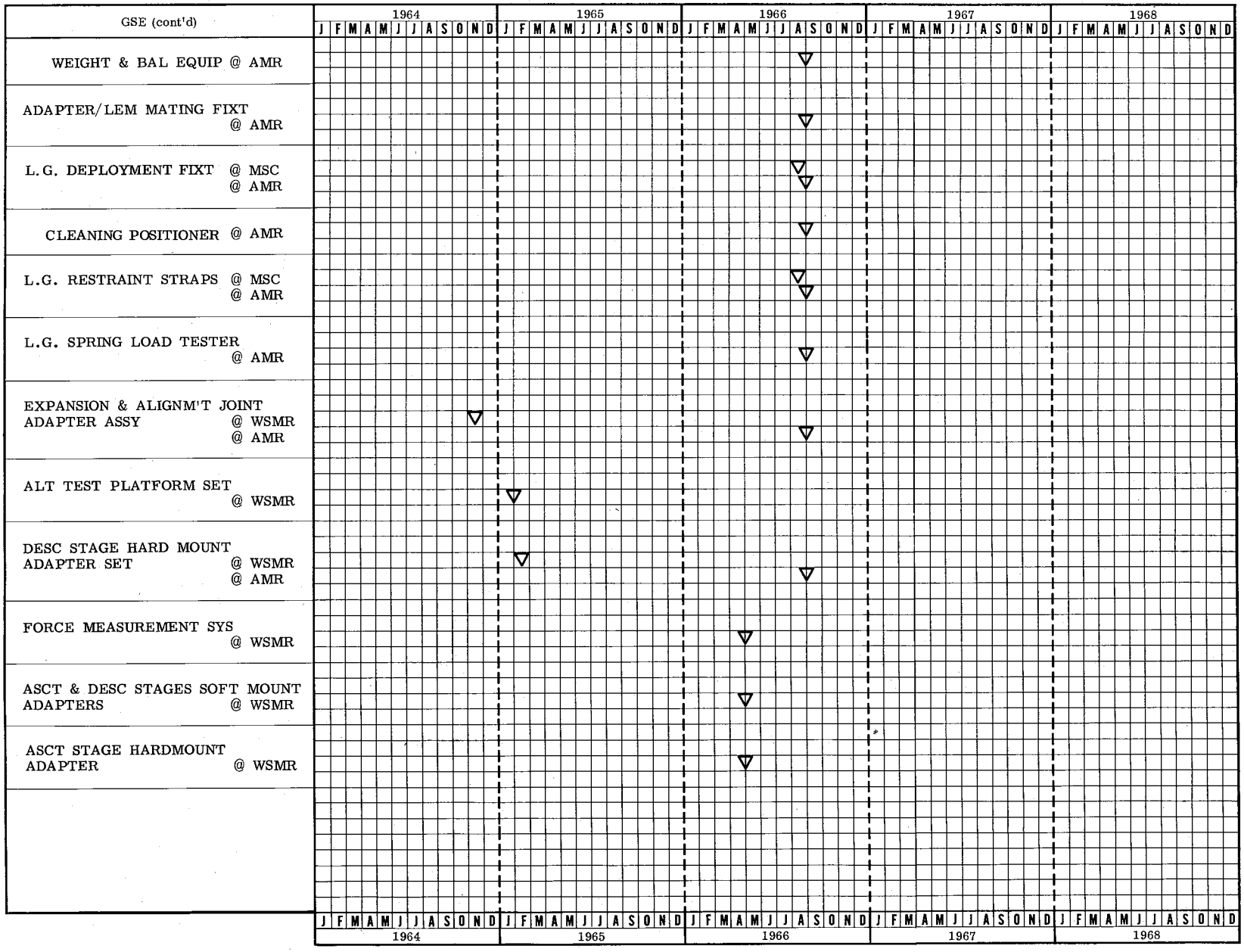

GSE (cont'd)
1964
1965
1966
1967
1968
J F M A M J J A S O N D
LEM SUPPORT STAND @ MSC
SLINGS FOR ASCT STAGE @ WSMR
@ MSC
@ AMR
TRANSPORTER COVER @ WSMR
@ GAEC
@ AMR
TRANSPORTER @ GAEC
DSCT STAGE @ WSMR
@ MSC
@ AMR
ARS SUIT CIRCUIT ASSY @ MSC
@ AMR
ASCT ENGINE INSTALL @ WSMR
@ MSC
@ AMR
RCS CLUSTER ASSY @ WSMR
@ MSC
@ AMR
DSCT ENGINE HOISTING @ WSMR
@ MSC
@ AMR
ASCT FUEL & OXIDIZER TANKS
@ WSMR
@ MSC
@ AMR
DSCT FUEL & OXIDIZER TANKS
@ WSMR
@ MSC
@ AMR

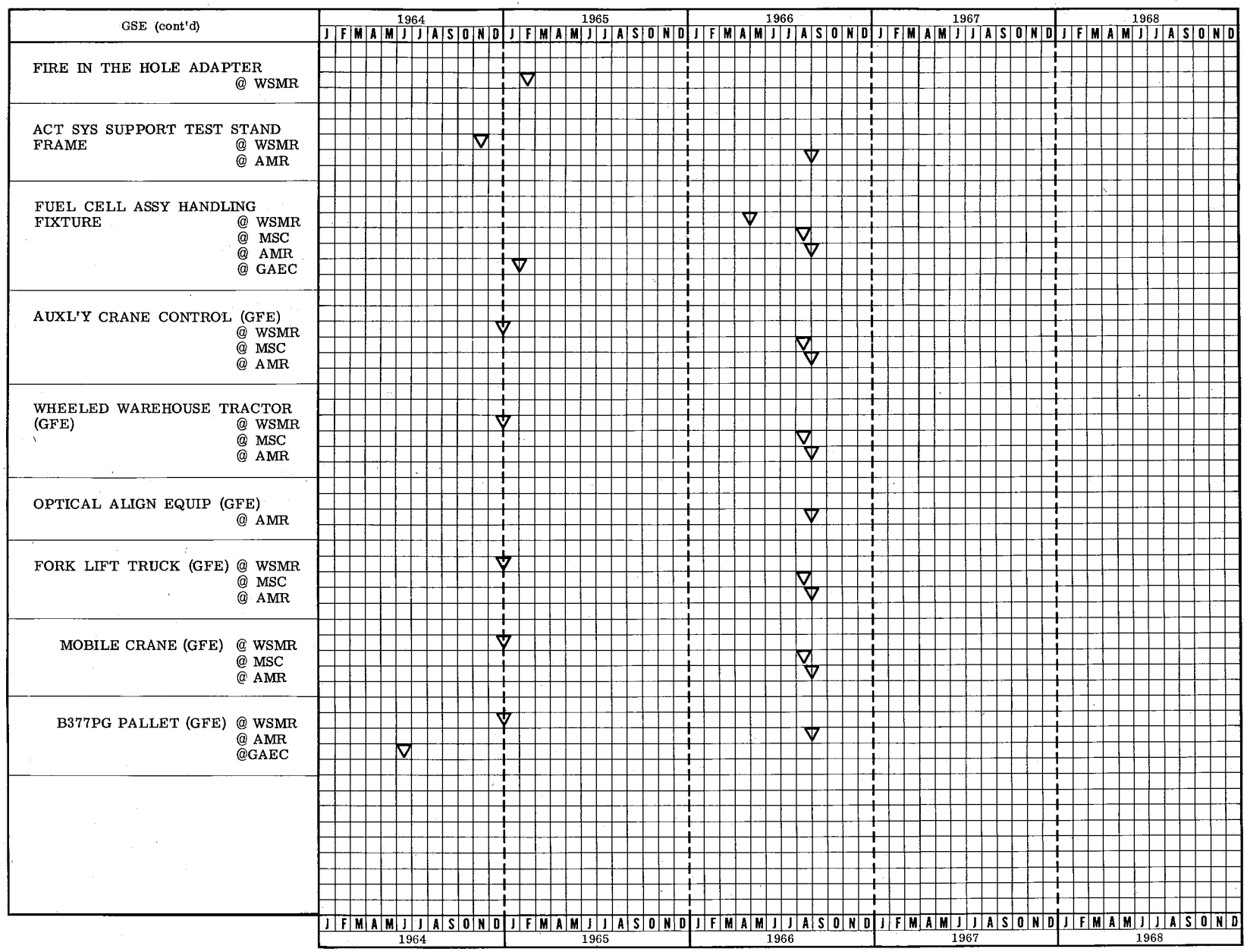

GSE (cont'd)
1964
1965
1966
1967
1968
J F M A M J J A S O N D
SHIPPING CONTAINER FOR LANDING GEAR
@ MSC
@ AMR
TRANSPORTER FOR ASCT STAGE
@ WSMR
@ GAEC
@ AMR
TRANSPORTER FOR DSCT STAGE
@ WSMR
@ GAEC
@ AMR
SHIPPING CONTAINERS FOR DSCT ENG
@ WSMR
@ MSC
SHIPPING CONTAINERS FOR ASCT ENG
@ WSMR
@ MSC
SHIPPING CONTAINER FOR FUEL CELL
@ WSMR
@ MSC
@ AMR
WORKSTANDS FOR LEM, ASCT & DSCT STAGES
@ WSMR
@ MSC
@ AMR
PROTECTIVE COVERS FOR LEM, ASCT & DSCT STAGES
@ WSMR
@ GAEC
@ MSC
@ AMR

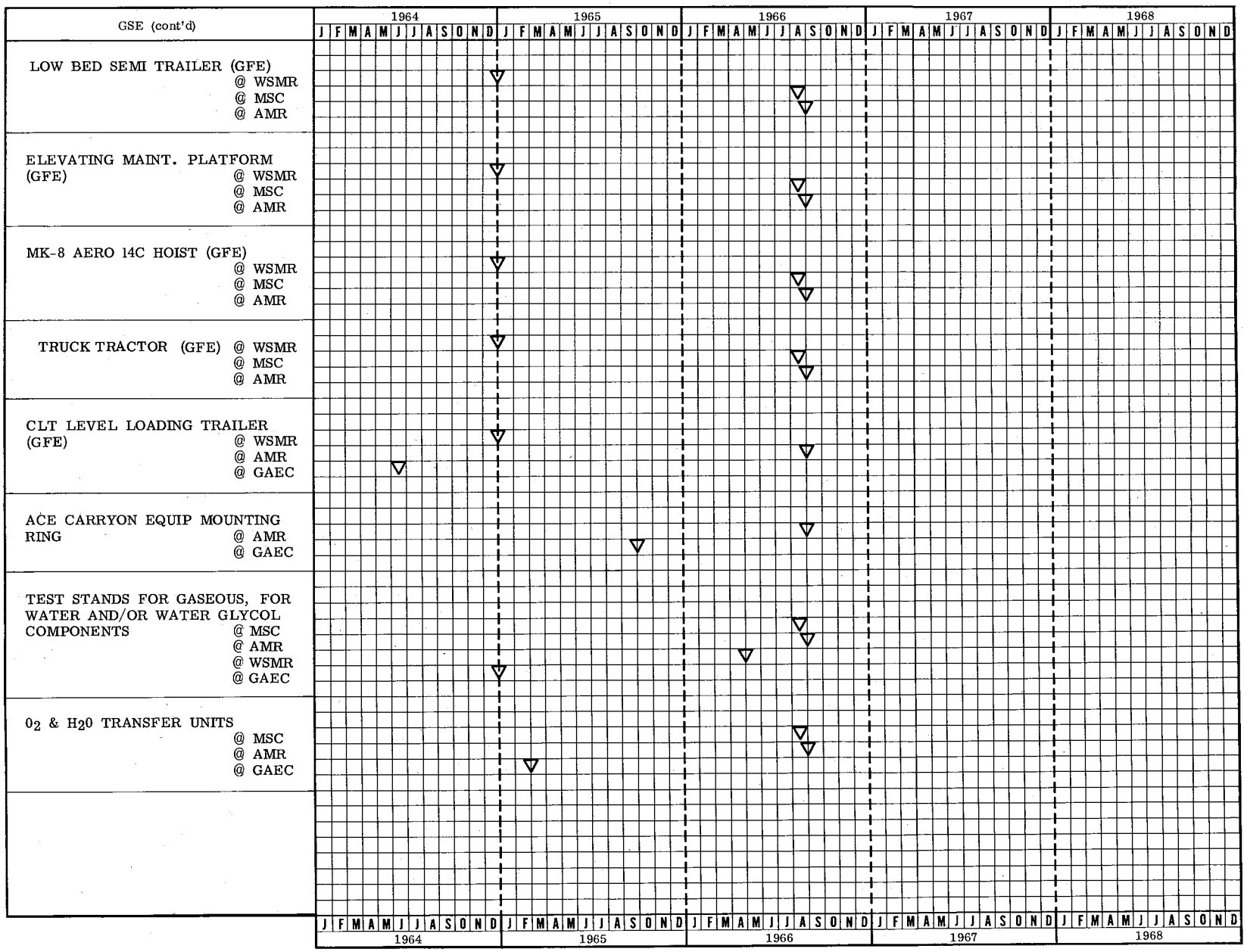
GSE (cont'd)	1964	1965	1966	1967	1968
HANDLING DOLLIES FOR DSCT ADAPTER @ MSC			▽		
@ AMR			▽		
HANDLING DOLLIES FOR ASCT STAGE @ WSMR		▽			
@ MSC			▽		
@ AMR			▽		
HANDLING DOLLIES FOR DSCT STAGE @ WSMR	▽				
@ MSC			▽		
@ AMR			▽		
DOLLIES FOR ARS SUIT CIRCUIT ASSY @ MSC			▽		
@ AMR			▽		
HANDLING DOLLIES FOR ASCT ENGINE & PROPULSION TANKS @ WSMR		▽			
@ MSC			▽		
@ AMR			▽		
HANDLING DOLLIES FOR DSCT ENGINE & PROPULSION TANKS @ WSMR	▽				
@ MSC			▽		
@ AMR			▽		
DOLLY FOR ACS CLUSTER ASSY @ WSMR		▽			
@ MSC			▽		
@ AMR			▽		
TEST SUPPORT PLATFORM RDA B'SITE RNG @ AMR			▽		
DOCKING HATCH DOOR ACCESS @ MSC			▽		
@ AMR			▽		

J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

1964 1965 1966 1967 1968


GSE (cont'd)
1964
1965
1966
1967
1968
J F M A M J J A S O N D
WEIGHT & BAL EQUIP @ AMR
ADAPTER/LEM MATING FIXT @ AMR
L.G. DEPLOYMENT FIXT @ MSC
@ AMR
CLEANING POSITIONER @ AMR
L.G. RESTRAINT STRAPS @ MSC
@ AMR
L.G. SPRING LOAD TESTER @ AMR
EXPANSION & ALIGNM'T JOINT ADAPTER ASSY @ WSMR
@ AMR
ALT TEST PLATFORM SET @ WSMR
DESC STAGE HARD MOUNT ADAPTER SET @ WSMR
@ AMR
FORCE MEASUREMENT SYS @ WSMR
ASCT & DESC STAGES SOFT MOUNT ADAPTERS @ WSMR
ASCT STAGE HARDMOUNT ADAPTER @ WSMR


GSE (cont'd)
1964
1965
1966
1967
1968
J F M A M J J A S O N D
FIRE IN THE HOLE ADAPTER
@ WSMR
ACT SYS SUPPORT TEST STAND FRAME
@ WSMR
@ AMR
FUEL CELL ASSY HANDLING FIXTURE
@ WSMR
@ MSC
@ AMR
@ GAEC
AUXL'Y CRANE CONTROL (GFE)
@ WSMR
@ MSC
@ AMR
WHEELED WAREHOUSE TRACTOR (GFE)
@ WSMR
@ MSC
@ AMR
OPTICAL ALIGN EQUIP (GFE)
@ AMR
FORK LIFT TRUCK (GFE)
@ WSMR
@ MSC
@ AMR
MOBILE CRANE (GFE)
@ WSMR
@ MSC
@ AMR
B377PG PALLET (GFE)
@ WSMR
@ AMR
@GAEC

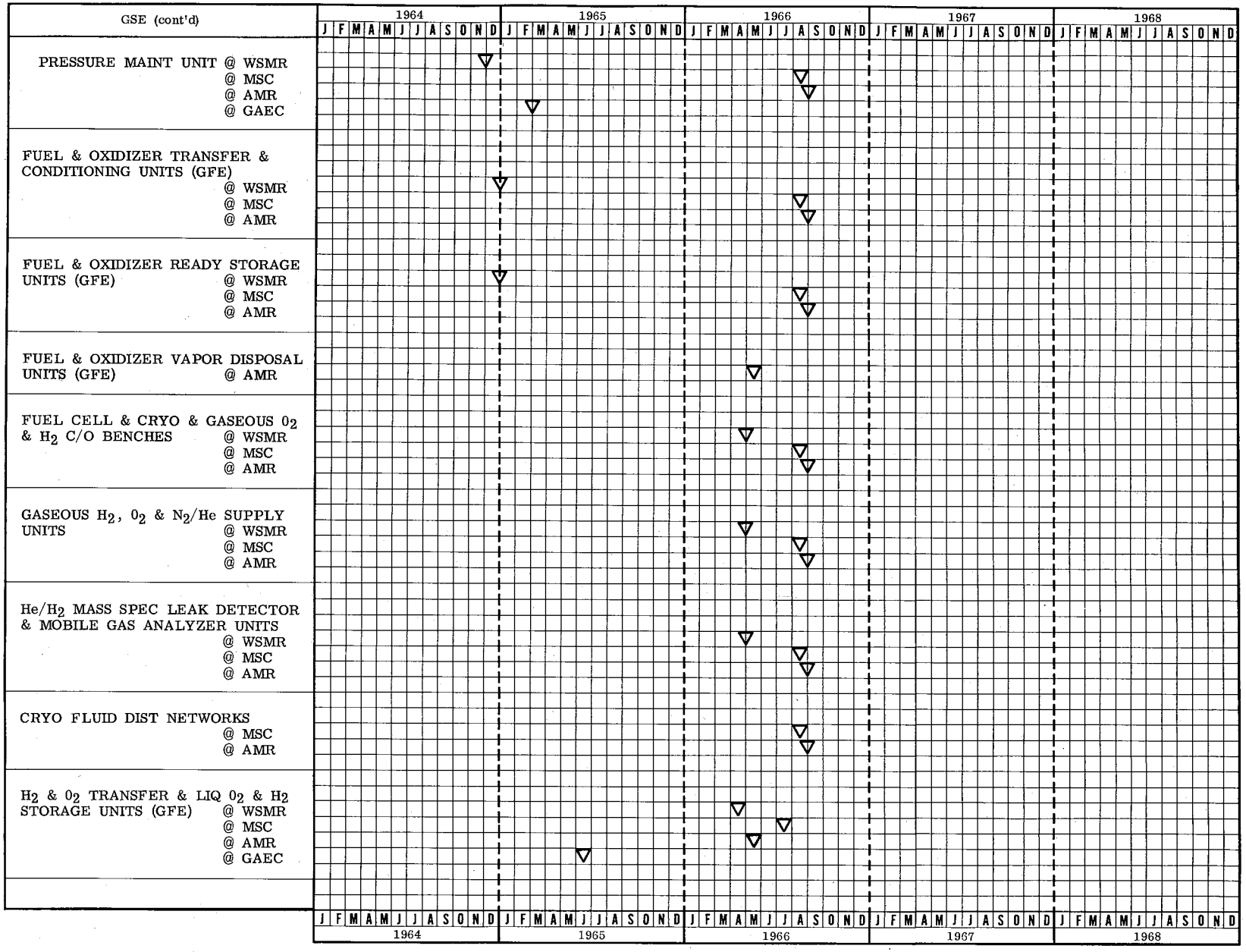

GSE (cont'd)
1964
1965
1966
1967
1968
J F M A M J J A S O N D
LOW BED SEMI TRAILER (GFE)
@ WSMR
@ MSC
@ AMR
ELEVATING MAINT. PLATFORM (GFE)
@ WSMR
@ MSC
@ AMR
MK-8 AERO 14C HOIST (GFE)
@ WSMR
@ MSC
@ AMR
TRUCK TRACTOR (GFE) @ WSMR
@ MSC
@ AMR
CLT LEVEL LOADING TRAILER (GFE)
@ WSMR
@ AMR
@ GAEC
ACE CARRYON EQUIP MOUNTING RING
@ AMR
@ GAEC
TEST STANDS FOR GASEOUS, FOR WATER AND/OR WATER GLYCOL COMPONENTS
@ MSC
@ AMR
@ WSMR
@ GAEC
O_2 & H_2O TRANSFER UNITS
@ MSC
@ AMR
@ GAEC

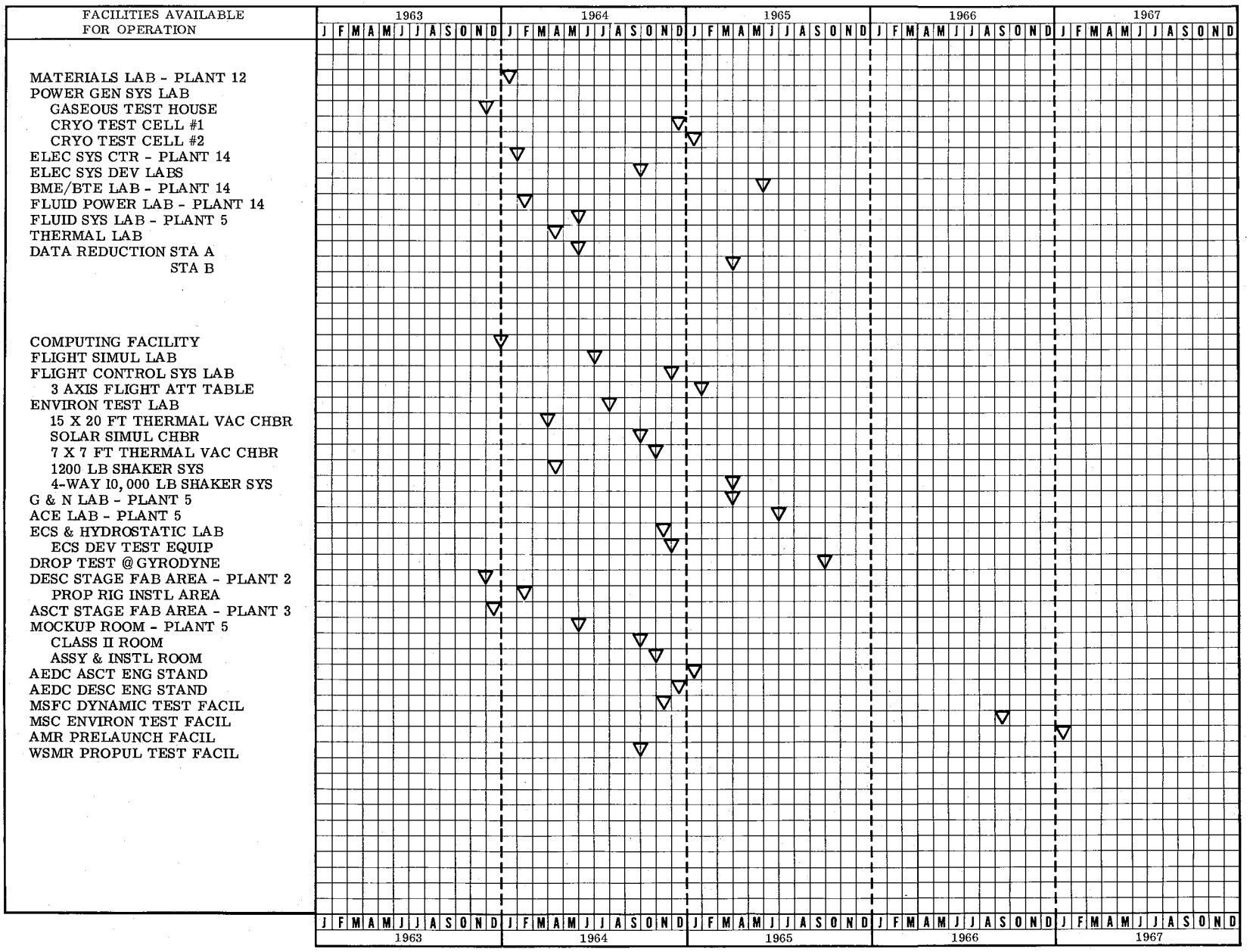
GSE (cont'd)	1964	1965	1966	1967	1968
CABIN LEAK TEST UNIT @ MSC			▽		
@ AMR			▽		
@ GAEC		▽			
FREON SUPPLY UNIT @ MSC			▽		
@ AMR			▽		
WATER GLYCOL TRIM CONTROL UNIT @ WSMR			▽		
@ MSC			▽		
@ AMR			▽		
@ GAEC		▽			
ATMOSPHERE REVITALIZATION CALIB TEST SET (GFE) @ MSC			▽		
@ AMR			▽		
@ GAEC		▽			
WATER GLYCOL SERVICE UNIT (GFE) @ MSC			▽		
@ AMR			▽		
@ GAEC		▽			
He COMP TEST BENCH @ WSMR	▽				
@ MSC			▽		
@ AMR			▽		
RCS CHECKOUT, RCS FUEL FLUSH & PURGE, & OXIDIZER FLUSH & PURGE CARTS @ WSMR		▽			
@ MSC			▽		
@ AMR			▽		
RCS FUEL & OXIDIZER TRANSFER CONTROL UNITS @ WSMR		▽			
@ MSC			▽		
@ AMR			▽		

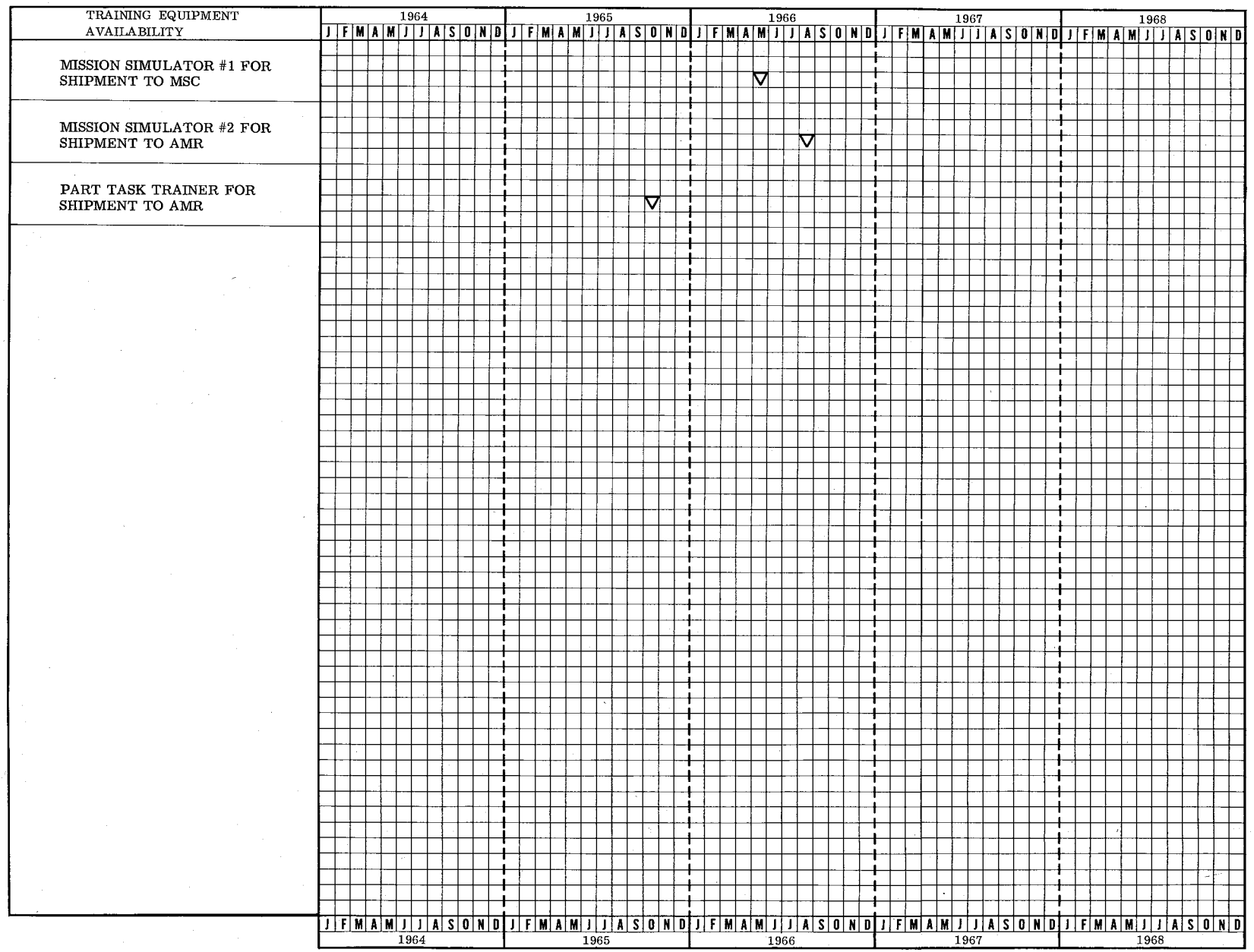
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

1964 1965 1966 1967 1968

GSE (cont'd)	1964	1965	1966	1967	1968
	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
He DISTRIBUTION, TRANSFER & BOOSTER UNITS (GFE) @ WSMR	▽				
@ MSC			▽		
@ AMR			▽		
RCS FUEL & OXIDIZER SERVICING UNITS (GFE) @ WSMR	▽				
@ MSC			▽		
@ AMR			▽		
He READY STORAGE TRAILER (GFE) @ WSMR	▽				
@ MSC			▽		
@ AMR			▽		
SUBSTITUTE FUEL & OXIDIZER TEST STAND COMPONENTS @ WSMR	▽				
@ MSC			▽		
@ AMR			▽		
PROPULSION SUBSYS C/O SET @ WSMR	▽				
@ MSC			▽		
@ AMR			▽		
PROPULSION FLUSH & PURGE UNIT @ WSMR		▽			
@ MSC			▽		
@ AMR			▽		
DESC ENG SIMULATOR @ WSMR		▽			
@ MSC			▽		
@ AMR			▽		
PROPELLANT WADING CONTROL ASSY @ WSMR	▽				
@ MSC			▽		
@ AMR			▽		
	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
	1964	1965	1966	1967	1968


GSE (cont'd)
1964
1965
1966
1967
1968
J F M A M J J A S O N D
PRESSURE MAINT UNIT @ WSMR
@ MSC
@ AMR
@ GAEC
FUEL & OXIDIZER TRANSFER & CONDITIONING UNITS (GFE)
@ WSMR
@ MSC
@ AMR
FUEL & OXIDIZER READY STORAGE UNITS (GFE)
@ WSMR
@ MSC
@ AMR
FUEL & OXIDIZER VAPOR DISPOSAL UNITS (GFE)
@ AMR
FUEL CELL & CRYO & GASEOUS O_2 & H_2 C/O BENCHES
@ WSMR
@ MSC
@ AMR
GASEOUS H_2, O_2 & N_2/He SUPPLY UNITS
@ WSMR
@ MSC
@ AMR
He/H_2 MASS SPEC LEAK DETECTOR & MOBILE GAS ANALYZER UNITS
@ WSMR
@ MSC
@ AMR
CRYO FLUID DIST NETWORKS
@ MSC
@ AMR
H_2 & O_2 TRANSFER & LIQ O_2 & H_2 STORAGE UNITS (GFE)
@ WSMR
@ MSC
@ AMR
@ GAEC


FACILITIES AVAILABLE FOR OPERATION
1963
1964
1965
1966
1967
J F M A M J J A S O N D
MATERIALS LAB - PLANT 12
POWER GEN SYS LAB
GASEOUS TEST HOUSE
CRYO TEST CELL #1
CRYO TEST CELL #2
ELEC SYS CTR - PLANT 14
ELEC SYS DEV LABS
BME/BTE LAB - PLANT 14
FLUID POWER LAB - PLANT 14
FLUID SYS LAB - PLANT 5
THERMAL LAB
DATA REDUCTION STA A
STA B
COMPUTING FACILITY
FLIGHT SIMUL LAB
FLIGHT CONTROL SYS LAB
3 AXIS FLIGHT ATT TABLE
ENVIRON TEST LAB
15 X 20 FT THERMAL VAC CHBR
SOLAR SIMUL CHBR
7 X 7 FT THERMAL VAC CHBR
1200 LB SHAKER SYS
4-WAY 10,000 LB SHAKER SYS
G & N LAB - PLANT 5
ACE LAB - PLANT 5
ECS & HYDROSTATIC LAB
ECS DEV TEST EQUIP
DROP TEST @ GYRODYNE
DESC STAGE FAB AREA - PLANT 2
PROP RIG INSTL AREA
ASCT STAGE FAB AREA - PLANT 3
MOCKUP ROOM - PLANT 5
CLASS II ROOM
ASSY & INSTL ROOM
AEDC ASCT ENG STAND
AEDC DESC ENG STAND
MSFC DYNAMIC TEST FACIL
MSC ENVIRON TEST FACIL
AMR PRELAUNCH FACIL
WSMR PROPUL TEST FACIL


TRAINING EQUIPMENT AVAILABILITY
1964
1965
1966
1967
1968
J F M A M J J A S O N D
MISSION SIMULATOR #1 FOR SHIPMENT TO MSC
MISSION SIMULATOR #2 FOR SHIPMENT TO AMR
PART TASK TRAINER FOR SHIPMENT TO AMR

SECTION 6
PLAN SUMMARIES

6.1 FACILITIES PLAN SUMMARY

Manufacturing facilities used for LEM are as follows:

- Ascent stage will be fabricated and assembled in Government owned Plant 3.
- Descent stage will be fabricated and assembled in Grumman owned Plant 2.
- Final assembly, installation and checkout of the LEM will be in controlled environment rooms provided by Grumman in Plant 5.

The existing engineering test facilities to be used include: the radar range and RF anechoic chamber and bench test areas in the Electronic Systems Center, the Dynamics Lab, Thermal Lab, Structural Test Lab, Materials Lab, the belljars, 4 foot by 8 foot and 15 foot by 20 foot thermal vacuum chambers, and shakers of the Environmental Test Lab. Additions to the test facilities include: 10,000 square feet expansion, with standard test equipment, to the Electronic Systems Center; a propellant feed system test facility (substitute propellants) at Plant 5; expansion of the Thermal Lab plus new spectrophotometers and belljars; expansion of the Environmental Test Lab plus a four-way shaker system, additional belljars, an 8 foot by 30 foot solar simulation vacuum chamber, and a 7 foot by 7 foot vacuum chamber; a cryogenic electric power system test facility at Peconic; a life support system lab; Flight Control System and Simulation Labs including flight attitude tables and computing equipment. Negotiations have been opened with Gyrodyne, Inc., to use the Navy-owned VTOL tower at the Gyrodyne plant for LEM drop tests. The Electronics Systems Center, and most equipment therein, is Grumman owned. Plant 5 and the Peconic area are Government owned except for the engineering test equipment.

At AMR the LEM program requires: office area and high bay and low bay lab area, and the man-rated altitude chambers in the O&C building; a test cell and control room in the Environmental Control Systems Building; a test cell and control room in the Hypergolic Test Building; the Cryogenic Test Building; 3200 square feet in the Weight and Balance Building; a new control

center and static firing stand with an altitude simulation chamber in the Static Test Complex; the Radar Boresight Range; Launch Complex 37; a bay in the Vertical Assembly Building, Launch Complex 39; and other supporting facilities.

At the Manned Spacecraft Center, LTA-7 and -8 will be environmentally tested in vacuum chambers A and B. Laboratory, maintenance and office areas are required in, or adjacent to, the Space Environmental Test Facility.

At the U. S. Air Force Arnold Engineering Development Center, altitude rocket test cell T-4 will be used for ascent engine tests, cell J-3 for descent engine tests, and cell J2A for tests of a section of the RCS and the ascent and descent stage engines.

At the MSC Test Area-WSMR, the LEM program requires a new Project Control Building, warehouse, test article Preparation Building, and a Static Test Area consisting of: three test stands, each capable of the static firing at simulated altitude conditions of the ascent propulsion system, reaction control system, and the descent propulsion system; a control center, two stand support buildings and signal conditioning rooms and supporting equipment.

6.2 TEST PLAN SUMMARY

The LEM Test Plan describes the tests that will be required to develop LEM for the lunar mission. Presently, the Test Plan consists of a single volume which contains a brief summary of all subsystem development tests; Test Model (TM), LEM Test Article (LTA), and Flight LEM (LEM) development programs.

The subsystem test plans presented, encompass design feasibility tests, design verification tests, and qualification tests. This covers those tests done to develop a given subsystem. In addition, the summary plan will include integrated subsystem testing, ESI, FCI, TM's, LTA's, and LEM's.

Detailed plans will be written in the future to finalize test requirements for all significant tests. The summary volume of the test plan will contain a listing showing the status of these plans. Also included in the summary volume is the test logic and philosophy that lead to the over-all development program as it now exists. Recently, Grumman has expanded on this logic to show, in detail, how the entire LTA and LEM program fits together. These constraints will be included in the next issue of the LEM Summary Test Plan.

These constraints and the implications involved in the major vehicle ground and flight test programs are summarized to indicate the effort required to develop LEM for its ultimate mission within the relatively short period allotted. The following paragraphs also describe, briefly, the utilization of the LEM Test Articles (LTA), FTA's and flight LEM's participating in the LEM development program.

LTA's

- LTA-1: LEM INTEGRATION

  LTA-1 will be a complete LEM ascent and descent structure capable of incorporating all subsystems. S&C, N&G, EPS (less cryogenics), communications, operational and R&D instrumentation will be functionally complete using Service test and/or prototype models. All other subsystems will be mocked-up dimensionally with their electrical components functionally operable.

  LTA-1 will be used at GAEC for installation, functional testing and electrical integration of all LEM subsystems. The overall installation will be used to insure the compatability of man and vehicle. Removable panels on the metal vehicle will facilitate tests and changes. Electromagnetic interference and compatability with GSE, ACE and A & I equipment also will be evaluated. LTA-1 will then serve as house spacecraft to support flight tests.

- LTA-2 DYNAMIC TESTS

  LTA-2 will have the correct weight(s) and c.g. location(s). Moments of inertia will be approximated.

  The ascent stage will be a steel frame arranged for correct weight and c.g. location with propellant tanks represented by metal blocks simulating full, 3/4 full, 1/2 full, 1/4 full, and empty tanks.

  Descent stage structure will contain equipment, engine, and tankage other than propellant tankage inertially simulated and with correct weight and c.g. location. The propellant tanks will be non-flight rated, "propulsion test unit" types, capable of holding inert fluids for ballast. Fill and drain provisions are required.

  A prototype landing gear will be attached in a fixed retracted position. Hardware used to attach the LEM to the SIVB adapter will be complete.

  The LTA-2 will be dynamically tested at MSFC with the Saturn V subsequent to the Saturn IB test program.

- LTA-3: STRUCTURAL

  LTA-3 will be a complete LEM structure, including landing gear, fired ascent and descent engines and ballasted to LEM weight and balance for all subsystems except ECS. A service test or prototype ECS will be installed to verify its structural integrity. Pressure and static tests for critical conditions, vibration, drop tests and finally, failing load tests will be performed at GAEC. These tests will qualify LEM structure for critical static loads, demonstrate failing strength margins, determine structural stresses, stiffness and dynamic response characteristics of the structure itself and the equipment support structure, and verify analysis and design assumptions.

- LTA-4: ENVIRONMENTAL DEVELOPMENT

  LTA-4 will be a complete LEM with all subsystems operational and of the service test level or higher. Prototype level is desired. This test program is to demonstrate satisfactory performance of the integrated LEM system under mission level environments of thermal-Vacuum, Vibration, and landing impact. Additional tests will check EMI and weight and balance and establish criteria to detect subsystem malfunctions or degradations using ACE and onboard instrumentation. Referee fluids will replace propellants and reactants in the onboard tanks.

- LTA-5: PROPULSION

  LTA-5 will be a LEM structural (ascent/descent) shell with complete propulsion and RCS subsystems. Each subsystem will consist of feed system tankage, helium pressurization system, and the thrust chambers. In addition, S & C, electrical power and partial ECS for equipment cooling will be included.

  LTA-5 will completely test the propulsion subsystem during test firings under simulated mission conditions at WSMR. Complete mission will be accomplished including starts, stops, throttling, and endurance runs during which the performance of the other subsystems will be evaluated under engine burning environment.

- LTA-6: APOLLO INTERFACE

  LTA-6 will be a structurally complete LEM with landing gear, crew seats, and mocked-up crew compartment duplicating ingress and egress conditions. LTA-6 will be ballasted to LEM weight and balance. Erection and instrumentation of the vehicle will be completed by GAEC at NAA Downey where compatability of LTA-6 and the CSM will be

tested under flight vibration conditions. Support required or other Apollo tests involving the integrated LEM/CSM will also be evaluated.

- LTA-7: ENVIRONMENTAL DEMONSTRATION
  LTA-7 will be a complete LEM except that substitute liquids will be used for the hypergolic propulsion and RCS fluids; liquid nitrogen will replace liquid hydrogen in the electrical power supply, the fuel cells will be operated with externally supplied gaseous reactions, and ballast will replace all pyrotechnic devices.

- LTA-8: LEM/CSM DEMONSTRATION
  LTA-8 will be the same configuration at LTA-7.

- LTA-9: PROPULSION TEST BACKUP
  LTA-9 will provide backup to LTA-5, the propulsion demonstration vehicle, when ground test propulsion support of the flight test program is required. The LTA-9 configuration is identical to LTA-5.

- LTA-10: LEM/ADAPTER TESTS
  LTA-10 is a descent stage structure ballasted to provide LEM weight and c.g. characteristics for use at NAA in LEM/adapter model and vibration tests, adapter structural tests, and adapter separation tests.

FTA's

- FTA-1 & 2: BALLASTED LEM'S
  The Flight Test Articles each will have LEM structure with mass representation of all subsystem equipment except that (1) propellant tanks will be capable of holding inert fluids (2) landing gear will be attached and (3) interim instrumentation will be used. Overall weight and c.g. will be correct, moment of inertia will be approximate. Terminal ends of all umbilical and servicing connections will be included.

LEM's

- LEM-1 (ON SA-206)
  LEM-1 will consist of a complete LEM structure, including all subsystems, and R & D instrumentation. A mission programmer is provided to perform the tests in an unmanned configuration.

  LEM-1, unmanned, will be the first LEM launch from AMR and will use the Saturn IB booster to achieve earth orbit to demonstrate the propulsion and RCS in an operational environment. The CSM will perform transposition with the LEM stabilized by the Saturn S4B stage. Following separation of the LEM from the S4B with RCS, the descent engine, descent stage separation and ascent engine

will be tested. During all tests and until exhaustion of attitude propellant, functioning of the flight control system and EPS will be monitored.

- LEM-2 (ON SA-207)

  LEM-2 will consist of a complete LEM including all subsystems, LEM mission programmer and R & D instrumentation. The unmanned configuration will allow a crew member from the CSM to board the LEM and realign the attitude platform before separation from the CSM.

  LEM-2, unmanned, will be launched from AMR and will use the Saturn IB booster to achieve earth orbit. The purpose will be to demonstrate propulsion and RCS subsystems rendezvous. The CSM will transpose and dock with the LEM and then separate from the S4B stage. A crew member from the CSM will enter the LEM, realign the attitude reference and set the LEM in attitude hold mode and then return to the CSM. The CSM will separate from the LEM and perform docking tests. The CSM, using its SPS for ΔV, will also perform rendezvous maneuvers with LEM. These rendezvous and docking maneuvers will demonstrate CSM retrieval of the LEM. The crew man will re-enter LEM, realign the platform and set up a stored program for LEM active rendezvous. LEM will then, after the crew man returns to the CM, perform a descent engine thrust, separate, and accomplish a thrust with ascent engine to automatically rendezvous with the CSM. The command module will dock with the LEM. Further docking exercises can be performed by the CSM until LEM RCS fuel is exhausted.

- LEM-3 (ON SA-503)

  LEM-3 will be a complete LEM with a Mission Programmer incorporated for unmanned full duration propulsion tests.

  Two missions for this LEM are proposed, depending on whether the Saturn V is man-rated at this time. For the non-man-rated booster, the LEM will be used to test the effect of long duration propulsion firing and cold soak on the LEM system. This will be accomplished after a translunar injection with the Saturn V booster. If the Saturn V booster is man-rated at this time, an earth orbital flight which will expand on the objectives achieved on the SA-207 flight, will be flown. Further manned usage of LEM systems will be accomplished within the capabilities allowed by ground testing and the SA-207 flight.

Rendezvous and docking with the CM active, and unmanned usage of LEM propulsion over the entire range of vehicle inertia to determine thrust vector control capability and control loop stability will also be accomplished.

- SUBSEQUENT MANNED LEM's
  The manned LEM's will be complete vehicles to test and demonstrate manned use and control of LEM. It is intended to develop full mission capability within earth orbital constraints before attempting lunar missions.

6.3 MANUFACTURING PLAN SUMMARY

The LEM Manufacturing Plan emphasizes a unified team effort for the management, implementation, and control of all manufacturing phases including:

- LEM fabrication, assembly, and subsystem installations.
- Manufacturing test programs for both in-house fabricated units and vendor supplied sub-system components.
- Fabrication of LEM Handling and Transportation GSE; Fluid Systems GSE; Electronic GSE; and Training Equipment.
- Design and manufacture of tooling for LEM fabrication, assembly, and installation operations.
- Selection, utilization and maintenance of manufacturing equipment and processes.
- Manufacturing Team support of field-site activities.

Grumman is using a development manufacturing approach to satisfy the high reliability requirements, to meet the critical schedule milestones, and to achieve the lowest possible overall program costs. This approach was selected to provide rapid response to LEM refinements resulting from the accumulation of space flight and test data. Low volume and rate of production and overlapping of design, tooling manufacturing and equipment efforts required to meet LTA and LEM schedules also influenced the selection of this approach. Advanced engineering design information is used to expedite the design, fabrication, completion and subsequent use of tools earlier in the program.

The LEM engineering design concepts are being developed with emphasis on state-of-the-art fabrication and testing techniques since reliability and schedule objectives are directly related to manufacturing producibility. Highly skilled development shop technicians and minimum tooling are utilized for the manufacture of early test articles. Some detail parts and minor subassemblies are fabricated on an experimental basis with adequate quality control. As engineering designs progress, existing tools will be improved and refined.

Additional tool families for an expanded sub-assembly breakdown will be provided to accommodate the average structural manufacturing rate of 1.1 units per month and an average installation rate of 1.5 units per month during the peak period.

Present facility planning for the LEM program indicates that virtually all Grumman manufacturing tasks will be performed within the Bethpage facilities. The plants selected for LEM manufacturing are located within a one mile radius of the centralized assembly, installation and test facility located in Plant 5.

The LEM ascent structure will be assembled in the Plant 3 facility which includes a complete range of equipment and facilities for manual or automatic fusion welding, resistance welding, chemical milling, spin forming, honeycomb, plexiglass machined parts, and mechanical assembly operations. Plant 3 will also provide backup for the vendored machined parts for both stages. Plant 2 is utilized to assemble the descent structure and will also produce the majority of the sheet metal parts required for the LEM program.

The sophisticated nature of the LEM program dictates the use of manufacturing "subsystem team" technicians identified with each LEM. Upon completion of a mission, the experienced team will revert to a subsequent module to assure clear lines of task continuity and the benefit of a high experience factor.

The Manufacturing Test Plan also emphasizes the aforementioned "subsystem team" approach for assurance of highest quality and reliability levels. Manufacturing test teams will use GSE equipment for bench tests of mechanical, fluid, and electrical/electronic subsystems. Periodic maintenance and calibration of manufacturing test GSE, dictated by an "IBM alerting system" will assure the required level of equipment performance.

Grumman will use existing Avionic, Hydraulic, Tool and Central Equipment shops, which are presently organized with the necessary specialized skills, equipment and facilities for the manufacture of GSE. Manufacturing will support the off-site activities with test technicians, who have been trained in-house by working with Manufacturing and Manufacturing Test "subsystem teams".

6.4 MAINTENANCE PLAN

This plan describes the LEM maintenance concepts, defines the various levels of maintenance, the levels of

maintenance planned at major sites, and procedures used to assure that maintenance operations are performed properly. The date for implementation of the plan at any site is related to the scheduled arrival of the first test vehicle.

The levels of maintenance are:

Subsystem Maintenance

Subsystem maintenance will be performed during all phases of operations at assembly, checkout, prelaunch, launch and test sites to the level of subsystem verification. Servicing, leak checking, removal and installation, subsystem calibration, scheduled maintenance, purging after shutdown, cleaning and unscheduled corrective maintenance are included. Repairs below the adjustment or removal/replacement level will not be performed as subsystem maintenance.

Assembly includes the following typical tasks:

- Assembly of the ascent stage to the descent stage
- Assembly of the adapter to the spacecraft
- Assembly of the LEM to the launch vehicle
- Alignment of the assembled equipments
- Integration of the spacecraft with the GSE.

Maintenance required during normal checkout and prelaunch operations includes servicing with fuels, coolant fluids, gases, etc., and adjusting the levels of regulators. Leak checks will be made and system calibration and verification tests will be performed. Pyrotechnics will be installed.

Other maintenance tasks are required after termination of system or subsystem tests. Typical post-operations actions are: system shutdown, defueling, subsystem purging, removal of pyrotechnics, subsystem integrity checks, calibration checks, cleaning and refurbishing of the spacecraft and ground support equipment.

The unscheduled maintenance is that necessitated by malfunctions, failure, or accidental damage to the spacecraft or its equipment.

Subsystem maintenance is required at many locations on a particular field site. The necessary support is furnished by both protable and fixed ground support equipment with ACE S/C serving as the primary means for checkout and troubleshooting at the subsystem and system levels. LEM Special Test units (LSTU's) will be used during checkout where ACE S/C is not available. Spacecraft and GSE transportation and handling will be necessary throughout these operations.

Bench Maintenance

The next level of maintenance, bench maintenance, can be considered as a more detailed type of support.

The bench maintenance equipment (BME) will be used to check the performance of uninstalled LEM assemblies, subassemblies and components down to the lowest removable, replaceable level. These functional checks, also referred to as pre-installation acceptance tests (PIA's), are quantitative determinations that the hardware being tested is operating within specified limits.

The BME will be capable of malfunction detection, isolation and confirmation at the assembly, subassembly and component levels. Other maintenance operations such as calibration and alignment will be possible. Interface compatability can be checked.

Repair verification will be possible at the assembly and subassembly level (provided that the subassembly or component used to effect the repair is a flight qualified spare). The BME shall be designed for ease of maintenance.

Specialized Mainteance

Specialized maintenance functions will be performed either at the contractor's plant or at the LEM vendor's plant. Although an effort will be made to include facilities for all necessary maintenance at each of the checkout and operating sites, it is recognized that there will a certain amount of maintenance capability which will exist only at the factories. This maintenance will consist of modification or repair of parts which required high skill levels and/or unique maintenance equipment. In some cases, this will require highly controlled environmental conditions.

Detailed or complete disassembly of GSE or LEM units for the purpose of overhaul will normally be considered as specialized maintenance.

The maintenance levels planned at the various sites are shown in the following matrix:

Site	Subsystem Maintenance	Bench Maintenance	Specialized Maintenance
Bethpage	Yes	Yes	Yes
AMR	Yes	Yes	No
WSMR	Yes	Yes	No
MSC	Yes	Yes	No
MSFC	Limited*	No	No
NAA/S&ID	Limited*	No	No

*Limited to Handling and Transportation GSE

Maintenance actions at a site are monitored by Quality Control personnel to assure that material is properly

inspected and checked upon receipt to ascertain that articles are not accepted unless they are complete and qualified, physically and functionally, to requirements of applicable control specification drawings, and subsidiary documents.

Prior to start of tests of a LEM or LEM units, Quality Control will

- Review test logs and/or travelers to determine that appropriate prior operations, required inspections, tests, and documentation of configuration status have been performed;
- Insure that fabrication and inspection operations performed previously have been carried out by properly trained and certified personnel and certified equipment as applicable;
- Visually inspect the unit to be tested, using applicable specifications and procedures;
- Check cleanliness;
- Ascertain that the correct test equipment is to be used;
- Ascertain that the test equipment and instrumentation are properly and correctly calibrated; and
- Review the test procedure to check that it is applicable to the specific item to be tested and verify that the procedure has been approved.

The actual tests will be monitored to assure that

- The test is conducted as described in the detail test procedure;
- Adequate and accurate documentation is maintained; through the test;
- Deviation from the test procedure is recognized, and that consideration is given to halting the test; and
- Upon occurrence of a malfunction, that an analysis is initiated, corrective and preventive action is incorporated and proper feedback is instituted.

Maintenance actions involving disassembly and changes, failure reporting, repair verification, packaging, preservation and storage of LEM units will also be monitored.

Ground support equipment maintenance procedures are closely related to those of the spacecraft since most of the equipment is used either to check out or simulate spacecraft installations or to service the LEM during subsystem and integrated system maintenance operations. The detailed distribution of GSE to the field sites is contained in the GSE planning and requirements list.

This plan is supplemented by the LEM support Plan and supported manuals, which will be the detailed working documents.

6.5 SUPPORT PLAN

The LEM Support Plan is in three sections: Material Support, Transportation, Handling and Storage, and Support Manual Preparation. It describes functional operations and documentary procedures which will be used to assure availability of equipment, materials, and manuals required to support LEM tests and missions at the field test sites.

The method used for the selection, procurement and inventory management of all contractor-furnished parts is included.

The selection of spare parts for Government-furnished ground support equipment will be made by the contractor, with the assistance of NASA in the form of provisioning documentation.

Requirements for Government-furnished property, including items such as magnetic tape and pen-recorder rolls for data gathering equipment, office equipment and supplies, will be submitted at the field test sites concerned.

The plan for the transportation, packaging, and storage of LEM hardware is described. This includes packaging and special handling requirements, and accountability procedures. Primary mode of transportation of spacecraft and test vehicles will be by air, with transportation by road as the back-up or alternate method. Shipment of all items will normally be made on Government Bill of Lading or by Government-furnished transportation.

The Aero-Spacelines, Inc. modified Boeing Stratocruiser (B-377PG), which can accommodate the vehicles packaged in the transporters complete with hard cover, is the preferred aircraft.

The preparation of the support manuals is presented. This consists of formats, the delivery schedules and the procedures for incorporating revisions.

Related documents in support of this plan are appropriately referenced.

6.6 TRAINING PLAN

6.6.1 Flight Crew Training

The flight crew training program emphasizes LEM vehicle operations and the interaction with GOSS, IMCC, C/SM systems, and support personnel. The major objectives of the training program will be to: 1) develop crew proficiency in the normal and contingency operation of the LEM, 2) develop the ability to make rapid and correct decisions, 3) integrate the flight crew into the entire Apollo mission complex.

The recommended flight crew training includes the following phases:

- Scientific Preparation: General studies of all disciplines directly involved in the LEM mission will be covered in this phase. The topics will include subjects from the areas of flight mechanics, atmospheric and space physics, terrestial and lunar geology, and physiology.
- Environmental Training: Noise, vibration, acceleration, fatigue, visual problems, disorientation, isolation, confinement, toxicological hazards, and atmospheric factors associated with the lunar or LEM cabin/suit environments will be included in this phase of training.
- Systems Training: This phase of training will cover the description, function, operation, test, and checkout of each subsystem. Contingency procedures associated with malfunction detection, isolation, and correction and subsequent changes in the nominal mission profile will be included. This phase will also involve participation in design development to provide a better insight into the total Apollo concept.
- Part Mission Training: This phase of training will be directed toward intensive practice on selected nominal and non-nominal procedures and toward developing skills required for unique maneuvers such as landing, docking, and separation.
- Full Mission Training: Total system understanding, operational skill, and procedural proficiency will be attained by providing real time exercises of the LEM mission.
- Pre-Flight Training: This phase of training will consist of participation in LEM hangar and launch pad checkouts, and control center and GOSS operations.

6.6.2 Training Equipment

The requirements for training and for training equipment have been determined through task and training analyses. The resulting training program will be implemented according to schedules derived from the planned mission operation time table.

The trainers proposed by Grumman are of the following types:

- Full Mission Trainers: These trainers will provide practice in all phases of the LEM mission and integrated training with IMCC, GOSS and C/SM. Dynamic characteristics and configuration of the operational LEM will be simulated as

closely as possible to aid in achieving the objectives of this phase of training.

- Systems Trainers: These trainers are to be used for subsystem familiarization.
- Operations Trainer: This trainer is to be used to develop skill in the diverse and critical procedural tasks involved in LEM flight operations.
- Free Flight Vehicle: A modified lunar-landing research vehicle is recommended for practice in the hover-to-landing phase of the lunar-landing mission.
- Part Task Trainers: These trainers are to be used to develop skill in critical part tasks of the mission such as manual control of docking and landing, rendezvous and separation.

6.6.3 Training Documentation

Documents recommended to support this training include the Instructors' Manuals, Familiarization Manual, LEM Description Manual, Operations Handbook, Flight Controller's Handbook, and appropriate engineering data. data.

6.6.4 Ground Crew Training

A ground crew training plan contains recommendations for training personnel in the areas of pre-flight operations, launch operations, flight operations, and ground maintenance.

The use of the systems trainers is recommended for all ground crew personnel for subsystem familiarization, and the use of the auxiliary portion (e.g. telemetry console) of the full mission trainer is recommended for flight operations personnel for training in integrated missions with GOSS and IMCC.

6.7 RELIABILITY PLAN

The LEM Reliability Plan describes the program which is designed so that all phases of the design, development, production, and use of the system, subsystems, and equipment, are controlled. The reliability plan includes:

- Apportionment of system reliability requirements.
- Vendor requirement document input for reliability goals and reliability analysis and documentation requirements.
- Vendor reliability program review
  Vendor reliability program negotiations
- Reliability system and subsystem estimates
- Monitoring of vendor reliability program
- Coordination with Quality Control
- Liaison with NAA and other Apollo contractors
- Define mathematical model required to predict, apportion, and assess reliability.
- Conduct system optimization studies such as: configuration circuit, failure-effect maintainability, and environmental analyses.

- Component selection to determine those items that will survice the LEM environments.
- Reliability assurance test program that will encompass all development, qualification, acceptance, ground, and flight tests.
- Data Control Center to provide continuous data to Grumman and NASA.

6.8 QUALITY CONTROL PLAN

The LEM Quality Control Plan describes the Grumman Procedures to be used to implement the requirements of NASA Quality Publication NPC-200-2, dated April, 1962. This plan outlines the Grumman quality policy and operating procedures to be used in the performance of all LEM quality tasks in the development, fabrication, delivery, and support of LEM articles. Existing procedures and systems are utilized wherever possible to maintain a continuity of corporate operation.

The Quality Control Plan is arranged in an order consistent with the format of NPC 200-2 for the following sections:

- Basic Requirements - Summary - This section describes the development of Grumman Quality System and its applicability to LEM contract quality requirements for documentation, change control, and effectivity.
- Management - Grumman has established for the LEM Program, a LEM Quality Control organization reporting to Program Management on a level with Engineering, Test, Business, and Manufacturing. This section describes the LEM Quality Control organization and functions and its relationship to the Corporate Quality Control Department.
- Design - LEM Quality Control shall review all LEM design, vendor and process specifications to insure inclusion of quality provisions adequate to meet contract requirements. Quality Control participation in qualification test programs, preparation of Qualification Status Lists and the Grumman system for LEM identification are described.
- Procurement Control - LEM Quality Control shall provide a procurement control program to insure that all LEM supplies or services meet contract requirements. Quality Control participation in vendor selection and control, establishment of vendor quality requirements, purchase order review, determination of Government Inspection, receiving inspection is described and applicable Grumman operating procedures included.
- Government Property Control - Government Property supplied to Grumman for use in the LEM Program hardware shall be inspected and tested as

required. Provisions shall be effected for the protection, periodic inspection of material and reporting of GFP status.

- Manufacturing Control - Inspection and test stations shall be located at significant points throughout the LEM fabrication program. Inspection station locations are planned by a systematic review of fabrication requirements, inspection facilities and equipment, in process and process controls. This section describes the control of tooling and test equipment, clean room operations, inspection records, and coordination of in-house and off-site inspection activities.
- Nonconforming Material - Grumman Material Review System is described and the implementing procedures included.
- Precision Measuring and Test Equipment - This section describes the Grumman procedures for the procurement, control, and calibration of precision measuring and test equipment and the operating departments responsible for such control.
- Inspection Stamps - Quality Control Procedures for the control of inspection stamps are in effect and meet contract requirements.
- Preservation, Packaging, Handling, Storage and Shipping - Provisions for the control, preservation, packaging, etc., are included in Design Specifications or Grumman Standard Specifications which are routed through LEM Quality Control for development and review.
- Statistical Planning, Analysis and Quality Control - Sampling Plans to be used on LEM material shall be in accordance with approved Grumman Sampling Plans or shall be approved by NASA. Statistical analysis, and charting techniques will be used where practical within contractual limitations.
- Training and Certification of Personnel - Training for the LEM Program shall be the responsibility of each operating department with overall training coordination effected by LEM Test and Support Group. This section describes the participation of LEM Quality Control in training activities and general categories of training and functions.
- Data Reporting and Corrective Action - Quality Control reporting systems in effect provide for recording, routing, and analysis of all inspection and test data. Corrective action procedures are described and included.

- Audits of Quality Program Performance - LEM Quality Control in conjunction with the corporate Quality Control Audit Office will assure Quality Control system conformance with procedural requirements and provide the contract required audit documentation.
- Documentation - This section describes the anticipated content and format of Contract NAS 9-1100, Exhibit E, Quality Documentation.