PRELIMINARY PROGRAM PLAN AND COST FOR THE MANNED ORBITAL TELESCOPE (MOT)

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Seattle, Washington

CONTENTS

1.0 INTRODUCTION

This report presents the study results involved in the development of a preliminary program plan and related costs for the Manned Orbital Telescope (MOT) system. The purpose of the study was to produce a development and operational program based on the MOT preliminary system concept for use in establishing furthur activities subsequent to this study. The definition of the MOT preliminary system concept was developed from NASA Documents CR-66047 and CR-66102. Industrial data was obtained from a survey made of related industries that was of significant value in the preparation of this report. Organizations surveyed were:

- The Lamp Division and the Missile and Space Division of General Electric;
- The Space Defense Division of the American Optical Company;
- Itek Corporation;
- Diffraction Limited, Inc.;
- Kollsman Instrument Corporation;
- Owens-Illinois, Inc.;
- Tinsley Laboratories, Inc.;
- Kitt Peak National Observatory.

The report was organized around the three basic functions of program planning, facility planning, and cost estimation. The program planning included task descriptions, sequencing; and scheduling; and the facility planning consisted of identifying the significant MOT-unique requirements. Costs associated with this planning were prepared for the basic MOT system but did not include logistic and space station system costs.

2.0 SUMMARY

The MOT program plan and costs presented in this report cover the development of the MOT system concept and the subsequent program activity involved in the development and operation of the system. The estimates of schedules and costs for the program will support long range funding and establishment of subsequent MOT program activities. For this study, a MOT in-orbit mission of 5 years was used. The logistics and space station systems were not included in the study since it is believed they will be developed in other major programs.

The total MOT program has been structured into three major phases: the concept development phase, the project development phase, and the project operation phase. This structuring recognizes the cost accounting categories of nonrecurring costs involved in the concept and project development phases and recurring costs involved in the project operation phase. The program structure and its relationship to the NASA-phased project planning concept is shown in Figure 2-1. The concept phase is defined as including the conduct of numerous

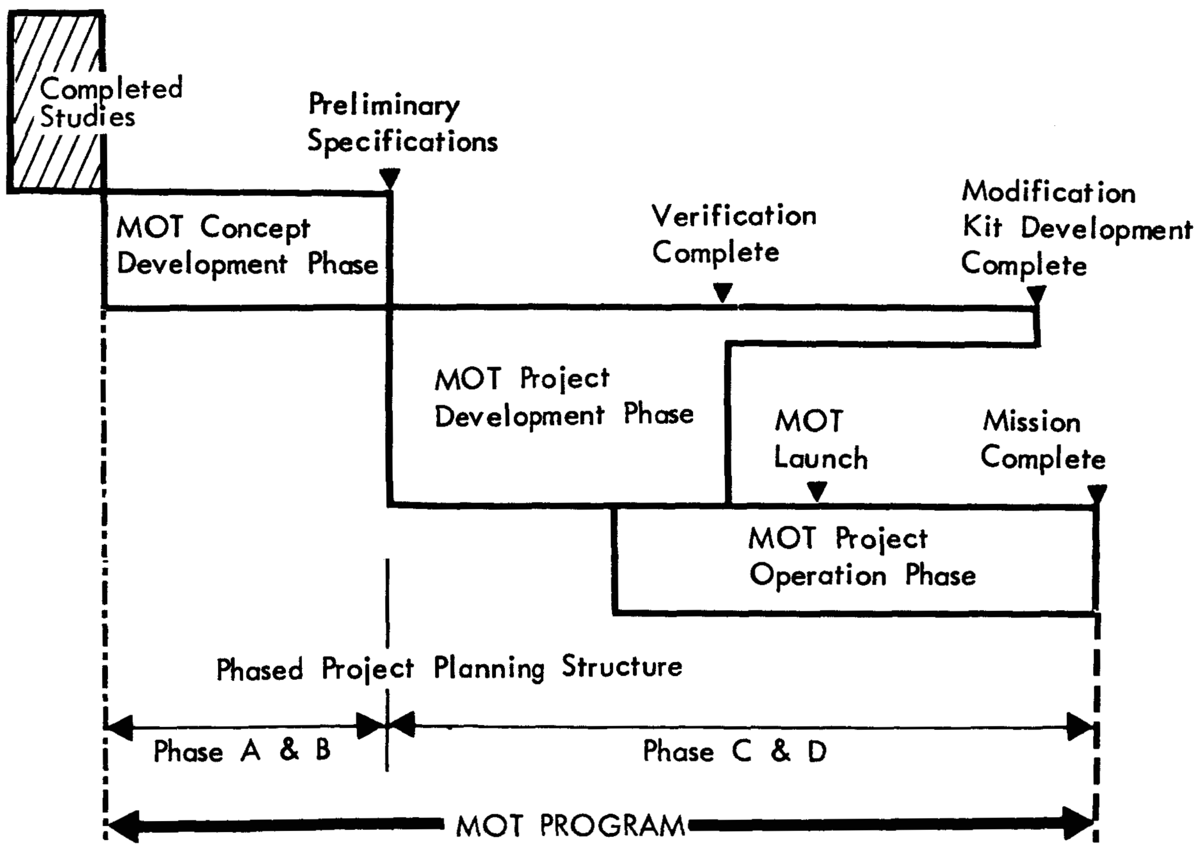

Figure 2-1: PROGRAM STRUCTURE

technical investigations leading to the selection of the most effective MOT system concept which will be defined in preliminary specifications at the completion of the the phase. After selection of the final system concept, detail development plans and costs will be prepared and used in the decision for implementing subsequent program phases. The project development phase includes the development of those elements that are typically project, such as personnel, facilities, MOT system equipment, and the supporting procedures and methods. A verification program demonstrating the adequacy of the project development is a key part of this phase. The project operation phase is divided into three segments. The first includes the factory operations to produce the MOT flight article utilizing the previously developed and verified project complex. The second includes Kennedy Space Center (KSC) operations to check and launch the flight article. The third is the mission operations from launch until completion of the mission, including control operations at Manned Space Center (MSC).

The configuration of the preliminary MOT system concept used in preparing the program plan and costs is shown in Figure 2-2. The principal configuration elements are the telescope, the MOT-unique equipment installed in the space station, the Saturn V launch vehicle, a universal shroud assembly for protecting the MOT during boost, logistic material periodically provided to the orbiting MOT such as spares, modification kits and supplies, MOT experiment control and data processing equipment located at the MSC mission control center, and astronaut training equipment. The telescope is approximately 60 feet long, 15 feet in diameter, includes a primary mirror of 120-inch diameter, and weighs about 28,000 pounds. Major subelements of the telescope are the optics; scientific instruments; structures and mechanisms; and attitude control, rendezvous, and miscellaneous flight support items.

2.1 PROGRAM PLANS

This section presents a summary of the total MOT program plan with the supporting concept development plan, project development plan, and project operation plan. The summary data is presented primarily in chart form illustrating significant program elements and their interrelationships.

2.1.1 MOT Program Plan

The total MOT program plan, shown in Figure 2-3, indicates the time sequencing of the three program phases and major events. A time span of 11 years is required from program start to MOT launch and 16 years to the end of the mission. The significant program event of selecting the final system concept occurs at the end of the third year. A major system interface occurs at the 10.5-year point, when the space station is required at Kennedy Space Center (KSC) for installation of MOT-unique space station equipment and checkout with the MOT flight model. The space station is launched shortly thereafter, at which time the first logistic system operation will be required to transport the crew to the space station.

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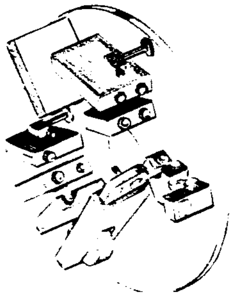
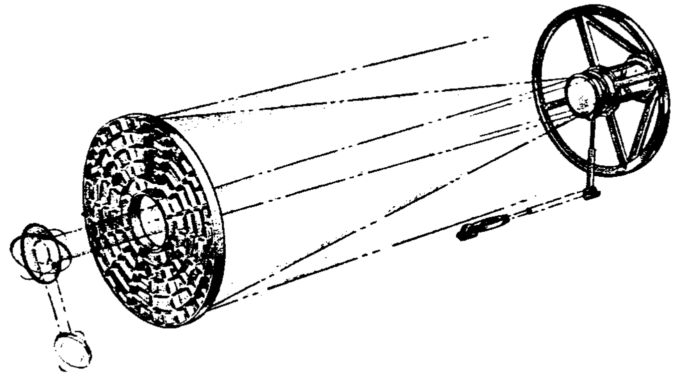
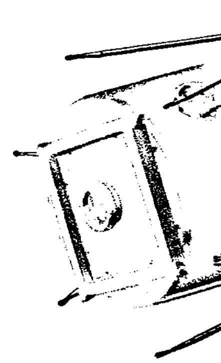
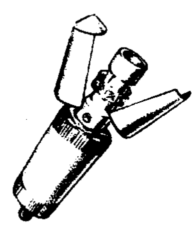


SCIENTIFIC INSTRUMENTS



OPTICS

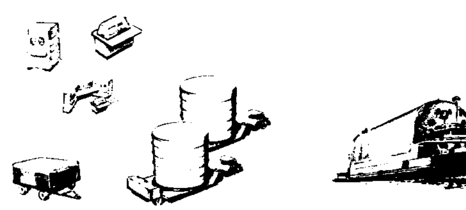




SHROUD ASSEMBLY

MOT-

SATURN V



GROUND SUPPORT EQUIPMENT

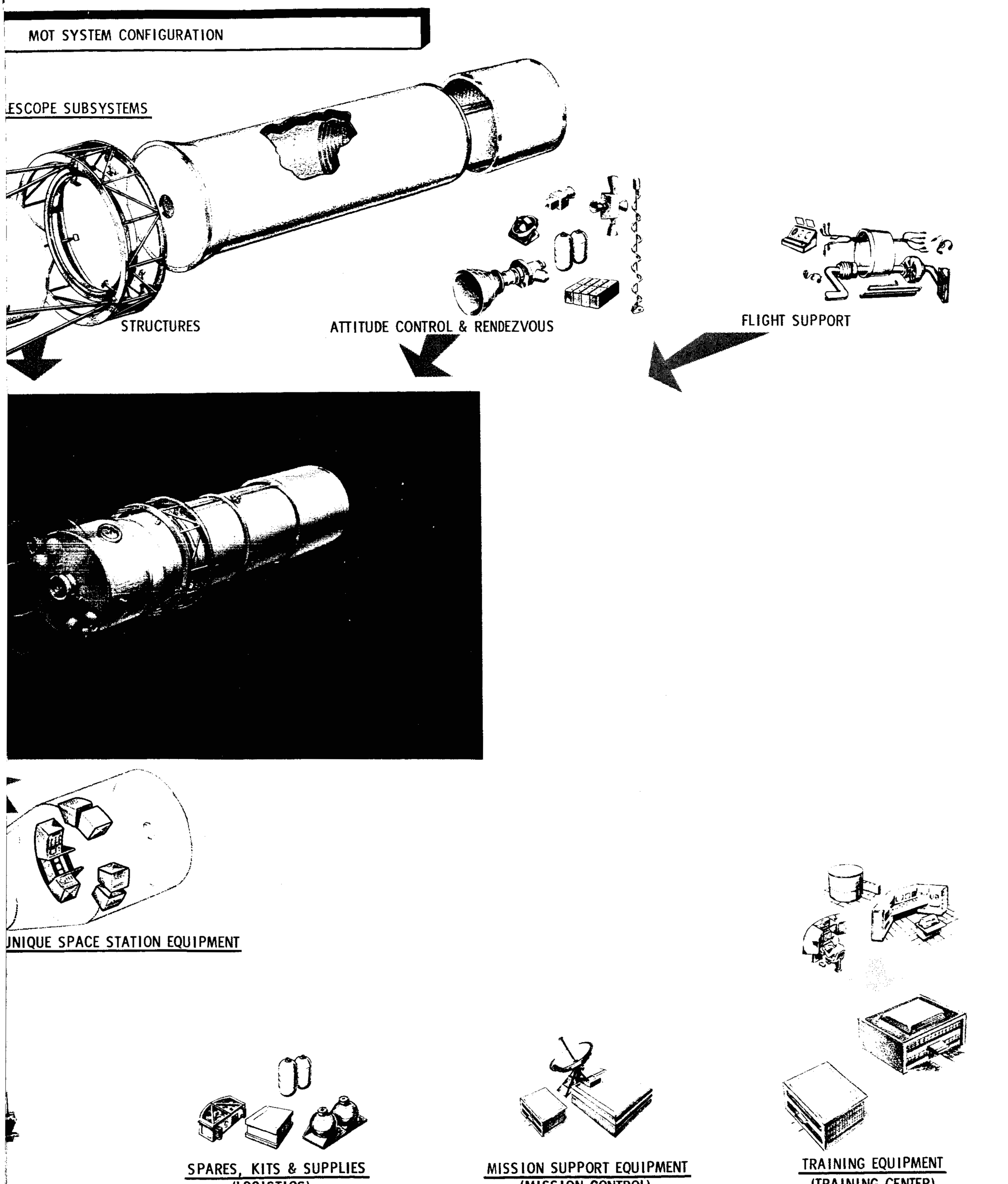


Figure 2-2: MOT SYSTEM CONFIGURATION

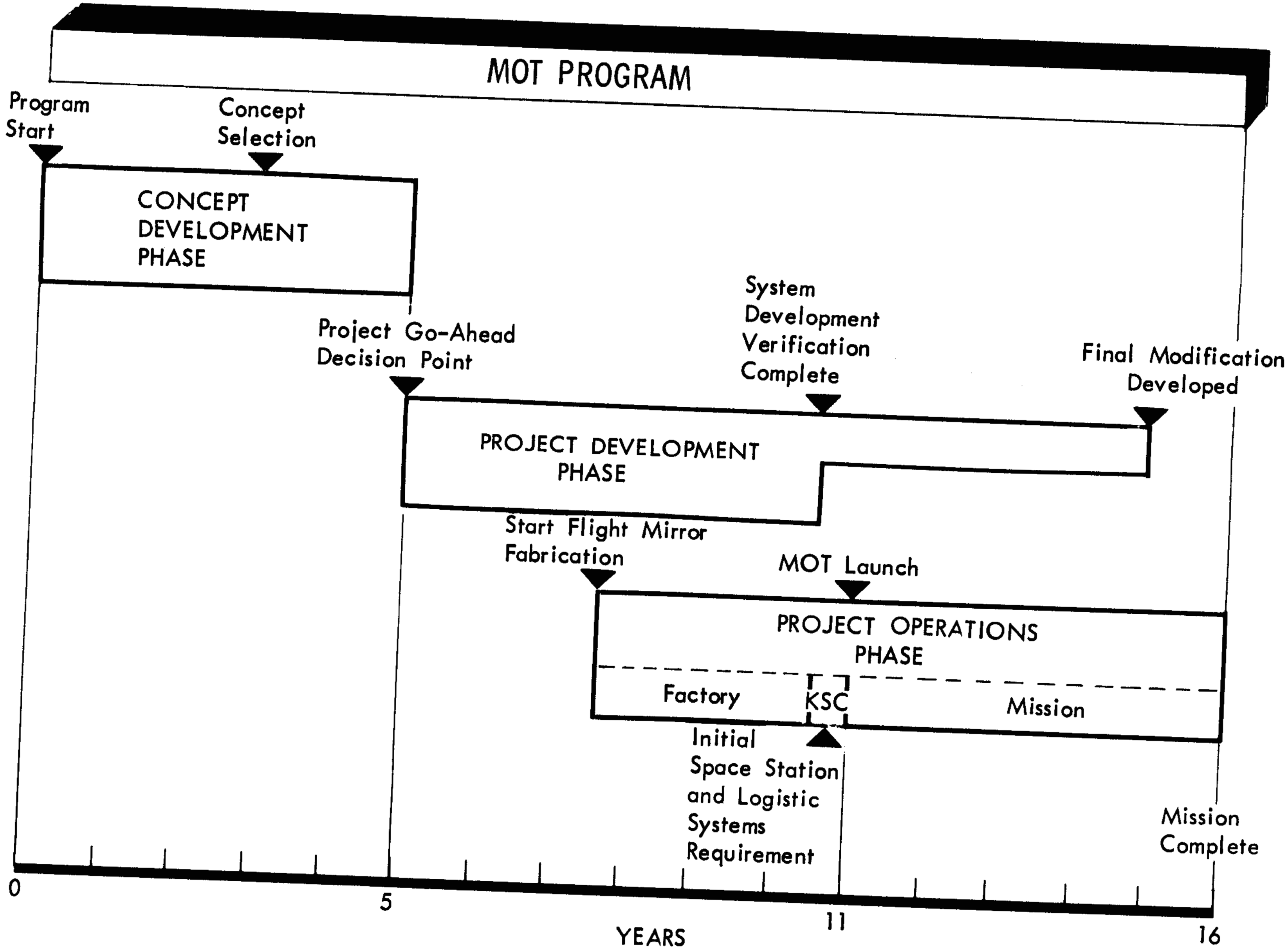


Figure 2-3: MOT PROGRAM PLAN

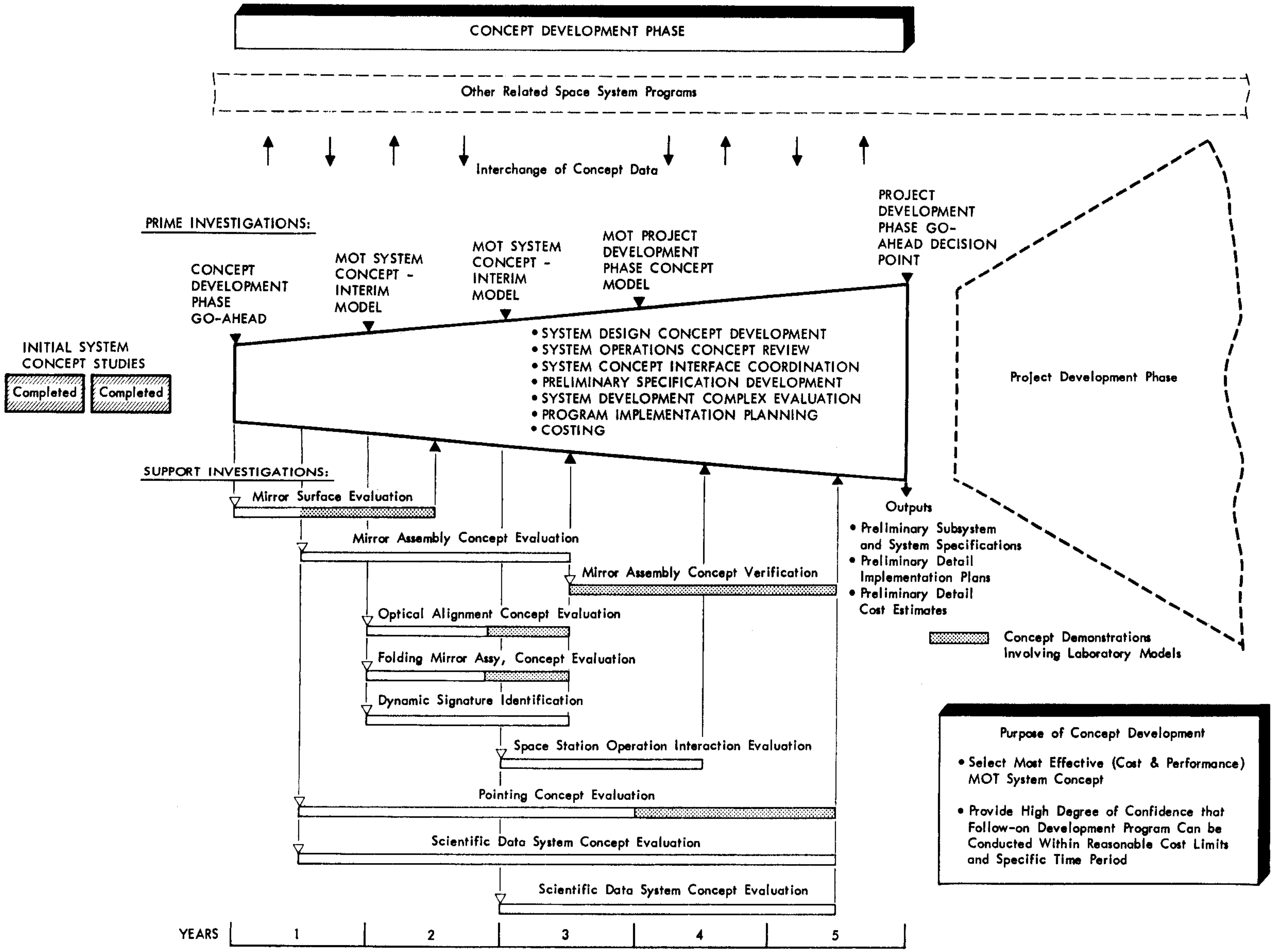


Figure 2-4: CONCEPT DEVELOPMENT PHASE PLAN

2.1.2 Concept Development Plan

Figure 2-4 shows the concept development plan outlining the steps to be accomplished between the completed study, which generated the preliminary system concept, and the project development phase that will develop the system equipment. The plan covers a 5-year time span including development of two interim system concepts with final system concept selection occurring at the end of the third year. The illustrated effort is one of a continuous and gradually increasing magnitude, culminating in preliminary specifications and detailed programming data for the selected MOT system concept. Seventeen investigations with some concept demonstrations are considered required during the 5 years to satisfy the purpose of the concept development phase. The plan recognizes the need to define the interface and phasing between the MOT and other major related NASA programs, such as Space Station, Logistic Vehicle, Orbital Astronomical Support Facility (OASF), Universal Shroud, and Apollo Applications Program (AAP).

2.1.3 Project Development Plan

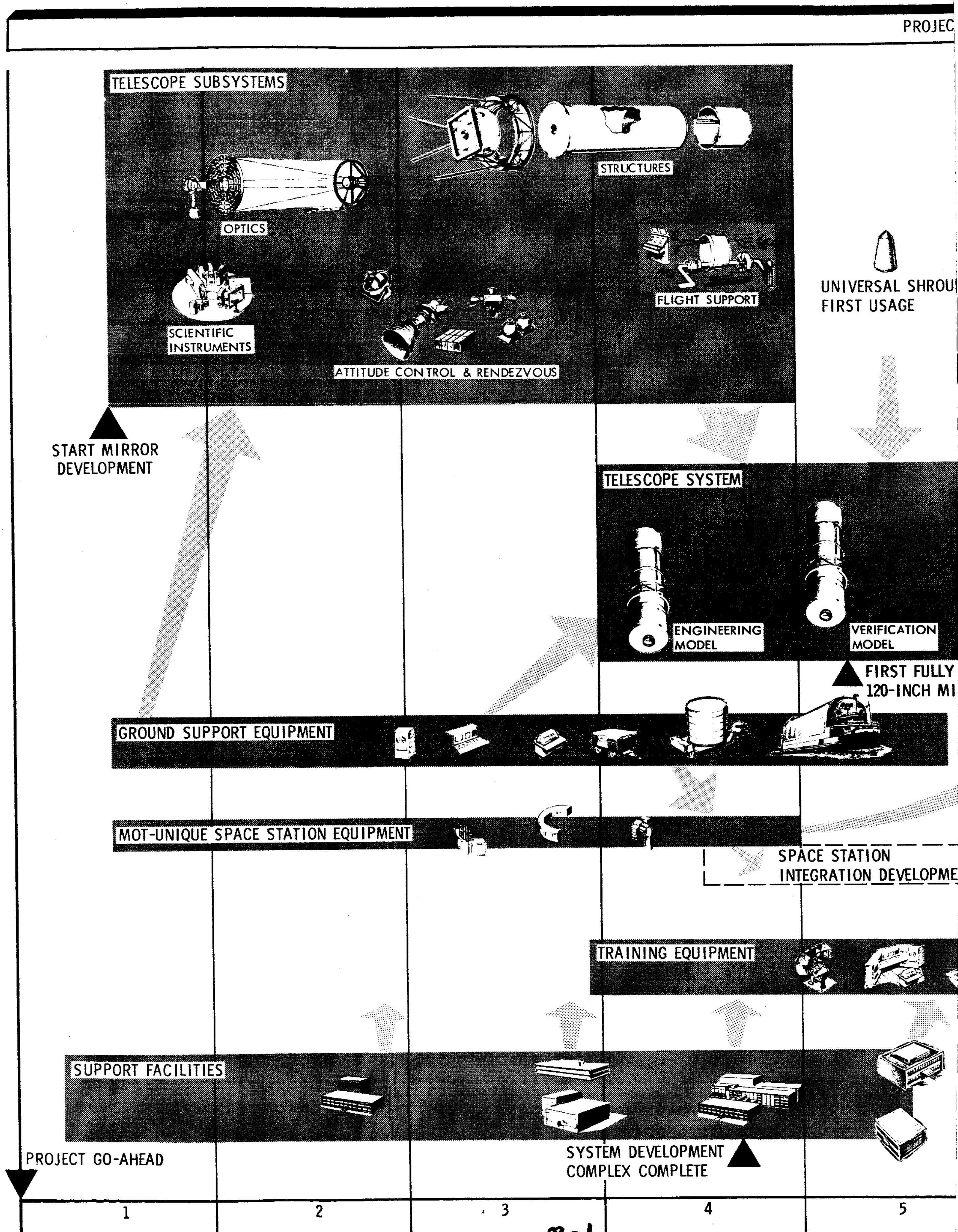
This plan covers the MOT project development and verification activities required to produce and operate the MOT system. The plan is presented in Figure 2-5 and shows 5.5 years to completion of system verification and 10 years to final modification development in support of the mission. The activity in this phase was divided into seven key development elements discussed below.

Telescope Subsystem — Development and verification of parts, components, subassemblies, assemblies, and subsystems are included under the telescope subsystem development. Early in the development program, a complete full-size structural model is used for static and dynamic verification testing, and a second full-size structural model is used for thermal evaluation testing.

MOT-Unique Space Station Equipment — These items are developed and verified as individual units and then integrated with the telescope and space station.

Ground Support Equipment — This equipment is developed to support both the telescope and the MOT-unique space station equipment, and consists of transportation and handling, checkout, and service equipment.

Telescope System — Development of the telescope system involves using three full-size major articles: engineering, project verification, and qualification. The engineering model is used for informal testing of the subsystems. The project verification model is used to verify the factory operations and KSC project operations. This model is built, factory tested, transported to KSC, and processed at KSC in the same manner as the flight model. The qualification model is tested at the factory under extreme conditions to substantiate design limits.


TELESCOPE SUBSYSTEMS
OPTICS
STRUCTURES
FLIGHT SUPPORT
SCIENTIFIC INSTRUMENTS
ATTITUDE CONTROL & RENDEZVOUS
UNIVERSAL SHROU
FIRST USAGE
START MIRROR DEVELOPMENT
TELESCOPE SYSTEM
ENGINEERING MODEL
VERIFICATION MODEL
FIRST FULLY
120-INCH MI
GROUND SUPPORT EQUIPMENT
MOT-UNIQUE SPACE STATION EQUIPMENT
SPACE STATION
INTEGRATION DEVELOPME
TRAINING EQUIPMENT
SUPPORT FACILITIES
PROJECT GO-AHEAD
SYSTEM DEVELOPMENT COMPLEX COMPLETE
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2
3
4
5

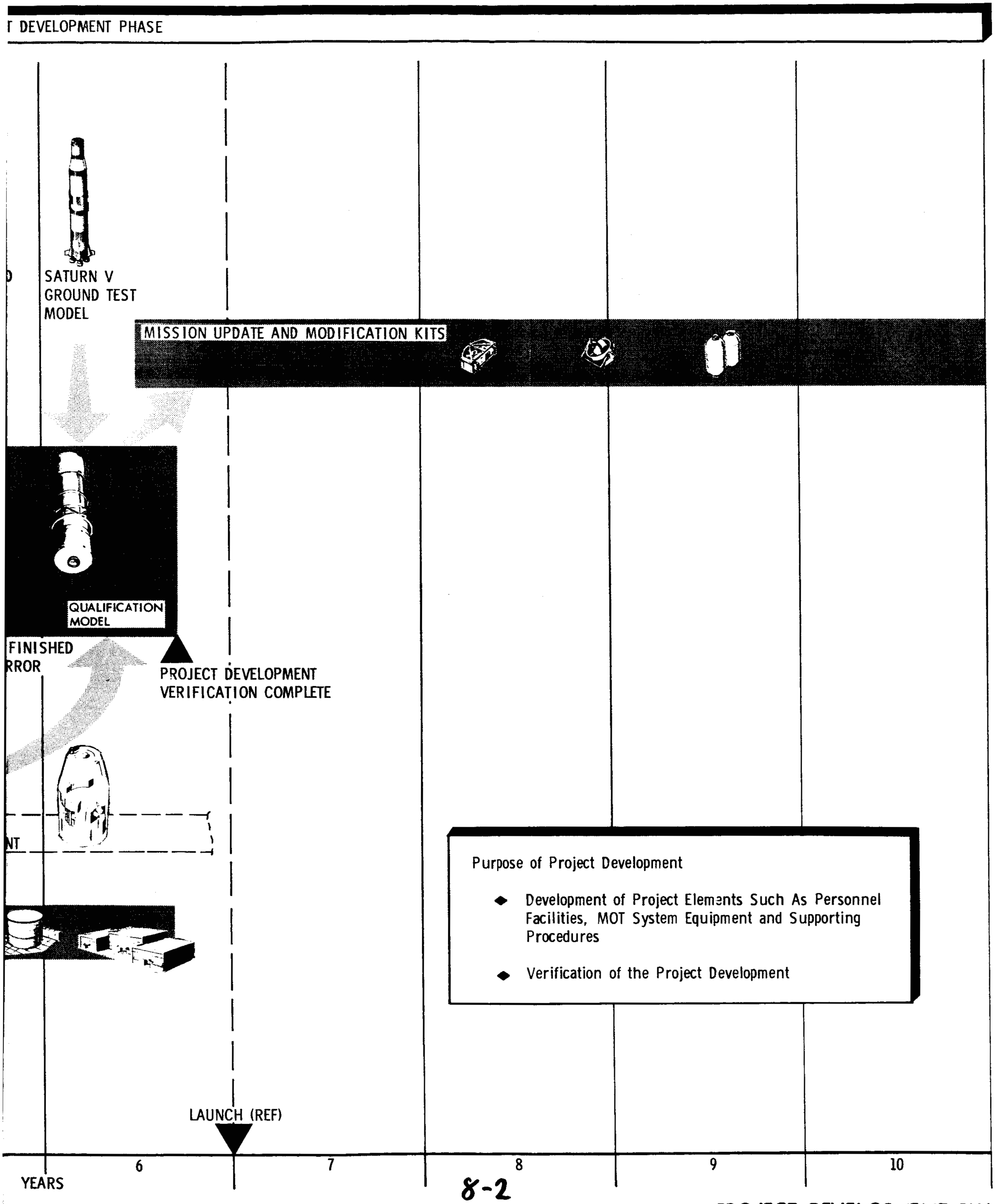

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Figure 2-5: PROJECT DEVELOPMENT PHASE

Astronaut Training Equipment — This is divided into two types: part task simulation and mission simulation. The part task simulator is used for training the astronaut in the telescope and space station tasks. The mission simulator is used for training the astronauts in operations related to ground-based mission control.

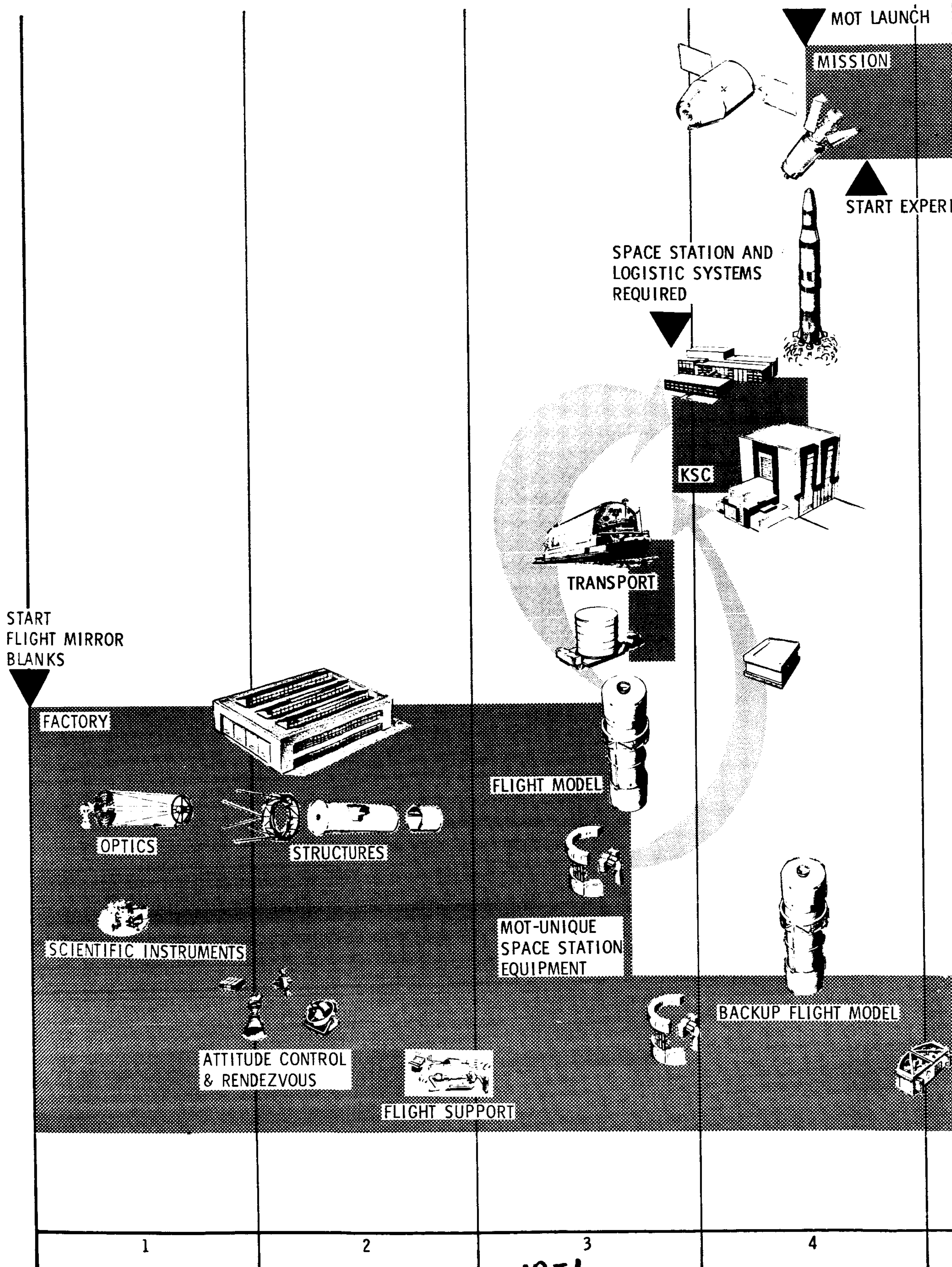
Facilities and Related Equipment — Proper timing is essential for completion of the facility complexes required in the project development phase. Many of the facilities are considered of major proportions and requiring considerable effort to meet the program timing.

Mission Update Modification — The project development phase continues beyond the launch to support modification of the basic telescope equipment and modifications of the scientific instruments to fit particular experiment requirements. Verification of the development of the modifications will be accomplished using the qualification model. The qualification model will also be used to duplicate troubles experienced in space during the mission to determine the required modifications.

2.1.4 Project Operations Plan

The operations phase is subdivided into factory, KSC, and mission operations elements as shown in Figure 2-6. The factory operations accomplishes production and testing of the flight model in 2.75 years, using the previously developed project system. As insurance against loss of the flight model due to a launch failure, a backup MOT is provided and available for shipment to KSC. This backup model is obtained by refurbishing the project verification model. The KSC operations, which were previously verified by the project verification model, accomplishes the processing of the flight model through launch in about 0.5 year. The processing includes reassembly, checkout with the space station, and assembly with the shroud. The total assemblage is then transported to the vertical assembly building (VAB) where it is mated to the Saturn V launch vehicle, which is then transported to the pad and launched. Previous to the MOT launch, the space station must be launched into orbit, manned, then checked and readied for the MOT.

In the 5 years of mission operation, the MOT is first placed in synchronous orbit, rendezvoused, and docked to the space station. The first 90-day operation is primarily an engineering activity to ensure proper system operation and performance. The remainder of the mission is devoted to experiments. The mission would be controlled through an engineering and experiment control center located at MSC. During mission operations, the factory would produce spares, modification kits, and expendable supplies. These logistic items would be transported to KSC for delivery to the MOT in orbit.


MOT LAUNCH
MISSION
START EXPERI
SPACE STATION AND
LOGISTIC SYSTEMS
REQUIRED
KSC
TRANSPORT
START
FLIGHT MIRROR
BLANKS
FACTORY
FLIGHT MODEL
OPTICS
STRUCTURES
SCIENTIFIC INSTRUMENTS
MOT-UNIQUE
SPACE STATION
EQUIPMENT
BACKUP FLIGHT MODEL
ATTITUDE CONTROL
& RENDEZVOUS
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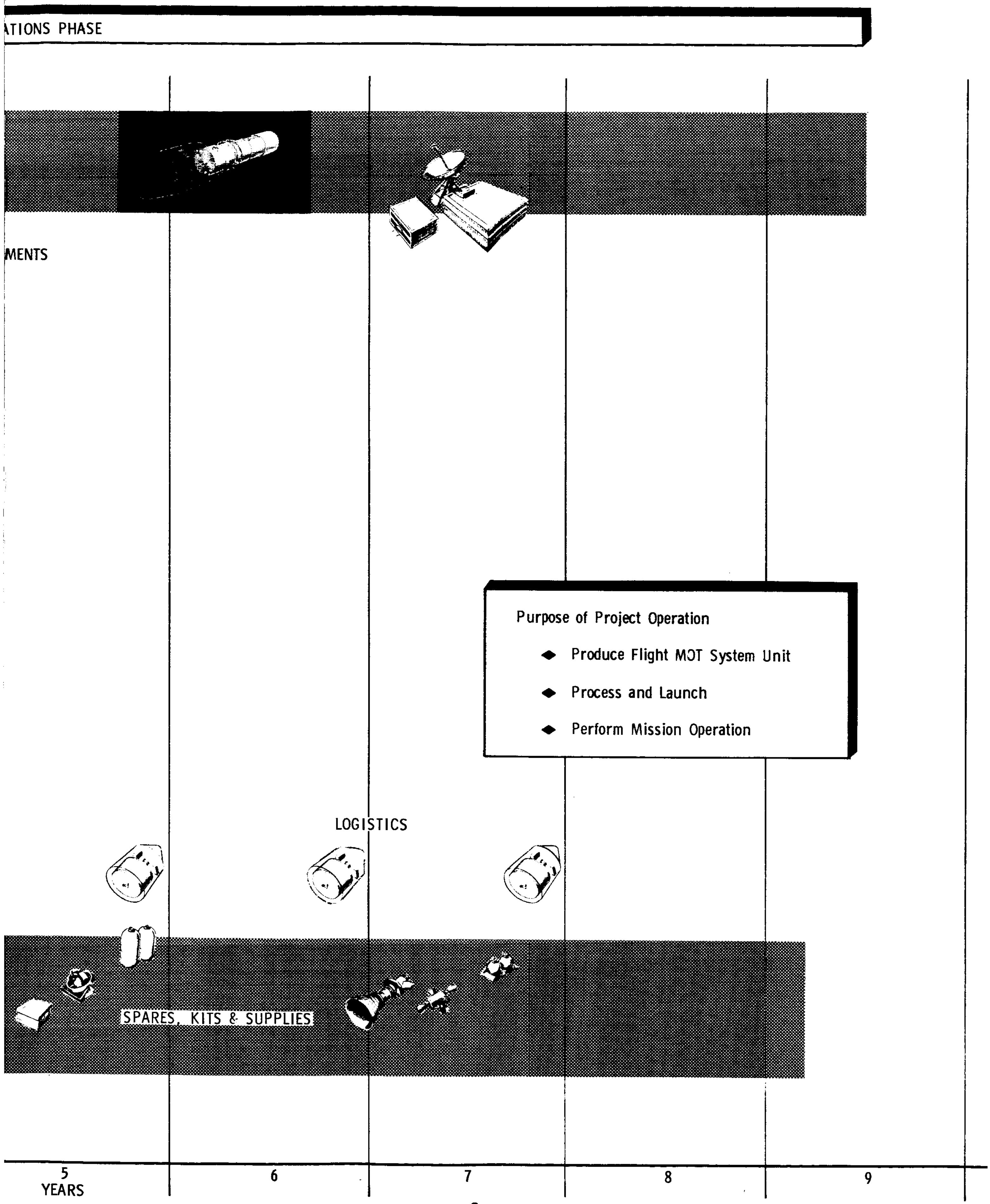

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Figure 2-6: PRODUCT OPERATIONS PHASE

2.2 FACILITY PLAN

The study has identified five new significant facility complexes required to support the program. These facilities are considered to be government-provided, based on the combination of their uniqueness to the MOT project and their cost magnitude, resulting primarily from the operating precision and physical characteristics of the system. Figure 2-7 shows the significant facility complexes with specific geographical location identified for those considered location-sensitive.

The facilities were selected on the basis of equipment similarity and sensitivity to transportation. The system development complex was located in the Michoud area to allow shipping the telescope directly to KSC in a vertical position, with minimum disassembly, in a protected transportation environment, and using the existing Saturn water-transportation system. This approach minimizes retesting at KSC and avoids the requirement for an expensive system test complex at KSC. The cost of new facilities and related equipment required for the program is estimated at $113,000,000, including the system development complex cost of $56,000,000.

2.3 PROGRAM COSTS

The estimated cost of the total MOT program is $1,300,000,000, expended over 16 years with a peak yearly expenditure of $250,000,000 occurring in the eighth year as shown in Figure 2-8. The costs for each of the program phases and their respective total program cost percentages are $57,000,000 (4%) for concept development, $1,000,000,000 (77%) for project development, and $240,000,000 (19%) for project operation. The trends of program cost with variation of telescope size and performance are also shown in Figure 2-8. The telescope size-versus-cost chart shows program costs to be relatively insensitive to variation of telescope diameter. This relationship may become significant should the Saturn V payload capability be more fully used than for previous studies.

The telescope performance variation with costs chart indicates systems with performance less than the preliminary system concept to be relatively insensitive to cost. For performances better than the preliminary system concept, approaching that requiring an ideal mirror finish, the program cost increases rapidly. Basically, the mirror in relationship to the other program items is not of major cost proportions until the near ideal surface finish is approached. This chart also shows that at a small cost increase, the preliminary system concept telescope has a significant performance advantage over a similar orbiting telescope having performance capabilities equivalent to Earth-surface observatories. In summary, the cost results indicate that the preliminary system concept performance is cost effective and that further investigation should be made regarding use of a larger primary mirror.

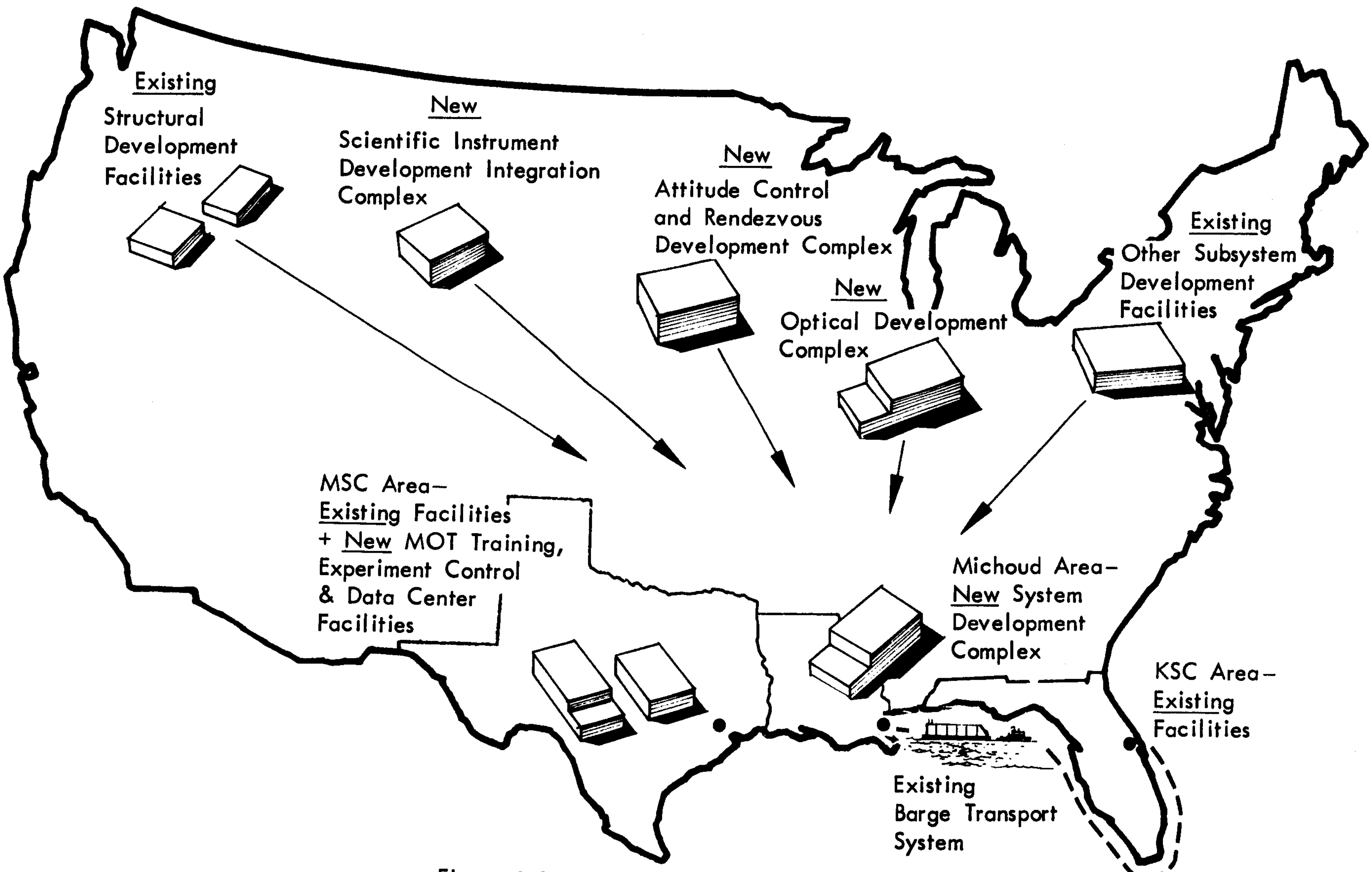
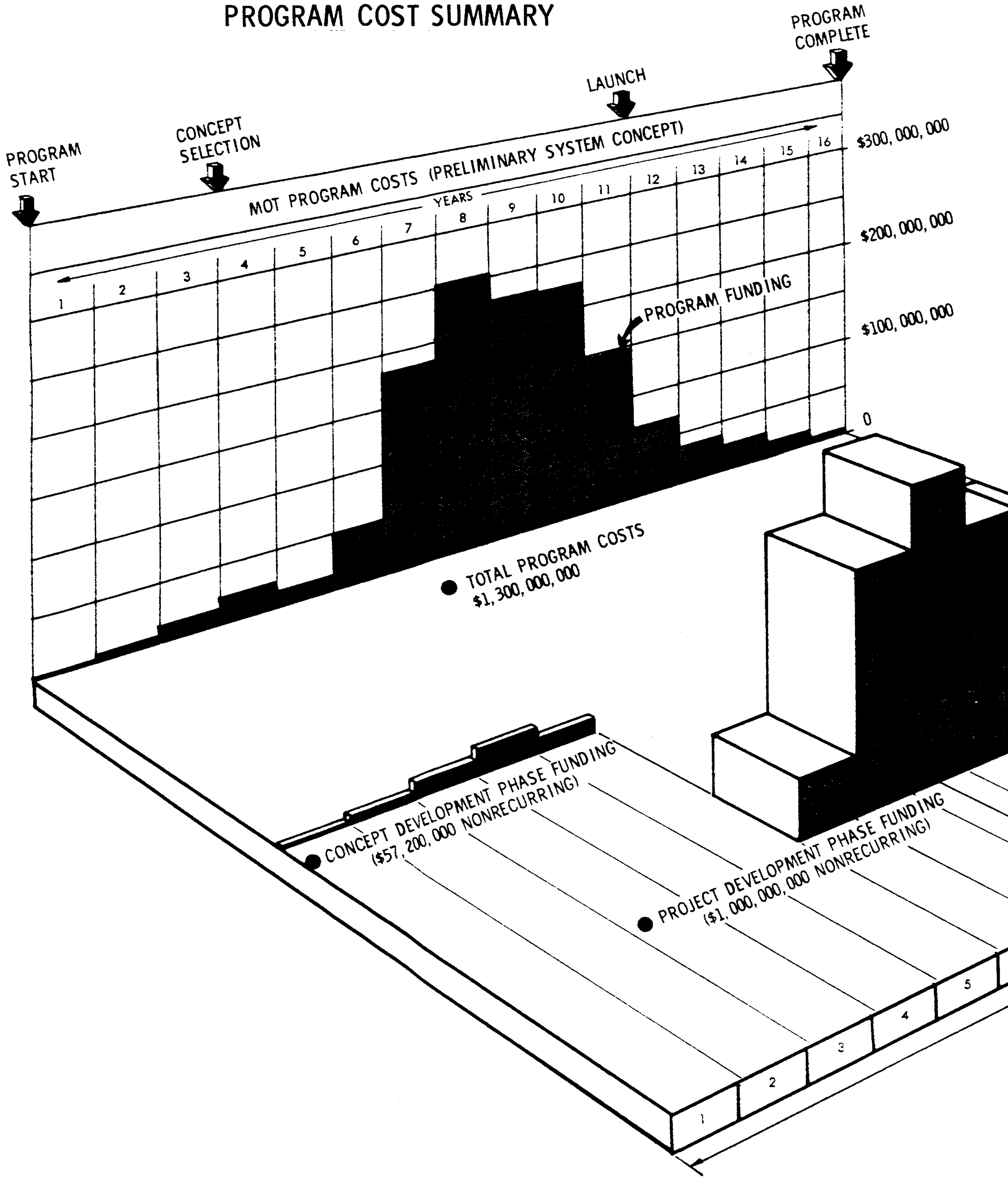
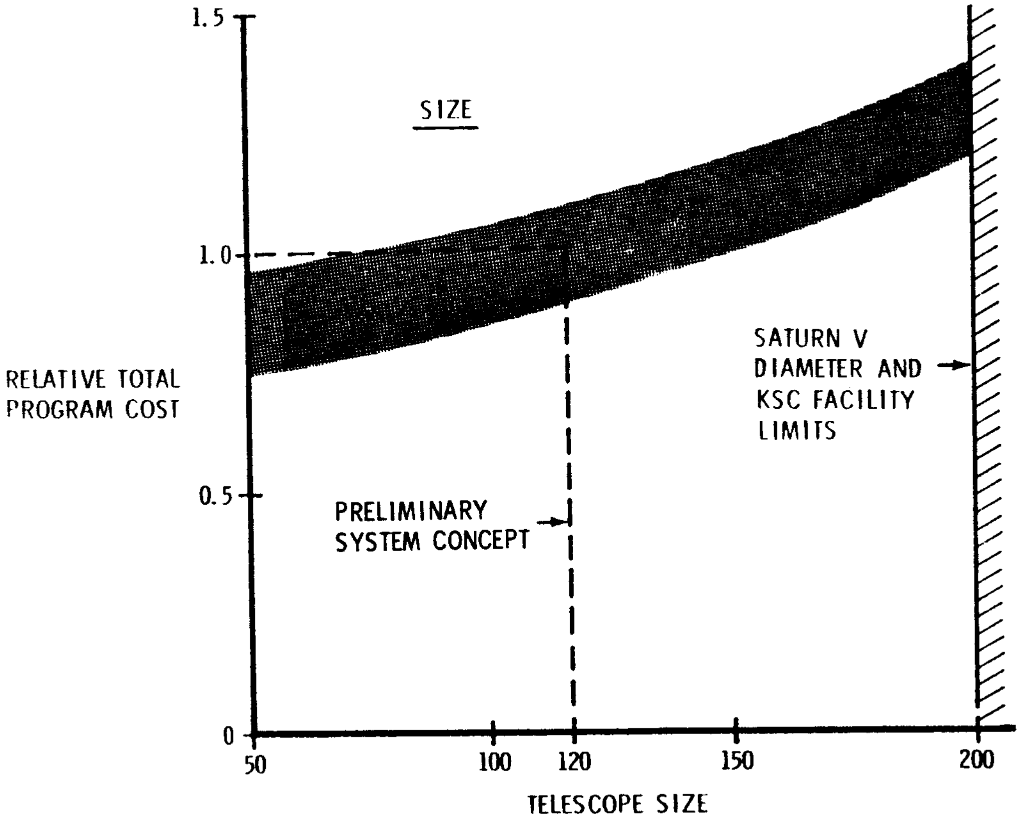


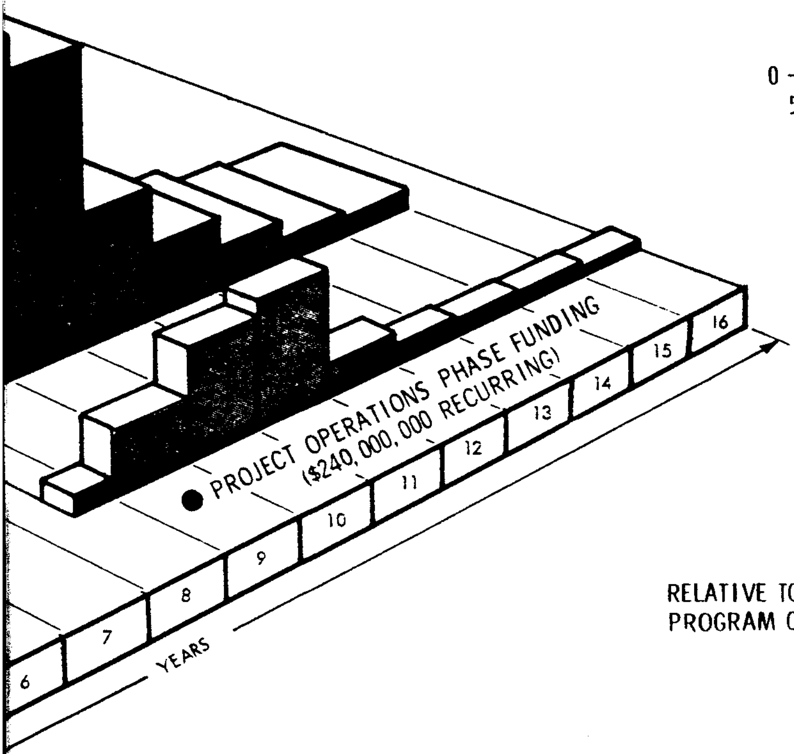
Figure 2-7: MOT FACILITY PLAN

PROGRAM COST SUMMARY



RELATIVE COST VS SIZE AND PERFORMANCE





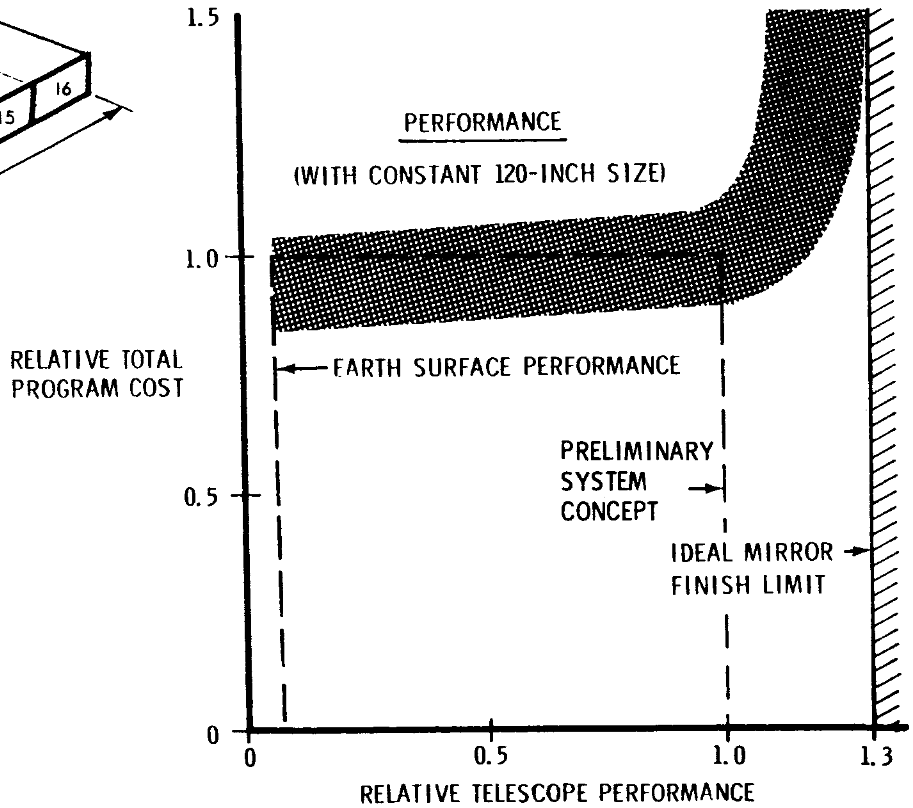


Figure 2-8: MOT PROGRAM COST

2.4 CONCLUSIONS

The significant study conclusions are:

1) There are several development problems considered of major proportion pertaining to the telescope portion of the preliminary system concept:

   a) The sensor system concept for fine pointing of the telescope requires further definition and development.

   b) The primary mirror structural system concept requires extensive definition to provide confidence in maintaining the mirror optical shape to the MOT accuracies.

   c) The structural intertie between the scientific instruments and the optical system must be designed to maintain relative microposition during orbital operations.

2) The use of beryllium for the primary mirror presents high development risks. Current beryllium material data indicates nonuniform volumetric thermal expansion and stress retention characteristics that might seriously degrade the mirror optical performance.

3) The concept of ground testing the MOT system is of major significance, since testing to full performance accuracy will require a test system of greater accuracy than the MOT.

4) Major elements of the system concept should be further defined before hardware development is initiated.

   a) The concept of the space station used with MOT should be reviewed. This review should include such concepts as a multipurpose space station launched separately, a separately-launched special MOT space station with multipurpose subsystems, and an integrated MOT and space station configuration involving a single launch.

   b) The telescope size should be reviewed with respect to effective use of the launch vehicle capability. This should include the possibility of a combined MOT and space station launch configuration.

   c) Methods for minimizing logistics system operations should be pursued because of the very high cost anticipated for a 5-year mission. Methods considered should include remote operation of the telescope from the ground with telescope-to-ground data transmission. Remote operation would then be supplemented with occasional logistics operations, to include man for maintenance and very accurate telescope experiments.

5) An intermediate-size telescope is not considered of significant value as a development stepping stone to the full-size MOT. Results of in-orbit operation of the smaller telescope would require excessive extrapolation for development application to the full-size MOT.

6) The figuring and finishing aspects of the optics to the accuracy of the preliminary system concept is not an expensive operation but does involve considerable time.

7) The telescope performance requirements selected for the preliminary system concept are considered cost effective.

8) MOT system performance gains might be realized by improvements in the instrumentation concept.

9) An advisory MOT committee of astronomers should be established to provide consultation throughout the concept development of the system to ensure its applicability.

2.5 RECOMMENDATION

It is recommended that the follow-on MOT activity be the conduct of a concept development program as described in this study. The decision required to implement this recommendation should consider the following aspects:

1) To obtain maximum effectiveness, the follow-on activity should include a continuous thread of increasing magnitude as opposed to intermittent activity lacking continuity.

2) Although the MOT operational date may be many years off, a methodical program initiated sufficiently early will provide the most effective results as opposed to later initiated compressed programming.

3) It is believed inevitable that a telescope of the MOT type will be developed. Therefore, early technology and conceptual development activity in the MOT area will be applicable even though the specific operational date may be uncertain.

3.0 PROGRAM PLANNING

This section of the report describes the basic program planning on which the succeeding facility planning and cost estimating were conducted. This planning was structured around the three program phases of concept development, project development, and program operation as described in Section 2.1. Using the preliminary system concept configuration (derived during an earlier study), the project development and operation phases were planned as illustrated by Figure 3-1.

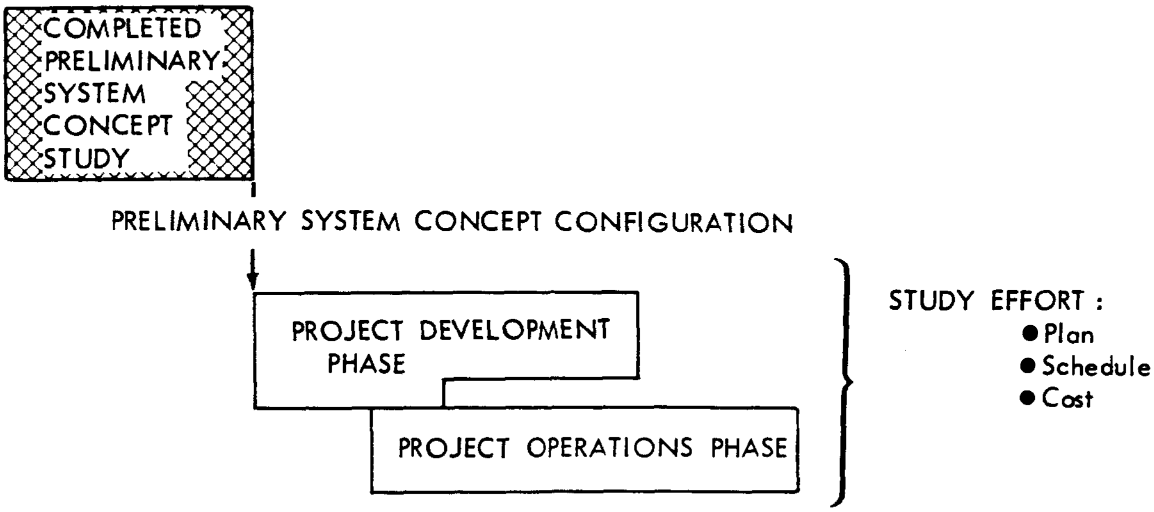


Figure 3-1: PROJECT DEVELOPMENT AND OPERATION PHASE PLANNING CONCEPT

Following this planning effort, an analysis was made to identify significant development problems. This analysis included a review of the results of the industrial survey conducted during this study.

From analysis of the development problems, it was concluded that the program as planned would be a high-risk program with respect to cost and schedules. Therefore, the concept development phase was developed so that these problems would be solved prior to the project development phase. This concept development phase and its relationship to the overall MOT program are shown in Figure 3-2.

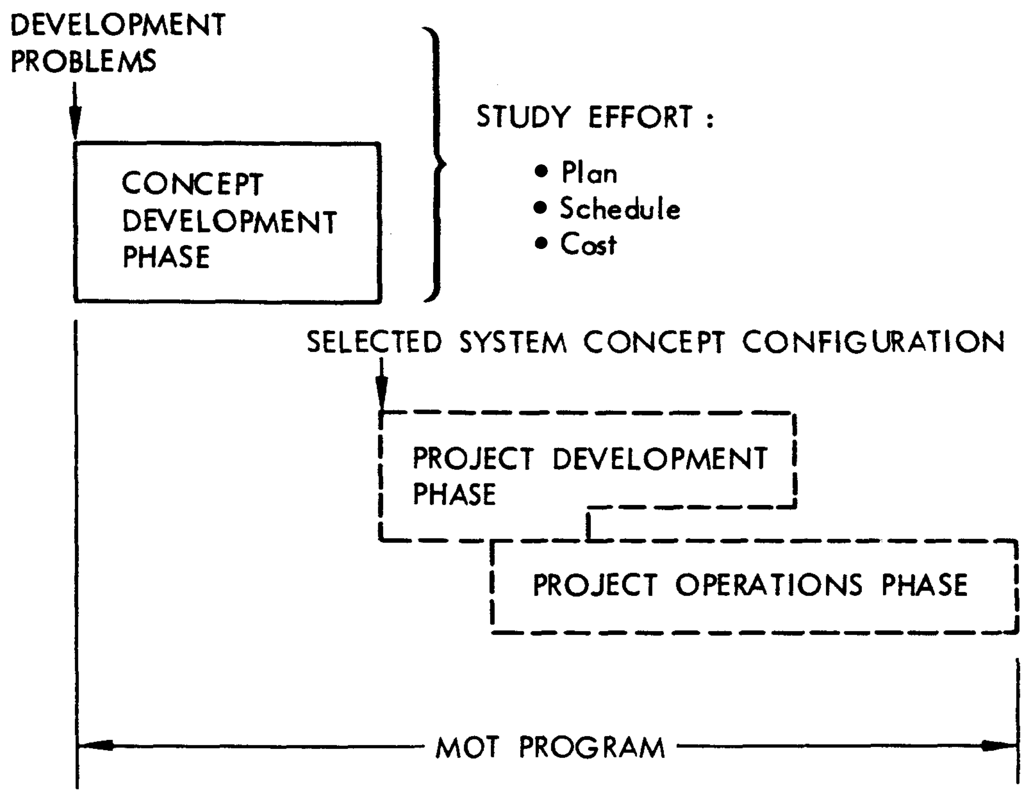


Figure 3-2: CONCEPT DEVELOPMENT PHASE PLANNING CONCEPT

A principal output from this phase will be the selected system concept, which the follow-on phase will develop and operate. It is assumed that the time and costs for the project development and operation phases for the preliminary system concept configuration are applicable to the same phases (Figure 3-2) for the selected system concept configuration. This assumption is considered valid since the depth of planning conducted is believed to be within the time and cost accuracy for either configuration. By following this approach, a total MOT program can at this time be planned in terms of both time and costs. The planning data presented in this section consists of development flows, equipment lists, list of development problems, investigation descriptions, work breakdown structures, program networks, and schedules.

3.1 PROJECT DEVELOPMENT AND OPERATION PHASES

The project development phase covers the development of project-type activities, such as human resources, facilities, MOT system, procedures, and verification of the adequacy of the development. The project operation phase includes the operation of the developed project to produce the flight model (FM) in the factory, transport it to Kennedy Space Center (KSC), process and launch it at KSC, and support its operation for a 5-year mission life. As a foundation for planning these phases, a model plan and a description of the preliminary system concept configuration have been prepared.

3.1.1 Model Plan

Planning for the two program phases has been based on the model plan presented in Figure 3-3. The planning has been organized to limit the models to a reasonable number and yet satisfy the development and operation requirements. In developing the structure, two models are used: one model is used to first accomplish the dynamic verification testing and then to conduct the static load structural verification testing. The second model is used to evaluate thermal characteristics of the structural system. Since the MOT design requires close thermal control over the optical and scientific instrument system, extensive thermal testing will be required on the structural system. The structure for these two models is considered to be of typical flight quality. Numerous models at subsystem level and below will be required of breadboard, prototype, and flight types. These subsystem models will be used for concept and design development and design qualification.

At the system level, three models are required for the project development phase: engineering model (EM), project verification model (PVM), and the qualification model (QM). The EM is used for informal testing of subsystem integration and system development. The equipment used in this model is prototype, coming primarily from the prototype subsystem models. The PVM is used to demonstrate the adequacy of people, paper, and equipment used to produce and process a flight model through the factory and KSC. For this task, the model contains 40% flight quality and 60% prototype equipment. The prototype equipment, such as primary and secondary mirrors, will be obtained from the subsystem model since this type of equipment is considered adequate for the purpose of the PVM. The third model (QM) is of full flight quality and is used to demonstrate design limit capabilities at the system level. After the design demonstration is complete, which will occur prior to launch, the QM will be used to provide development support to the mission. The QM, since it fully represents the flight model, will be used to duplicate and evaluate equipment difficulties being experienced in space. Also, it will be used to develop and verify equipment update modifications for the MOT in orbit. A full MOT-system mockup along with the EM, PVM, and QM are identified as major articles in this report.

Two models are required for the project operation phase — the flight model (FM), and a backup flight model (BFM). The BFM is produced by refurbishing the PVM used in the previous program phase. All prototype equipment in the PVM

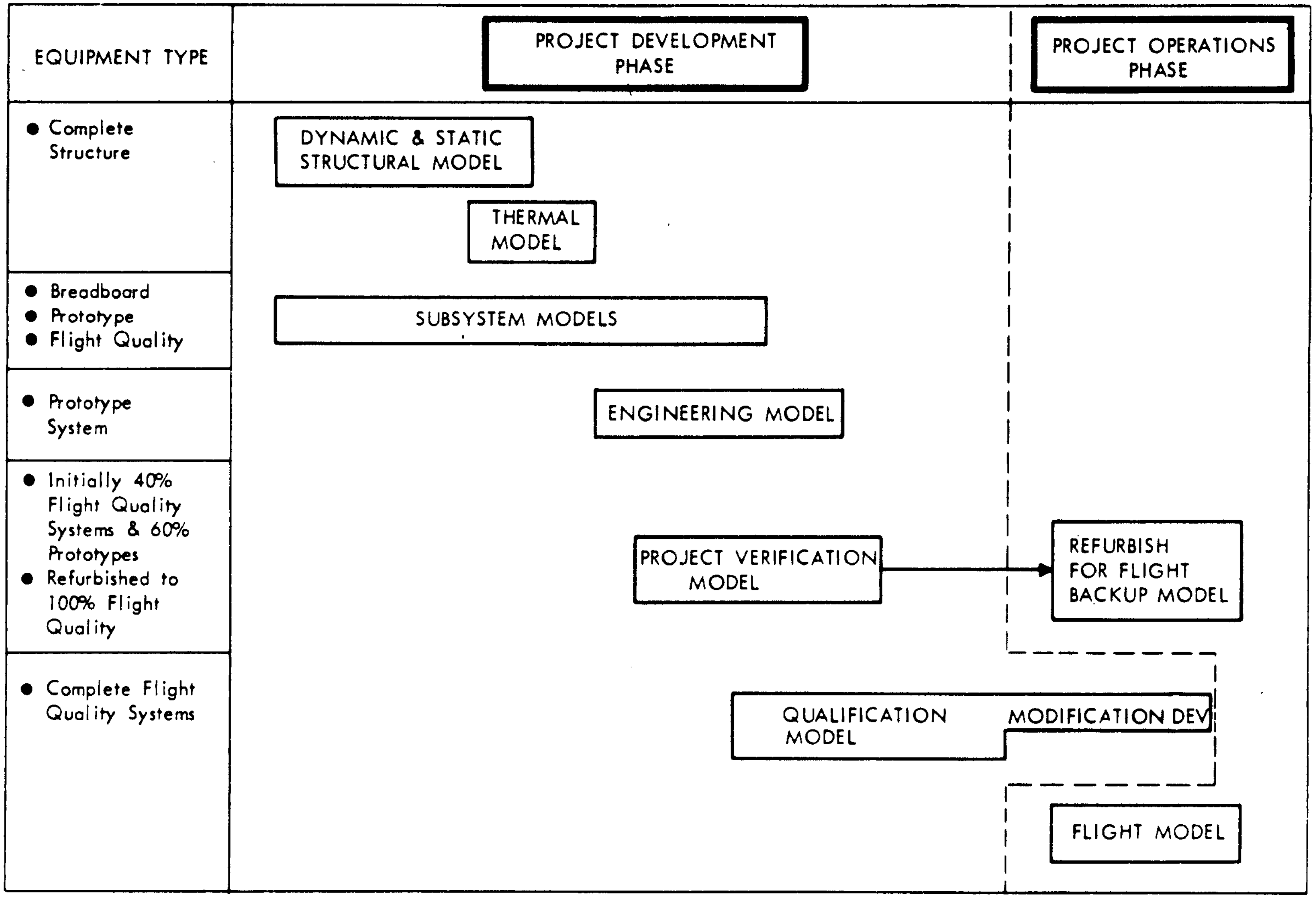


Figure 3-3: MODEL PLAN

will be replaced by flight quality equipment, and the completed model will be factory retested.

3.1.2 Preliminary System Concept

The preliminary system concept is based on previous MOT-system concept study (NASA Documents CR-66047 and CR-66102). The configuration top assembly, identified as the MOT project, has been subdivided as follows:

- MOT System
  - Telescope
    - Structures and Mechanism Subsystem
    - Optics Subsystem
    - Attitude Control Subsystem
    - Rendezvous Subsystem
    - Scientific Instrument Subsystem
    - Flight Support Subsystem
  - MOT-Unique Space Station Equipment
  - Ground Support Equipment (GSE)
  - Training Equipment
  - Mission Support Equipment
- Universal Shroud Assembly
- Launch Vehicle System
- Logistics Equipment

The following configuration description, as well as the program planning activity, has been structured around this configuration outline.

MOT System — As shown in the above outline, the MOT system comprises the equipment that is unique to MOT.

Telescope — The MOT configuration is designed around a diffraction-limited, 120-inch-diameter, Cassegrainian optics system and a system of astronomical instrumentation. The tube containing the principal optical components is attached to a cabin containing the astronomical instrumentation and the supporting subsystems for operation of the telescope and protection of the crew. The telescope in-orbit configuration is approximately 60 feet long, 15 feet in diameter, and 28,000 pounds in weight.

Structures and Mechanisms — The cabin of the telescope contains the instrumentation and operating equipment for the telescope and provides a protective environment for the crew when the cabin is occupied. The cabin shell is a cylinder with flat pressure-type bulkheads on both ends. A docking system and crew access tunnel are located in the center of one flat bulkhead, the telescope tube is attached to the cabin shell at the other end. A retractable pressure door between the cabin and telescope tube is opened during observations to unblock the optical path.

The telescope tube is of double construction: the inner tube supports the optical system, and the outer tube provides meteoroid and thermal protection. The inner shell, mirrors, mirror support structure, and the platen in the cabin (on which the scientific instruments are located) are mounted to the cabin as a unit by a truss system that isolates it from any cabin bulkhead deflections. The secondary mirror support and adjustment cell is attached to the inner tube by four truss-type struts. The primary mirror is attached to the inner tube by a three-point suspension system of tangent bars to minimize mirror distortions due to thermal variations.

An extendable section of the outer tube serves as a light shade during operation. Doors in front of the primary mirror protect the mirror surface, protect against earthshine when the telescope is pointed toward the Earth, and prevent possible exposure of the optics to direct sunlight. The telescope is thermally protected by low-absorptivity coatings on the outer surface and superinsulation around the inner tube.

An Apollo-type docking system is used for the initial docking of the MOT with the space station. After docking, connecting truss members are installed between the space station and the outer truss ring of the telescope soft suspension system. A flexible access tube is then installed to enable shirt-sleeve transfer between the space station and the telescope cabin. The soft suspension is an arrangement of gimbals and soft springs that effectively isolates the telescope from disturbances emanating from the space station. The suspension system is rigidized to permit slewing of the station-telescope combination for large angular changes.

Optics Subsystem — The optics system is a diffraction-limited modified Cassegrainian system consisting of an f/4, 120-inch diameter primary mirror, two secondary mirrors, and two flat folding mirrors. Equivalent focal ratios of ef/15 and ef/30 with 0.5-degree and 2.0-minute fields of view, respectively, are achieved through use of pertinent secondary and folding mirrors. For operation at ef/15, the light beam from the primary mirror is reflected off the ef/15 secondary mirror to a rotatable folding mirror behind the primary mirror. This folding mirror redirects the light into the ef/15 astronomical instrument being used. For operation at ef/30, the ef/15 secondary mirror is retracted to expose the ef/30 secondary mirror. The light is then reflected to the first folding mirror, which in this case is held in a fixed position and reflects the beam to a second rotatable folding mirror. The second folding mirror is rotationally indexed to direct the light into the instrument being used.

The f/4, 120-inch-diameter primary mirror is polished to a surface variation of $\lambda/30$ (rms) at 5000 Å — approximately 0.654×10^{-6} inch. A center circular opening of 34 inches in diameter allows passage of the light beam reflected from the secondary mirror. The beryllium primary mirror is a 0.625-inch-thick solid face, stiffened by a waffle grid back. Overall mirror thickness varies from approximately 7 inches at the center opening to 9 inches at the outer edge. The front surface is plated with Kanigen nickle for final polishing and aluminzed for high reflectivity.

The secondary mirrors are approximately 30 and 19 inches in diameter and manufactured to a surface accuracy of $\lambda/100$ (rms) at 5000 Å — approximately 0.196 x 10^{-6} inch. A small flat surface and reticle, located in the center of each mirror, are parts of the alignment and focus system.

Provisions for alignment and focus of the telescope optics are incorporated in an adjustable support mount for the secondary mirrors. The mirrors may be adjusted in tilt and lateral position for alignment correction, and in longitudinal position for focusing. Autocollimator units located inside the primary mirror opening sense offset and tilt of the small flat surface and reticle in the center of the secondary mirror. An interferometer unit, also located in the primary mirror opening, senses focusing adjustments required. The secondary mirror supports can be adjusted either manually or automatically to meet the following alignment and focus tolerances:

	ef/15	ef/30
Secondary-mirror tilt	±11.5 sec	±18.0 sec
Secondary-mirror lateral displacement	±0.007 in.	±0.007 in.
Secondary-mirror longitudinal displacement	±0.00062 in.	±0.00064 in.
Focus tolerance	±0.00885 in.	±0.0354 in.

Attitude Control Subsystem — The primary function of the attitude control subsystem is to provide high-accuracy pointing control of the telescope during astronomical observations. (Major changes in inertial orientation are performed by the reaction control system of the space station with the telescope gimbal system rigidized.) The space station control system orients the telescope line of sight to within ±0.5 degree of the desired object of observation. The telescope attitude control system then operates, with the gimbal unlocked, in the following three pointing modes to accurately acquire the object and maintain pointing stability:

Mode	Approx Angular Range of Operation	Stabilizing Accuracy	Sensors
Coarse Pointing	±1.0 degree	±3 minutes	Star trackers
Intermediate Pointing	±6 minutes	±2 seconds	Star trackers
Fine Pointing	±4 seconds	±0.01 seconds	Fine-pointing sensor in scientific instruments

Telescope-control torques are provided by control moment gyros. The gyros have sufficient momentum storage capability to operate continuously throughout the longest viewing period required and are desaturated as necessary by variable-thrust reaction jets.

The attitude control subsystem also operates to control midcourse corrections, plane changes, and telescope attitude during rendezvous and docking of the telescope with the space station. Control torques and forces during these operations are provided by the reaction jets.

Rendezvous Subsystem — The terminal rendezvous maneuver consists of any necessary plane change and correction of guidance and control errors at the end of the Hohmann transfer into synchronous orbit, to place the MOT in the proximity of the space station. Rendezvous guidance commands to the MOT are received from the space station, which tracks the MOT by radar and direct vision and computes the MOT maneuver commands.

The terminal rendezvous maneuver is performed with two 1000-pound-thrust, multiple-restart engines aboard the MOT. Rendezvous guidance equipment in the MOT consists of a radar transponder and command receiver for operation in conjunction with the space station tracking and command equipment. Batteries in the MOT provide electrical power for the MOT rendezvous subsystem.

Scientific Instruments Subsystem — Nine scientific instruments are used with the MOT:

For ef/15:

- Wide-field camera (0.5 degree) includes astigmatism corrector lens for telescope optics
- High-dispersion ultraviolet spectrometer
- Low-dispersion ultraviolet spectrometer
- Low-dispersion spectrograph

For ef/30:

- Narrow-field camera ($<$ 10 arc-minutes)
- High-dispersion spectrograph
- High-dispersion infrared spectrometer
- Photoelectric photometer
- Thermoelectric photometer

These scientific instruments are arranged within the telescope cabin in two circular groupings, one for each effective focal length. In addition, a television camera is located in each group for real-time remote viewing of the target area.

Flight Support Subsystems — A pressurized, life-supporting environment is maintained in the cabin when it is occupied by a crew member for setup, servicing, and maintenance operations. Before periods of observation, the cabin is depressurized by pumping down and storing the air. Facilities for performing these functions are provided by the space station environmental control subsystem.

Batteries in the telescope supply electrical power during launch, rendezvous, and docking operations. After docking, electrical power is drawn from the space station.

Radio equipment in the telescope receives commands from the space station during rendezvous and docking. After docking, a hardline hookup between the telescope and space station will be used for communication and data transfer. Monitoring units, including the TV cameras located with the scientific instruments, will use a hardline hookup. Data will be transmitted to ground installations via the space station systems.

MOT-Unique Space Station Equipment — Unique equipment located in the space station and used for support of the MOT includes:

1) MOT Operations and Control Station

- A console of readout instrumentation and controls for monitoring and controlling the conditions and operation of the telescope
- Intercommunication system for support of MOT operations
- MOT cabin atmosphere pumpdown system
- MOT electronics, except MOT-located attitude control and rendezvous subsystems electronic components

2) Rendezvous Control Station

- Tracking radar and command equipment for directing the MOT during rendezvous and docking
- Docking and attachment equipment

3) Power Distribution System

- Equipment for supplying electrical power and atmosphere support to the MOT after docking with the space station

Ground Support Equipment — The ground support equipment for the MOT system consists of (1) handling and transportation equipment for processing the MOT subassemblies and assemblies through and between the various facility complexes (2) checkout equipment for testing the ability of flight articles to meet their performance requirements and (3) servicing equipment for preparing the flight articles for launch.

Training Equipment — Two types of crew training centers are required for the MOT. One consists of part task trainers concerned with the operation of the telescope, its subsystems, and the supporting MOT-unique equipment located in the space station. A mission training center provides for the training of crew members with respect to mission operations between the space station and the ground-based mission control center.

Mission Support Equipment — Control of the MOT orbital operation will be directed by the existing mission control center located at Manned Space Center (MSC). The mission control center functions will be supported by two control subcenters: engineering and experiment. The subcenters, in addition to performing the control support function, will receive and process their respective type data received from the space station. Existing MSC facilities and equipment are considered adequate in performing the engineering functions. A new facility, including equipment, will be required to handle the MOT experiment control and data functions.

Universal Shroud Assembly — The baseline MOT configuration assumes that a universal shroud and Saturn V adapter have been previously developed as multipurpose devices and are available for the MOT project development and operation.

Launch Vehicle System — The selected MOT configuration was for a synchronous orbit operation and therefore the launch vehicle required is a Saturn V. No significant modifications are considered required for the launch vehicle.

Logistics — It is assumed that the logistics delivery requirements for the MOT will be accommodated by the logistics system supporting the space station. Specific logistics items requiring delivery to the MOT in orbit will include (1) expendable supplies, (2) spares, and (3) equipment and material for updating of the scientific experiments and telescope as these modifications are determined throughout the orbital lifetime of the MOT. Physical return of the scientific data will be accomplished in conjunction with rotation of the space station and MOT crew members to the Earth.

3.1.3 Project Development Planning

The detail project development planning was accomplished by preparing development flow plans for significant elements of the MOT project. The plans follow a basic pattern of first showing the development function for the particular equipment and then showing the verification functions demonstrating development completion. Traditional design qualification functions are indicated and are considered in the overall planning as satisfying the verification demonstration requirements. Design is considered to be included in the development functions. The flows have been structured around the model plan described in Section 3.1.1 and the configuration top assembly subdivision as described in Section 3.1.2.

Structures and Mechanism Subsystem — The development plan for this subsystem is shown in Figure 3-4. A significant activity is required to develop material and process specifications for this and other subsystems. The environment accuracy and life requirement of the orbital system will require extensive material evaluation and good process definition and control. Various prototype subassemblies will be required to develop the subsystem design. The primary level of activity for this subsystem is the testing of the structural dynamic and static model and the thermal model. The models are full size and of typical flight quality structure. The dynamic tests will demonstrate the basic dynamic design of the structural subsystem and will verify equipment mounting dynamics by using simulated equipment masses. After the dynamic tests are completed the structure will be subjected to static load tests verifying strength and deflection characteristics. The thermal model with simulated equipment heat loads is tested extensively in a vacuum chamber having solar and deep space thermal capabilities. The thermal control capability of the structural design will be verified, and the expected temperature conditions on the critical equipment elements (e.g., optical mirrors) will be determined. Due to the high-performance requirement of the MOT, very accurate temperature control of the critical telescope elements is necessary. The present preliminary system design provides a temperature of approximately -120°F on the primary mirror with a temperature variation across the mirror of no greater than ±0.01°F. Further design concept effort is required to verify this thermal requirement; however, it does illustrate the need for rather extensive thermal testing.

Optical Subsystem — The development plan for this subsystem is shown in Figure 3.5. Development effort below the subsystem level is divided into four assembly areas: primary and secondary mirrors, the folding mirror assembly including actuation system, secondary mirror automatic alignment assembly, and the ef/15 secondary mirror interchange assembly.

Development of the mirror blanks is the first step in the total mirror development. The primary blank is made by first grinding cast beryllium into fine powder. The powder is then placed in a mirror-shaped die and pressed to approximately 1500 psi at 2000°F. Existing blank size fabrication capability is about 80 inches, using the largest existing press in the United States — 50,000

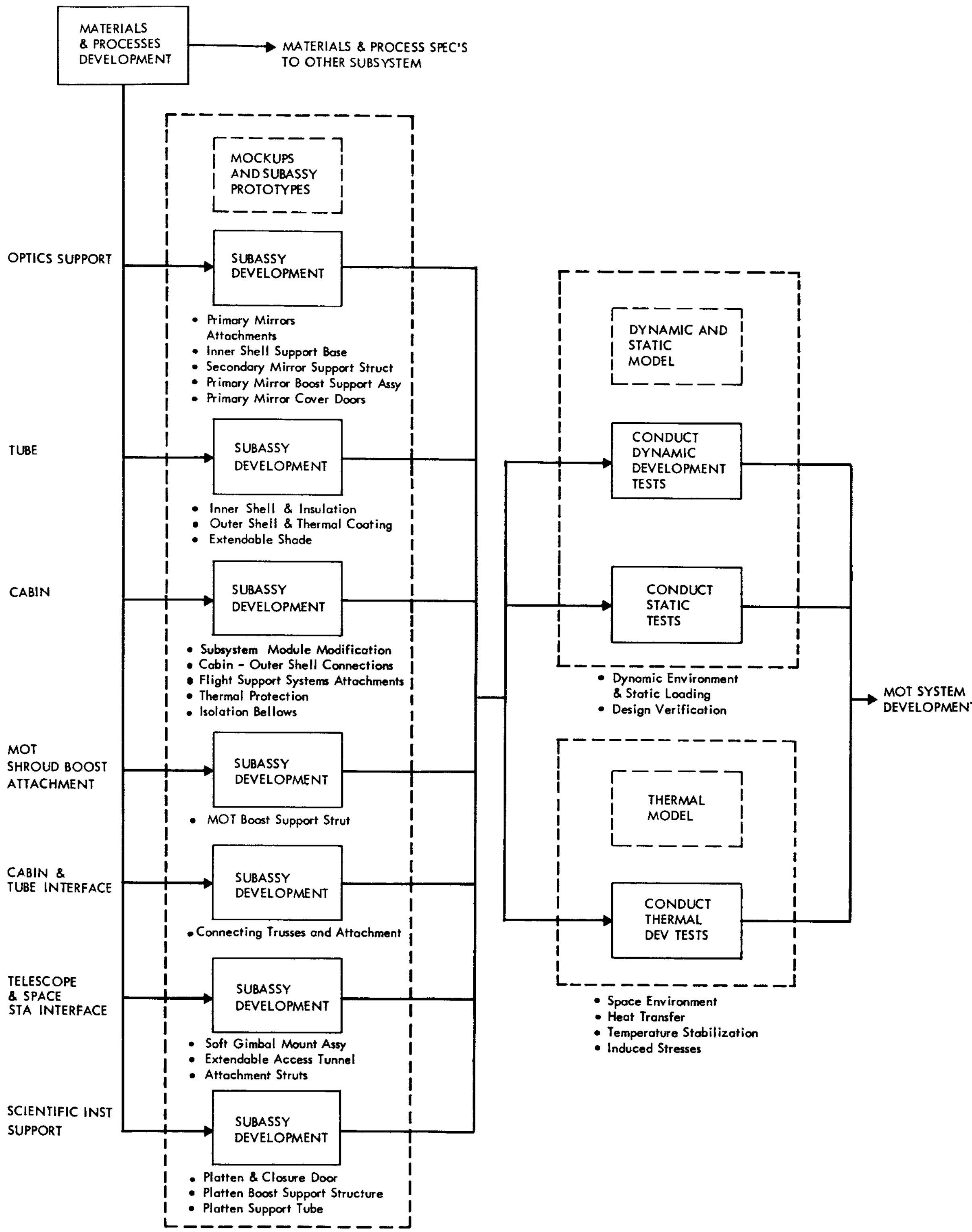


Figure 3-4: STRUCTURES AND MECHANISMS SUBSYSTEM DEVELOPMENT — PROJECT DEVELOPMENT PHASE

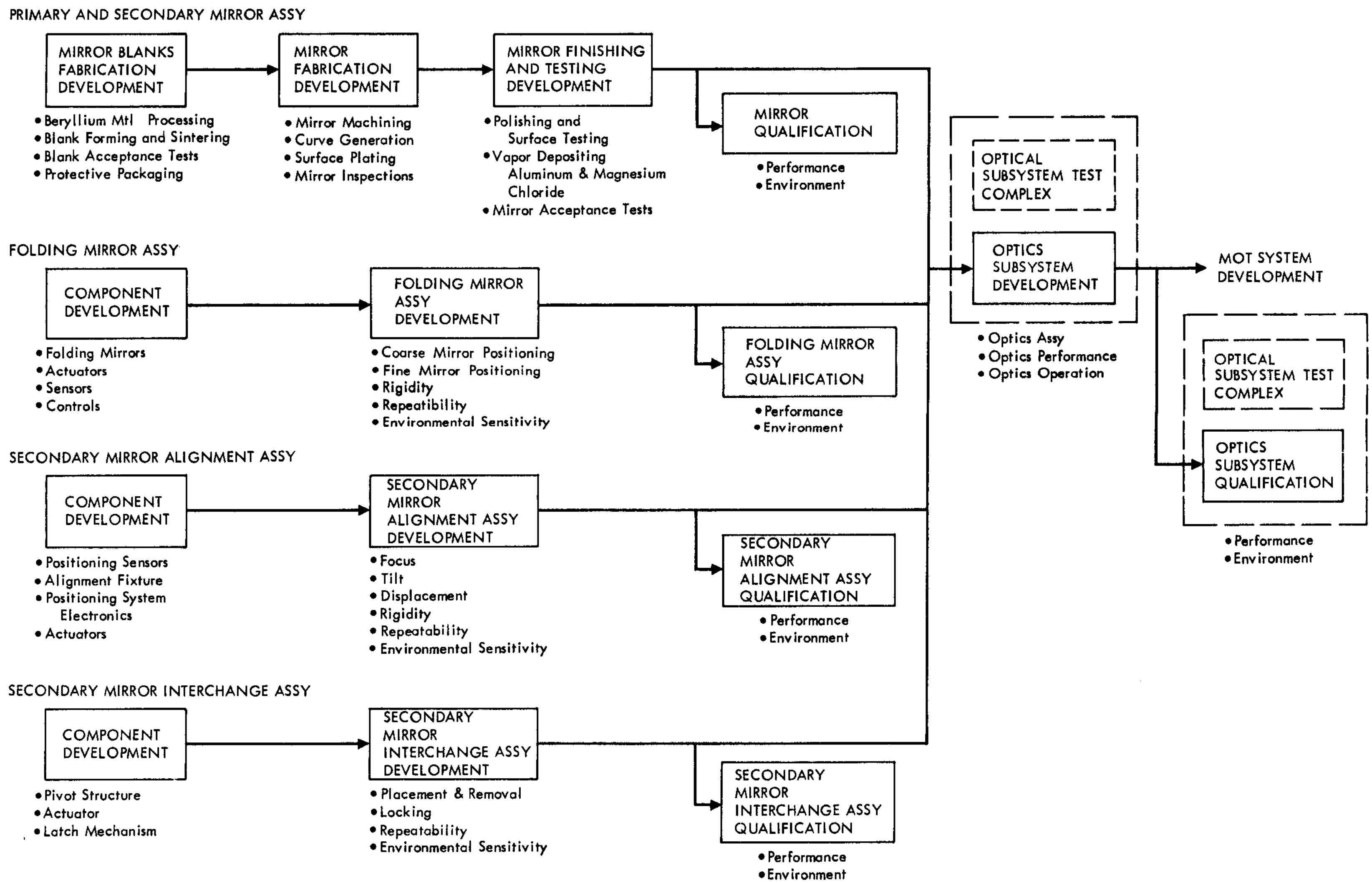


Figure 3-5: OPTICAL SUBSYSTEM DEVELOPMENT PROJECT DEVELOPMENT PHASE

tons capacity. Above 80 inches, the press is throat limited but this problem, it is believed, can be reasonably solved. Existing concepts, such as segmented hydrostatic fluid presses and explosive charge techniques, could be applied at reasonable expense. After the mirror blank is developed, the mirror finishing and testing system must be developed. This includes machining the blank to a shape for plating. The mirror surface will then be electroless nickel (Kanigen) plated and then rough and fine polished. During this process, the mirror surface will be continuously measured under simulated orbital thermal conditions. (A mirror-measurement system with the accuracy required for the MOT, including a method of calibration and certification, must be developed. The accuracy required is greater than currently being employed; however, it is believed that an upgrading of existing systems, such as laser interferometers, will apply.) The next step in the process is to vapor deposit an aluminum coating and then a magnesium chloride overcoat. The magnesium overcoat may require a mirror surface temperature near 400°F, presenting a thermal problem requiring development investigation.

Beryllium was selected as the mirror material in the preliminary system concept. As a result of this study, however, there is considerable doubt as to the feasibility of using beryllium. Development of the beryllium configuration would require solution to such problems as:

1) Variable thermal expansion coefficients across a typical mirror surface;

2) Characteristics of retaining and adding internal stresses;

3) Thermal stresses due to the combination of material on the beryllium and a plated substrate of different characteristics. (Kanigen nickel is the most likely plating material, but slippage plane lines are introduced during finishing, thus affecting mirror performance.)

This study in the project development phase planning has not outlined any detailed development program for solving these problems, but they are assumed to be of a routine nature. In this respect, the planning would be more applicable to whatever mirror material is selected from the concept development phase where the final material selection will be based on minimum development problems. This development discussion is based on the use of beryllium, but the process steps are largely applicable to any of the materials that might be used.

The folding mirror assembly requires considerable development because it must be actuated remotely between scientific instruments with microinch precision. The development will include microactuators, sensors, and controls. The ability to maintain the required accuracy in the expected environment will be demonstrated. The secondary mirror must be automatically aligned with respect to the primary mirror. The alignment involves tilt, focus, and displacement, and the alignment assembly will include microactuators mounted on the secondary mirror support for this purpose. The secondary-mirror alignment sensor system is mounted on the primary mirror in the center hole. Development of this assembly to operate accurately in the expected environment will entail considerable effort. The secondary-mirror interchange assembly involves a mechanism that remotely moves the ef/15 secondary mirror between its center operating position and its stowed position (against the side of the telescope tube). The development will include the ability for this mechanism to operate repeatedly.

Following development of these four assemblies, development at the subsystem level will be conducted. The four assemblies will be mounted in a simulated MOT telescope looking at a simulated stellar source. The combined subsystems will be subjected to typical orbital vacuum and thermal environment to demonstrate overall optical subsystem performance. During this subsystem development, the prototype scientific instruments will be integrated to demonstrate basic MOT performance capability.

Attitude Control Subsystem — The attitude control subsystem has two basic guidance functions: the coarse and intermediate guidance function slews the telescope to within ±3 minutes of the target star, then the intermediate and fine pointing guidance function controls the pointing to within ±0.01-second accuracy.

The control moment gyros, sensors, electronics, inertial reference platform, and reaction control system are package elements of the subsystem; each require individual development as shown in Figure 3-6. The two areas of the greatest development difficulty are the control moment gyros and the fine guidance sensor. The other elements are considered to require typical development effort.

Ability of the control moment gyros to produce the minute forces required and to do this reliably for the life of the telescope must be developed and demonstrated. The fine guidance sensor in the baseline design concept, which senses the target or guide star through the telescope optics using an amount of starlight that does not materially affect the telescope output, requires extensive development and demonstration.

This subsystem development requires extensive test facilities primarily due to the high pointing accuracies involved. These facilities are described in detail in Section 4.0

Rendezvous Subsystem — This subsystem is used to maneuver the telescope after it has separated from the Saturn V third stage and to dock it with the space station. This operation will be controlled from the space station. The development flow of this system is shown in Figure 3-7. The subdevelopment elements are the propulsion, communication and controls, and electrical power systems. The propulsion assembly will be developed from existing propulsion components. Subsystem development will be conducted again using the coarse and intermediate guidance test complex (Section 4.0) but without the rendezvous propulsion assembly. Development of the rendezvous subsystem is not considered a major effort since similar systems have been developed and flown.

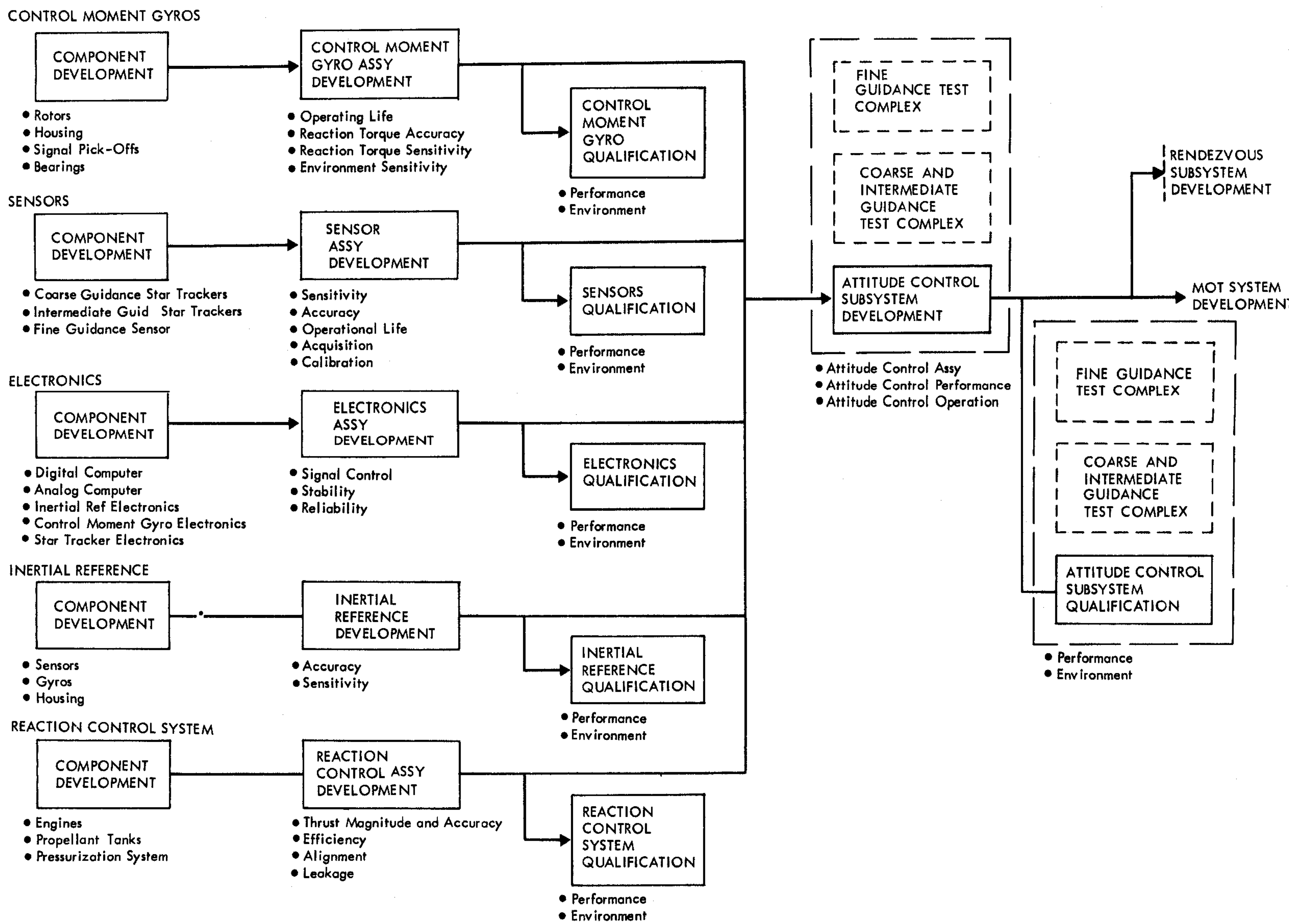


Figure 3-6: ATTITUDE CONTROL SUBSYSTEM DEVELOPMENT — PROJECT DEVELOPMENT PHASE

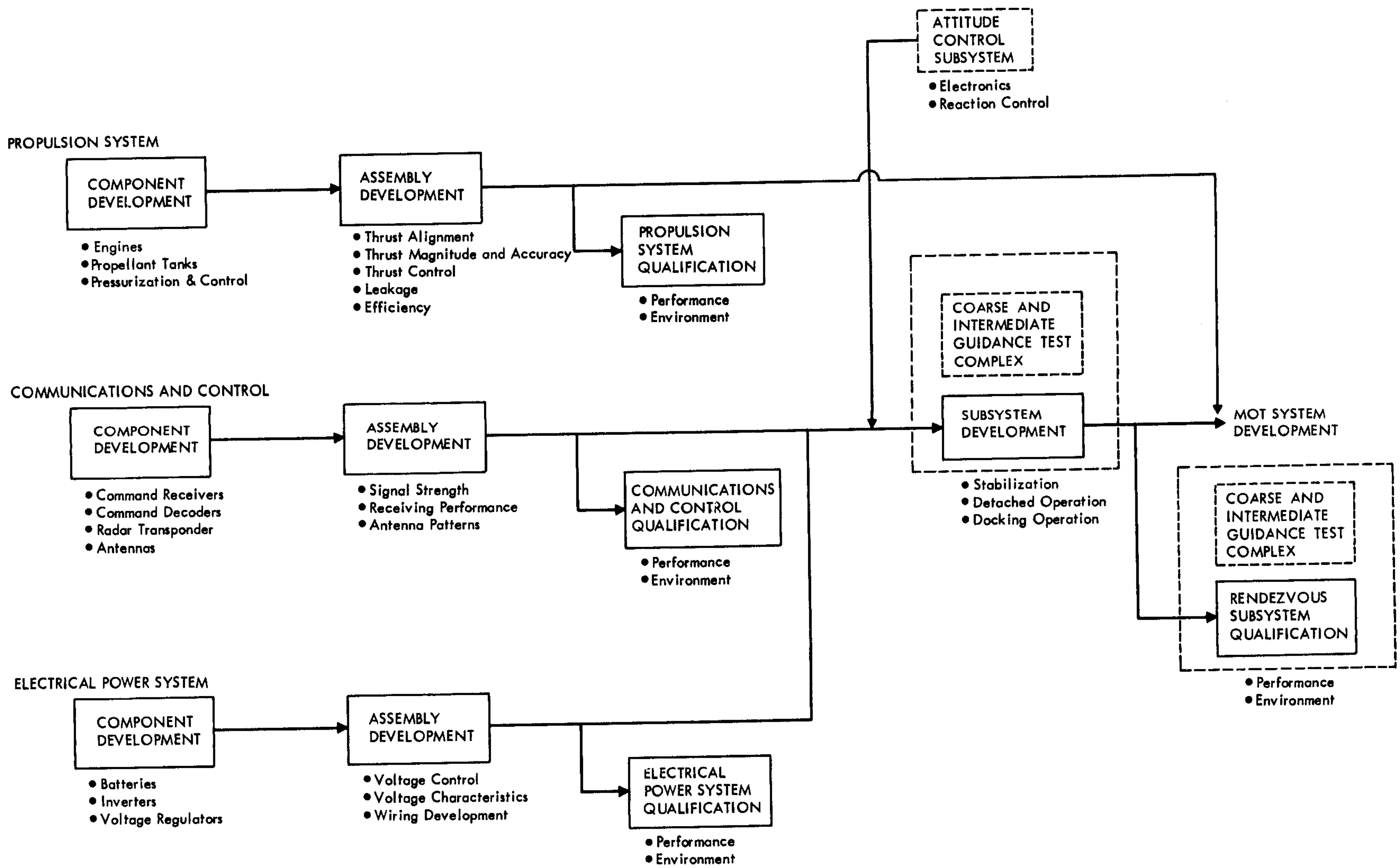


Figure 3-7: RENDEZVOUS SUBSYSTEM DEVELOPMENT PROJECT DEVELOPMENT PHASE

Scientific Instrument Subsystem — The design concept baseline requires initial development of nine instruments as shown in Figure 3-8. It is visualized that each instrument would be developed individually and integrated development would continue at a subsystem level. Development at the subsystem level will use a simulated portion of the telescope involving the instruments, a simulated telescope cabin, and an optical image. Included in the cabin will be the common instrument platen. Integration development will include consideration of expected orbital vacuum and thermal environment conditions. A rather extensive data center in the test complex will be required to analyze input and output characteristics for each instrument and to develop mission data operation techniques. After the instruments have been developed at the subsystem level, the prototype assembly will be installed in the optical subsystem development complex to demonstrate the optical and instrument input-output performance. Development of these types of scientific instruments will be a continuing effort beyond the launch, extending to about 1 year prior to the end of the mission. This overlap is believed necessary to take advantage of technology development during the MOT mission life and to be fully responsive to future experiment needs.

Flight Support Subsystem — This subsystem, containing miscellaneous elements required for operation and control of the telescope, include: (1) the equipment involved in distributing electrical power from the space station to various telescope components; (2) the system involved in transporting the heat generated by the telescope cabin equipment to the outside of the telescope; (3) the equipment necessary for the audio intercommunication between the telescope and space station to coordinate manual operations; (4) wiring and engineering data transponders, the signals from which are sent to the space station for transmission to the ground; (5) the cabin atmosphere system including fans, ducting valves, and controls for moving the atmosphere supplied by the space station; and (6) the operation and control station in the MOT cabin, which is used for manual operation of the telescope during maintenance and checkout. The development flow for this equipment is shown in Figure 3-9. The individual elements are developed as an entity and then developed into a subsystem in the telescope engineering model. Development of this subsystem is considered routine with no technological advancements required.

Engineering Model Program — The engineering model will be used for initial functional integration of the various telescope subsystems. The program is an informal operation, designed primarily for the use of the design organizations involved. The development flow is outlined in Figure 3-10. The model will be constructed of typical flight quality structures and mechanisms into which prototype subsystems are installed under the immediate direction of the design engineers. The model will be in continuous use throughout the subsystem and system development.

Project Verification Model Program — The project verification model will include people, procedures, facilities, and production equipment (Figure 3-11) and will be used to verify development completion of the MOT project at the factory and

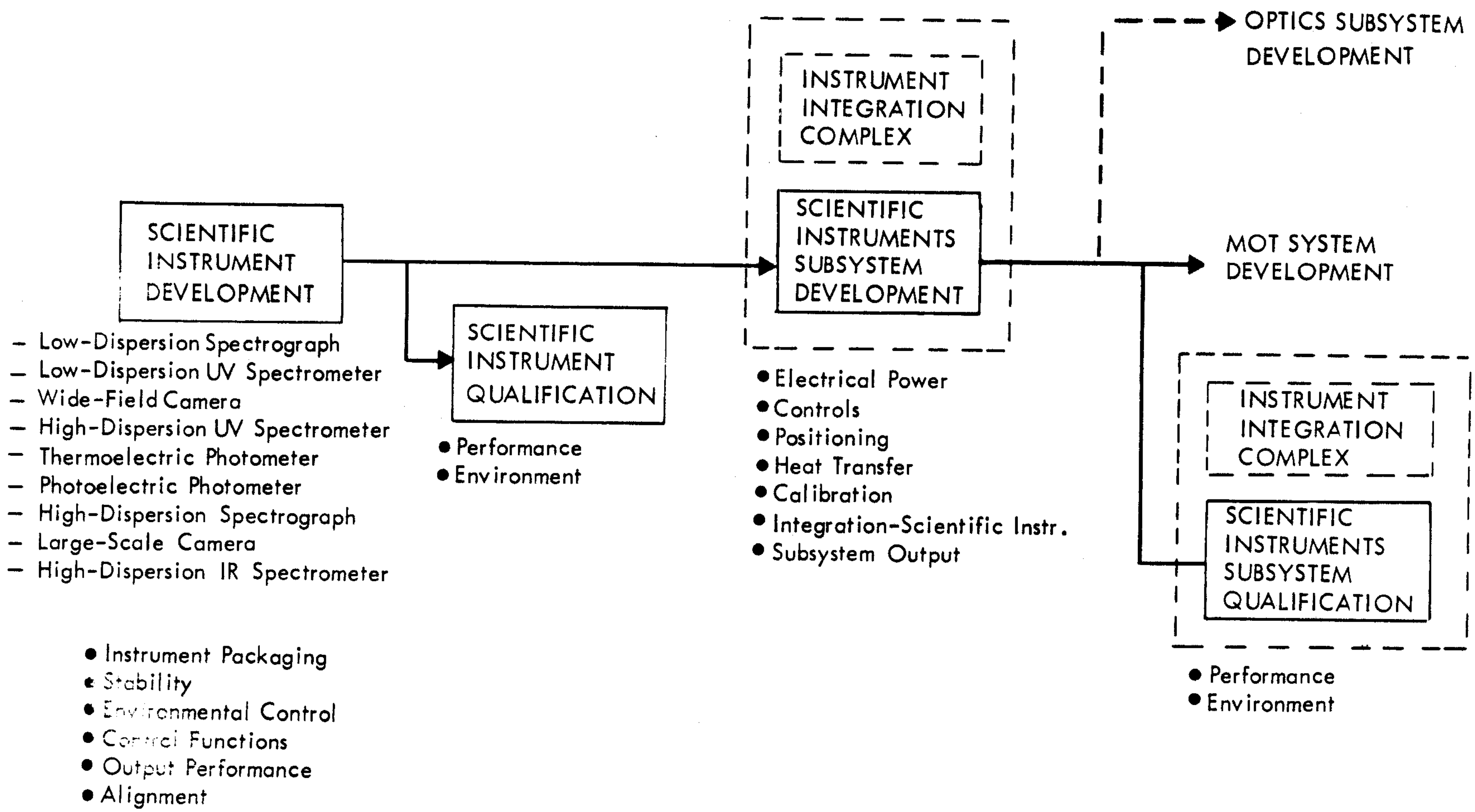


Figure 3-8: SCIENTIFIC INSTRUMENTS SUBSYSTEM DEVELOPMENT — PROJECT DEVELOPMENT PHASE

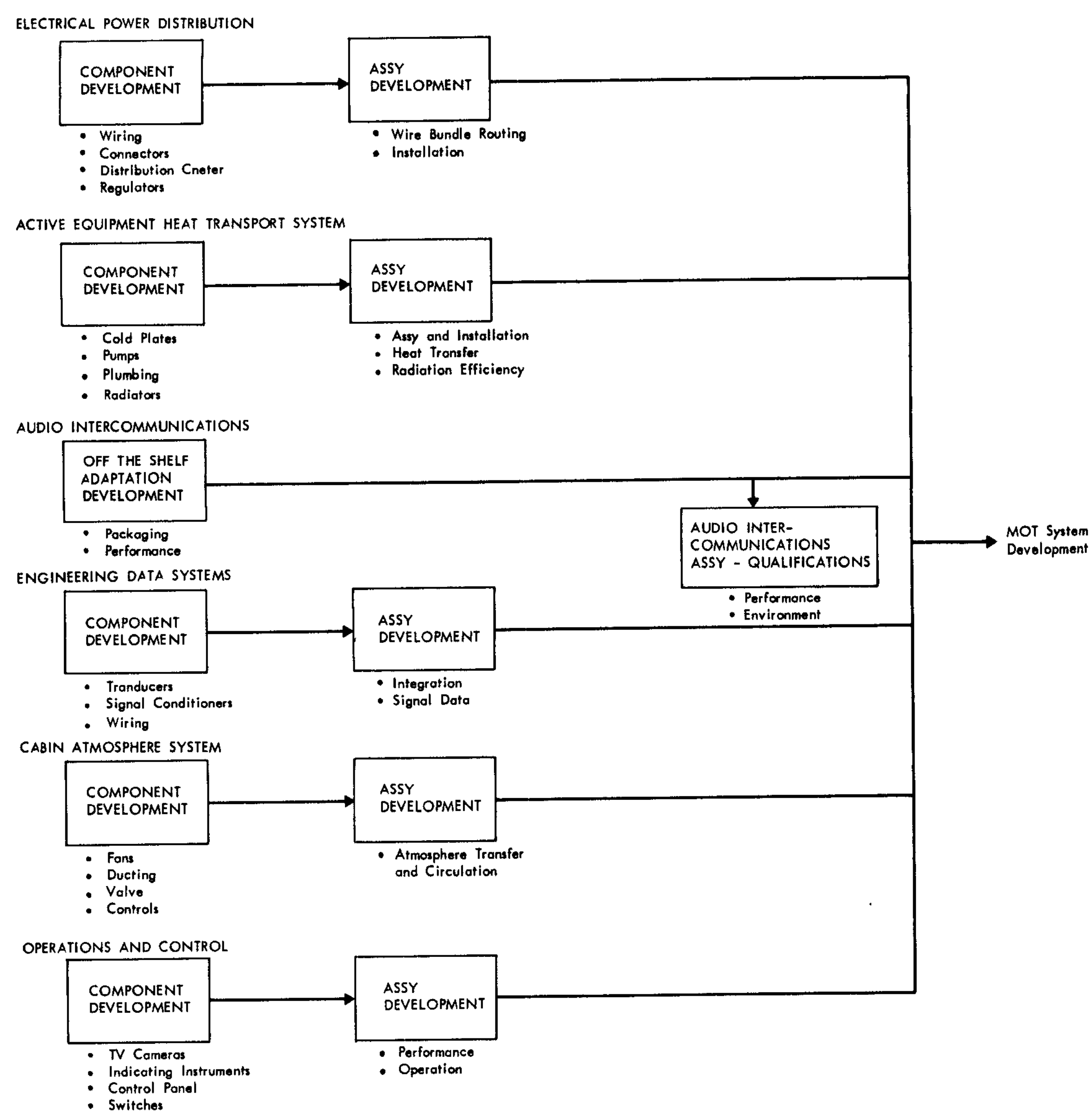


Figure 3-9: FLIGHT SUPPORT SUBSYSTEM DEVELOPMENT PROJECT DEVELOPMENT PHASE

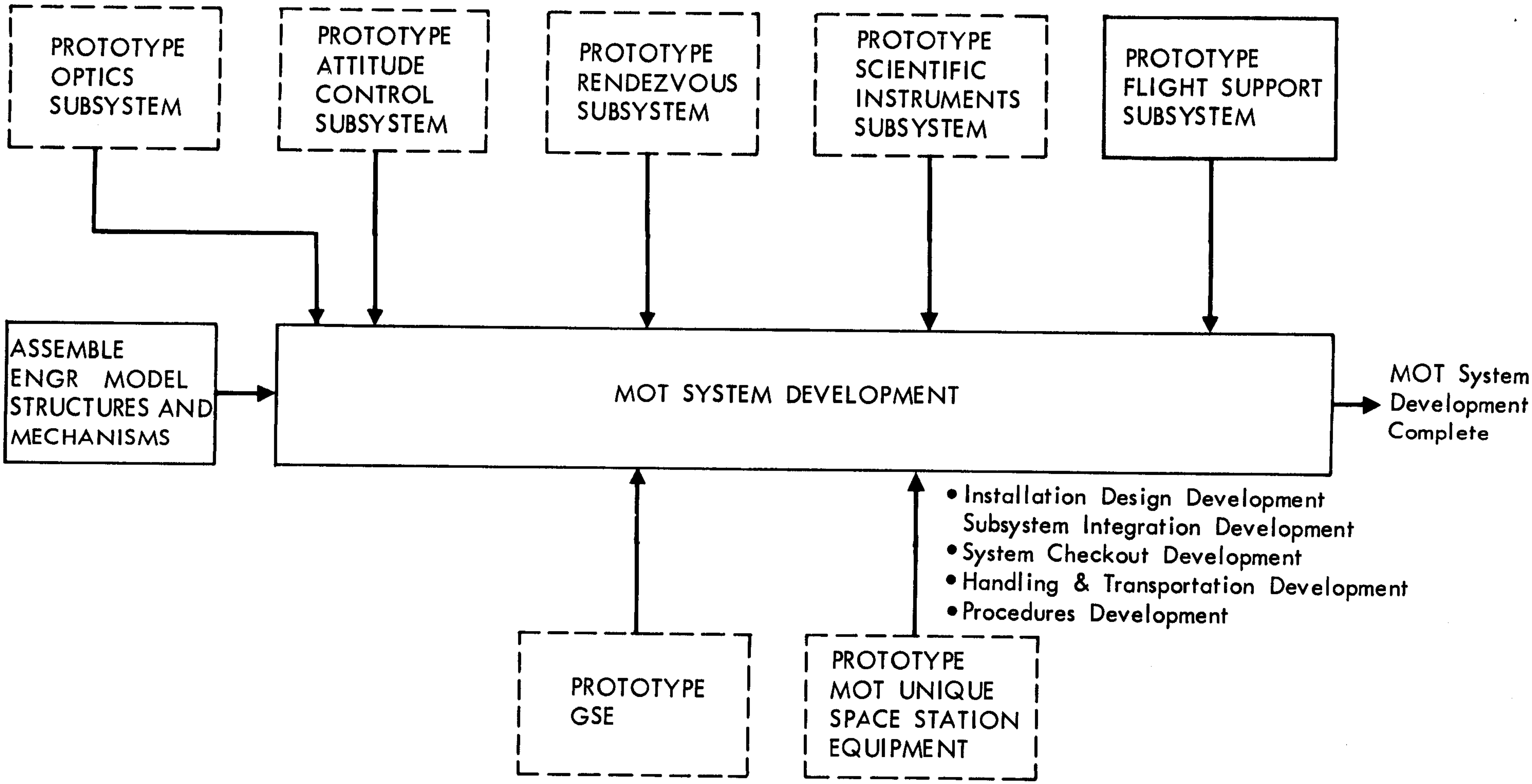


Figure 3-10: ENGINEERING MODEL PROGRAM — PROJECT DEVELOPMENT PHASE

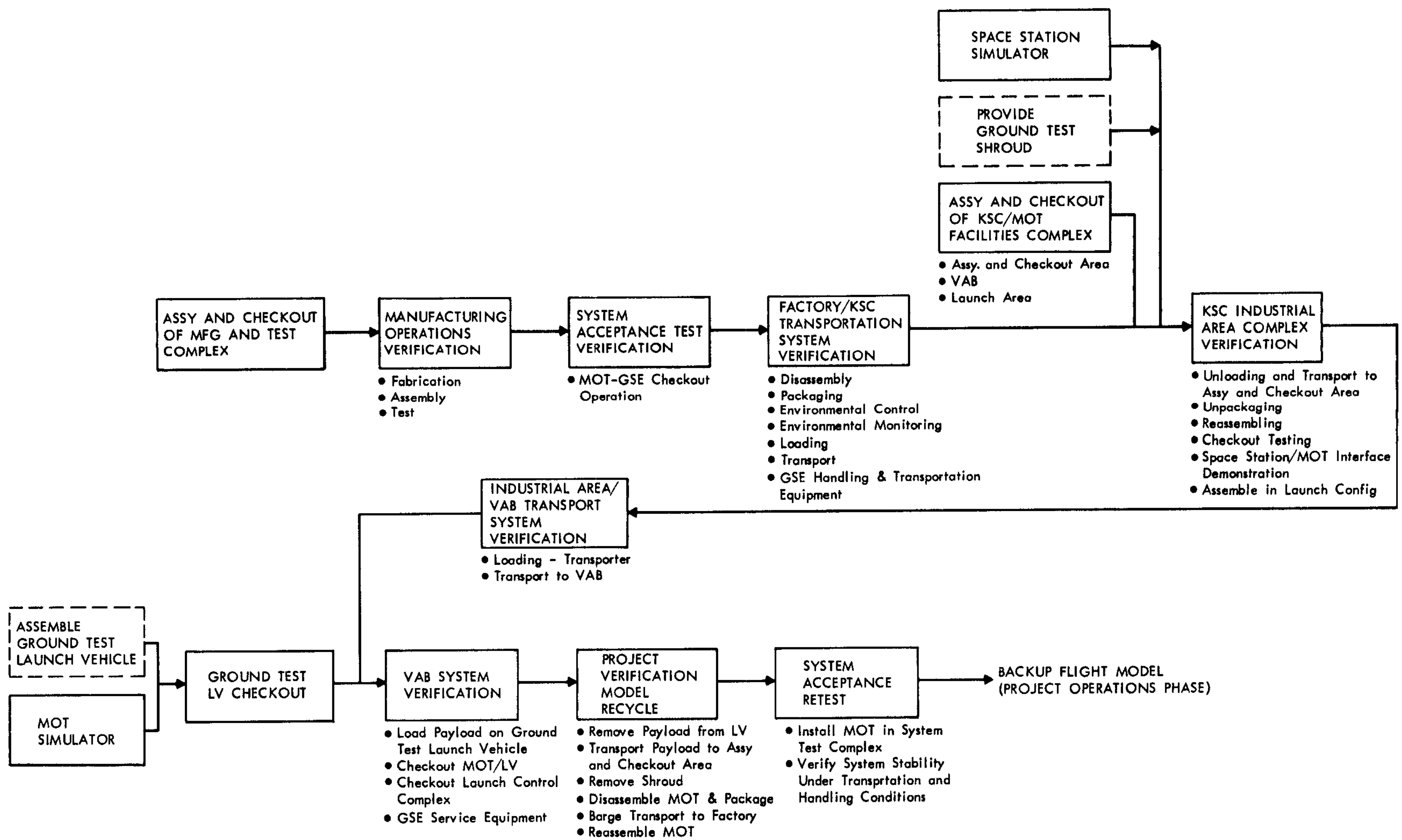


Figure 3-11: PROJECT VERIFICATION MODEL PROGRAM — PROJECT DEVELOPMENT PHASE

Kennedy Space Center (KSC). This model will be produced in the same factory manufacturing and testing facilities where the flight model will be produced. It will be developed in a production-like manner, including acceptance tests. Acceptance testing will include vibration, acoustic, and electromagnetic compatibility. A system test will be conducted using the rather extensive MOT system test complex and conducted under simulated orbital environmental conditions; it will include fine guidance operation with optical stellar inputs and will verify scientific instrument outputs. Following these tests, the telescope will be disassembled and packaged for transportation to KSC by barge. The telescope and transportation system will be engineered to minimize the need for retesting at KSC. To accomplish this, the telescope structure will contain a production break just above the soft gimbal assembly, thereby allowing disassembly into only two major sections. These two sections will then be placed in controlled environment shipment containers that hold the sections in a vertical position.

On arrival at KSC the sections will be transported to the manned space operations building (MSOB) for reassembly and test of those items affected by the disassembly and reassembly effort. The space station simulator, including the MOT-unique space station equipment, will be interfaced and tested with the telescope. Then the space station simulator will be disconnected and the telescope placed in a space transportation mode and encapsulated in the universal shroud assembly. The telescope in this transportation mode will be placed on a transporter and moved to the vertical assembly building (VAB) for installation on a ground test Saturn V launch vehicle. Just prior to this, the Saturn V will have been assembled and checked out using a MOT launch vehicle simulator. A checkout of the complete launch complex will be made with the project verification model mounted on the ground-test Saturn V launch vehicle. At the completion of this checkout, the model will be removed from the launch vehicle (following the reverse sequence) and returned to the factory. At the factory, the model systems should be retested to verify that their sensitive and accurate components have not been damaged during this ground operation. This model will be refurbished and reidentified as the flight backup model in the project operations phase as described in Section 3.1.5.

Qualification Model Program — This model will be used to demonstrate design limits of the system and will be of full flight quality. The program flow to accomplish this purpose is shown in Figure 3-12; all activities occur at the system development complex at the factory. The model will be put through typical launch-to-end-of-mission operations with the environment and operations being conducted at the design limits to verify design-limit capabilities. This testing should be completed prior to shipment of the flight model to KSC. At the completion of this qualification program, the model will be used in the development support activity throughout the mission.

MOT-Unique Space Station Equipment — This equipment performs those unique functions in the space station involved in MOT mission operation and control, rendezvous control, and power conditioning and distribution from the space

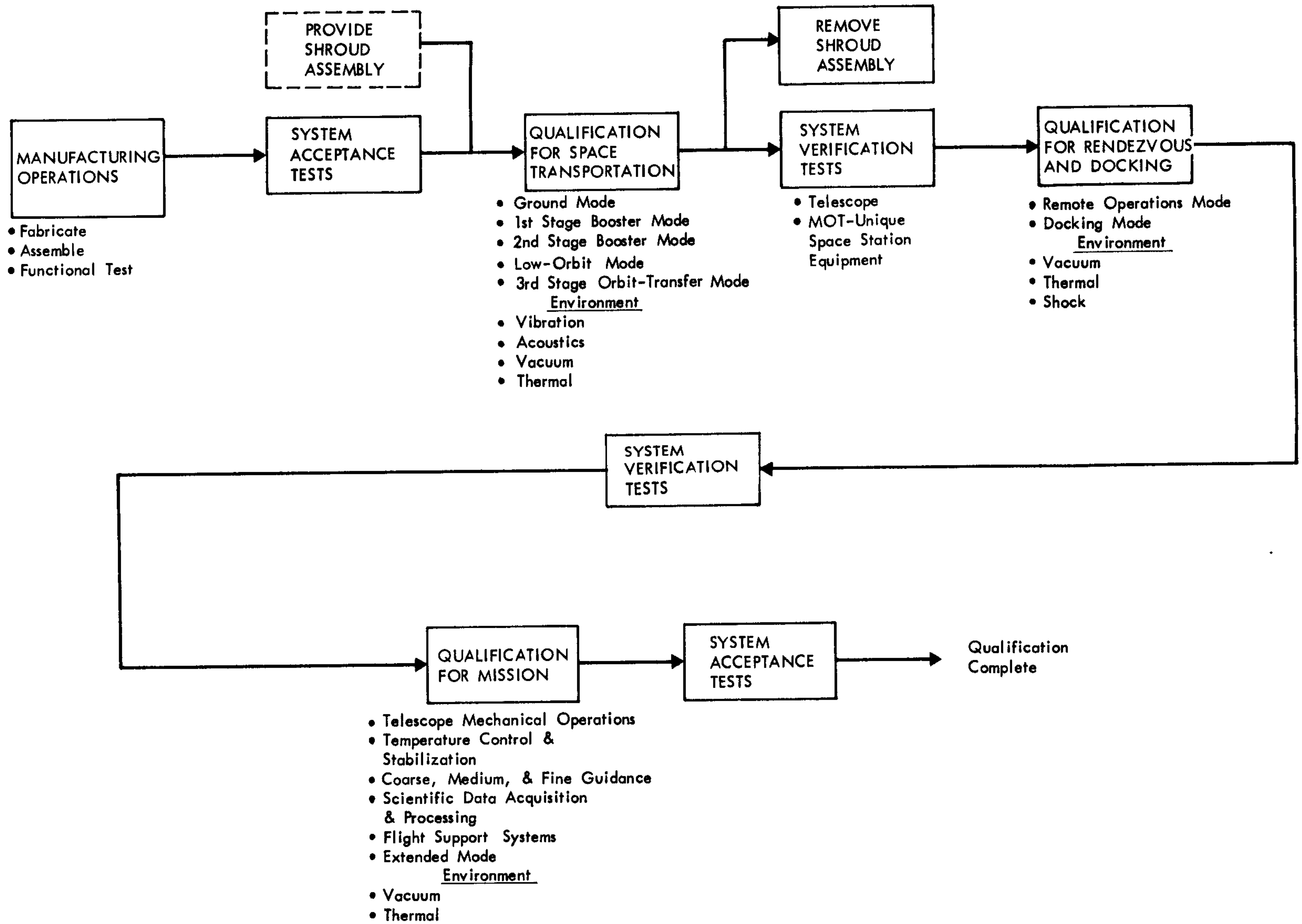


Figure 3-12: QUALIFICATION MODEL PROGRAM — PROJECT DEVELOPMENT PHASE

station power source to the MOT. The development plan for this equipment is shown in Figure 3-13. The three equipment assemblies are developed as entities and integrated using the MOT computer simulator and engineering model. In addition, system integration development will include the use of the associated prototype GSE checkout equipment. Units of the system are used in the project verification model program and the qualification model program. Development integration of this equipment with the space station will be conducted, ensuring physical and functional compatibility. Because of the number of interfaces, development of this equipment is considered a significant effort but does not require any technological advancement.

Ground Support Equipment — This equipment performs handling, transport, checkout, and servicing functions. The handling and transportation development flow is shown in Figure 3-14, using the engineering model as a major development tool. The significant development aspect of this equipment is the care that must be considered in the handling and transporting of many of the delicate components of the MOT system. During handling and transportation of the telescope between the factory and KSC, its environmental limits must not be violated; this will be considered in the design. This, together with proper telescope design for transportation, will minimize the amount of retesting required at KSC. These considerations are considered essential to avoid unnecessary duplication of expensive system testing facilities at KSC, which a project such as MOT would require if an inadequate transportation and handling system were provided.

The GSE checkout equipment will be used to check the telescope, MOT-unique space station equipment, and MOT project interface elements, such as MOT and the space station and MOT and the launch vehicle. The development flow for this equipment is shown in Figure 3-15; the MOT engineering model plays a major role. Some equipment will be permanently installed at the MOT system development complex and in the MSOB at KSC. MOT-project interface simulator equipment will be sent to the launch vehicle operation area at KSC and to the factory of the space station contractor. The development magnitude for the checkout equipment is considered large, as it is on similar programs, but no technological improvement effort is required.

The servicing equipment will be used to perform functions such as battery charging, and propellant loading at KSC. Development of this equipment is not considered significant and, therefore, no detail flows have been included.

Training Equipment — The MOT training equipment consists of: (1) part task simulator, (2) mission simulators and (3) subsystem trainers. The development flow for this equipment is shown in Figure 3-16. The part task simulator will use a nearly complete telescope and space station, including MOT-unique equipment for astronaut training for in-space tasks. Training controls will be tied to the telescope and space station subsystems and to an instructor's control panel. With a supporting computer complex, various simulated orbital problems can be programmed for astronaut training in the telescope and space station. The sys-

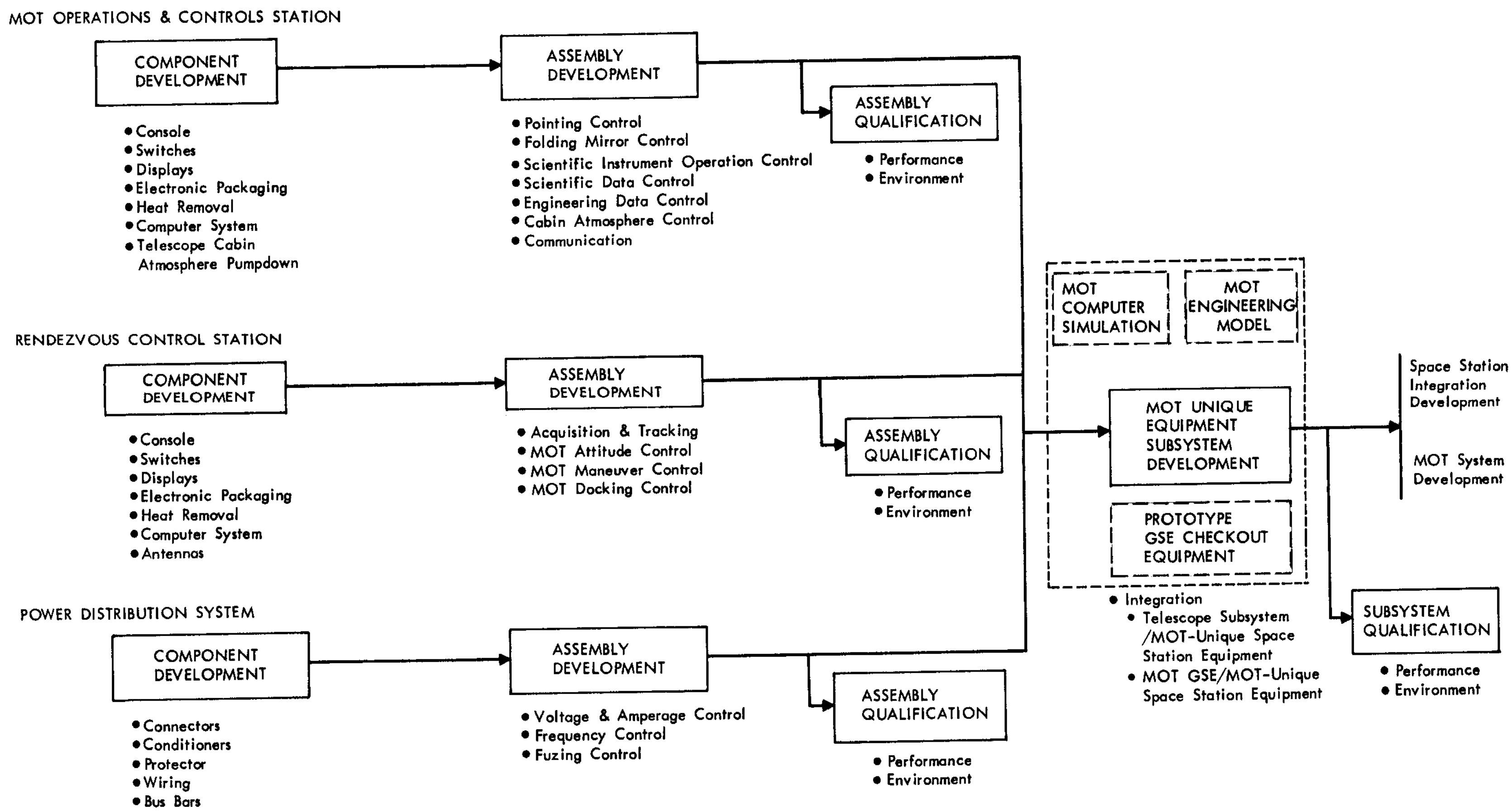


Figure 3-13: MOT UNIQUE SPACE STATION EQUIPMENT — DEVELOPMENT PROJECT DEVELOPMENT PHASE

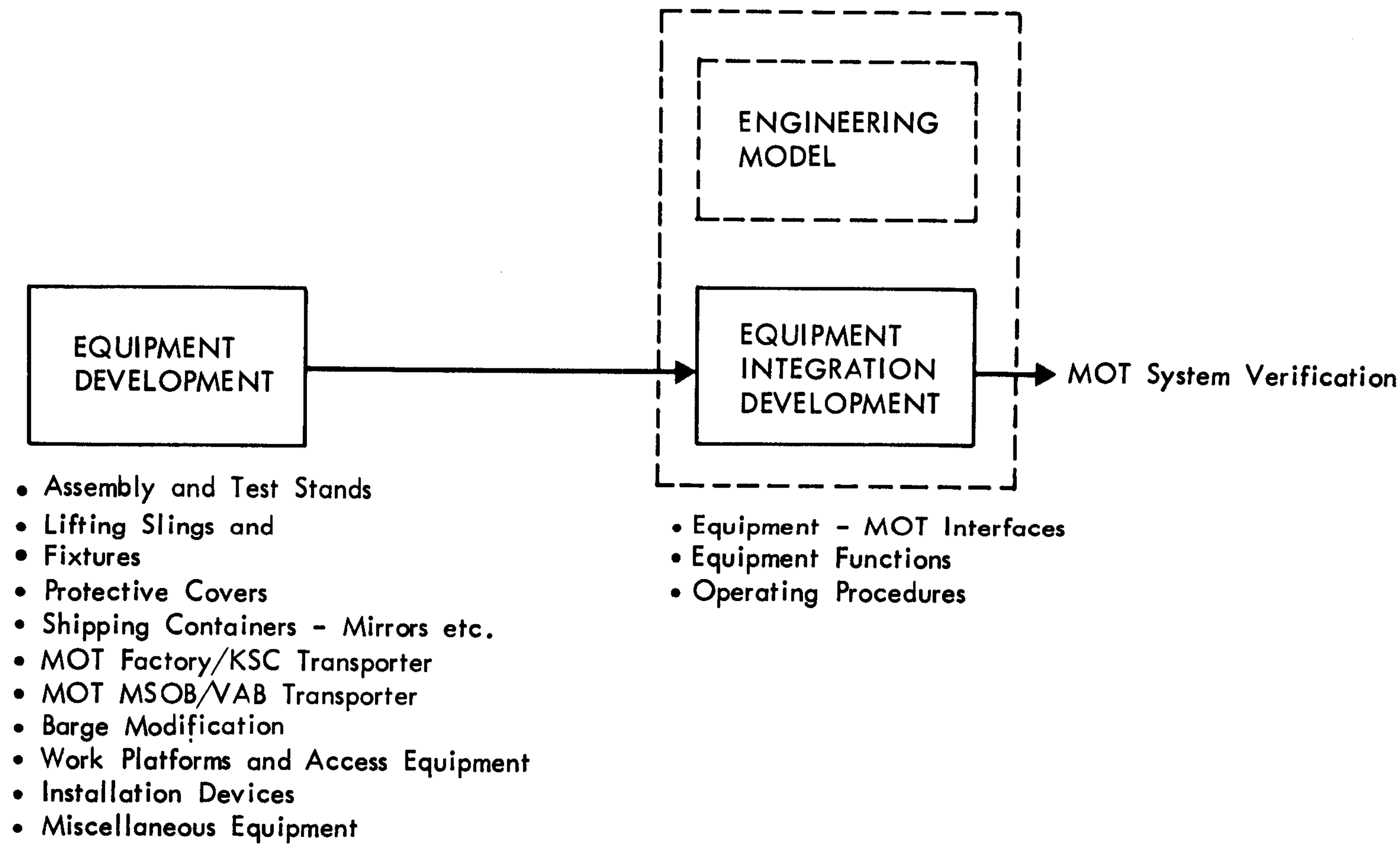


Figure 3-14: GSE HANDLING AND TRANSPORTATION EQUIPMENT DEVELOPMENT PROJECT DEVELOPMENT PHASE

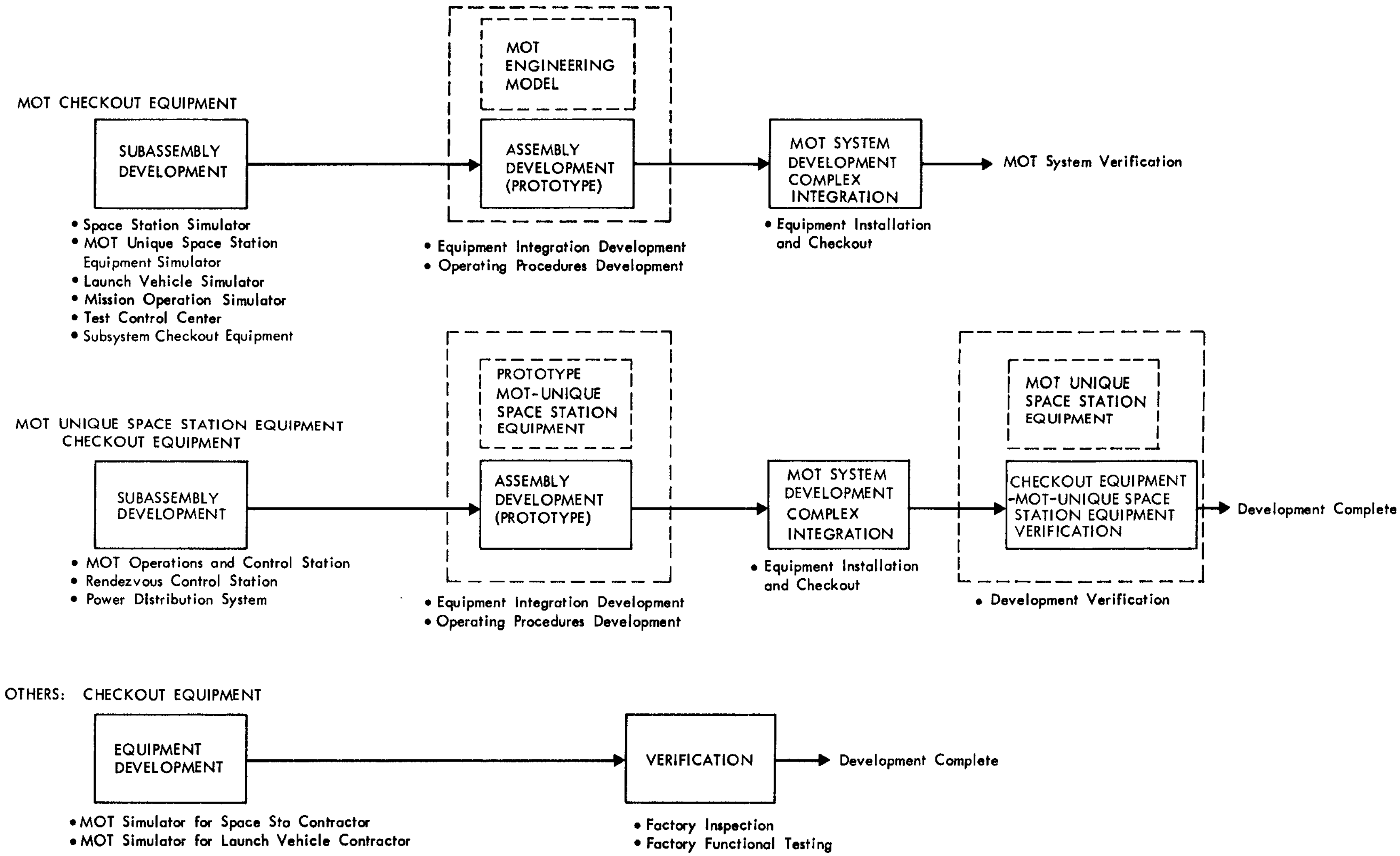


Figure 3-15: GSE CHECKOUT EQUIPMENT DEVELOPMENT PROJECT DEVELOPMENT PHASE

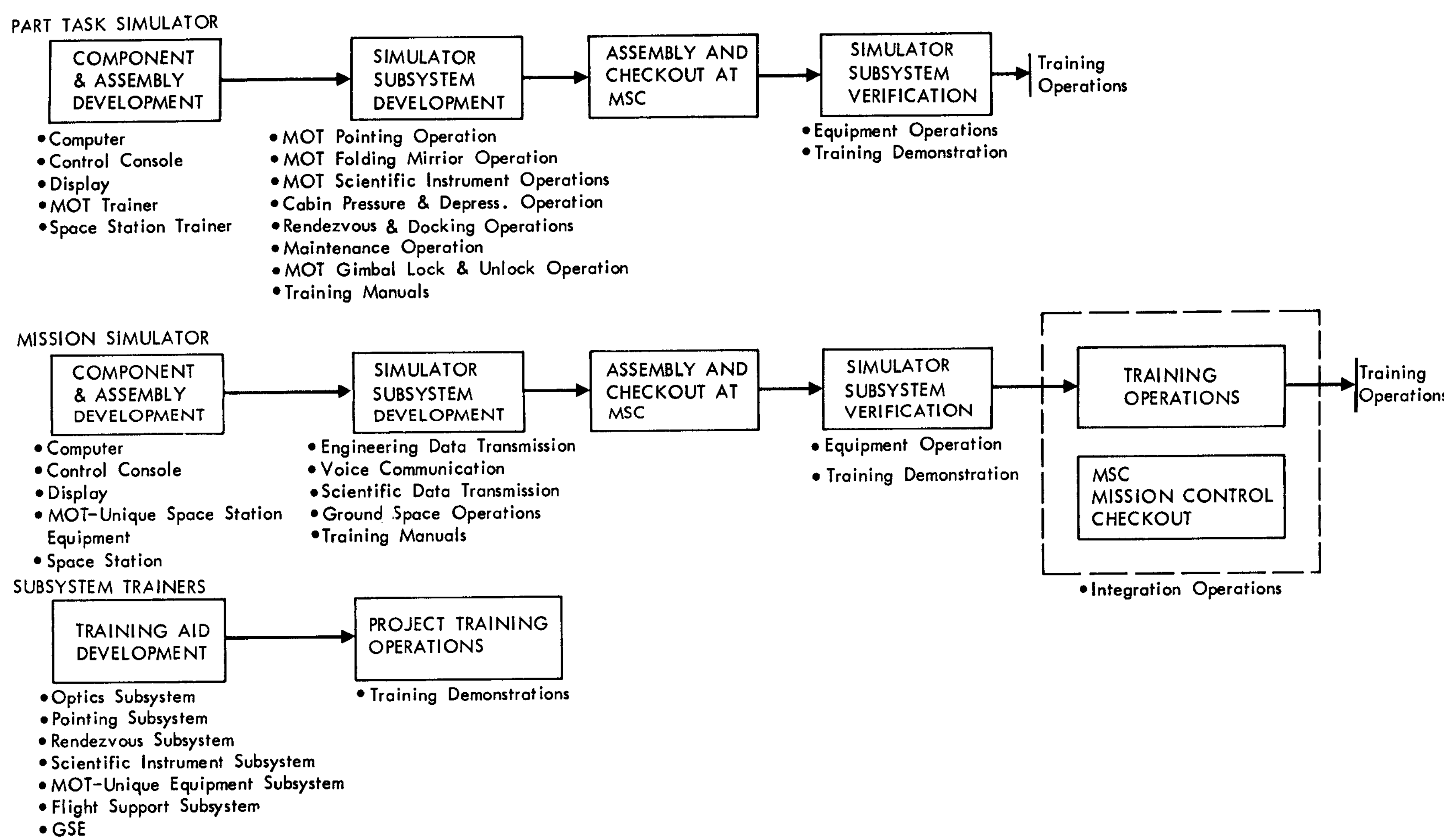


Figure 3-16: TRAINING EQUIPMENT DEVELOPMENT — PROJECT DEVELOPMENT PHASE

tem is considered complex and will require a significant amount of development. The mission simulator involves: (1) a space station with the MOT-unique equipment installed and (2) an electronic telescope simulator. The combination is connected to computers and an instructor's console to allow astronaut training in orbital telescope operation with the ground-based mission control center. No major problems are anticipated in the development of this equipment. The subsystem trainers are functional mockups of each telescope subsystem and are used for training MOT project ground personnel. No significant development activity is anticipated for this equipment.

Mission Support Equipment — The mission support equipment consists of additional equipment required at MSC to support the MOT mission control operations. The functions supported by this equipment are: (1) engineering mission control, (2) engineering data processing, (3) experiment mission control, and (4) experiment data control. This equipment will include an experiment control subcenter interconnected to mission control. This center will provide whatever ground instructions are required for orbital experiment operations. Supporting this center will be an experiment data center, which will receive, process, and analyze the transmitted data. Data at various stages in the process will be given to astronomers on request. The MSC data analysis and recommendations from the astronomers will be used by the experiment control subcenter to determine instructions to the orbiting MOT. The major new equipment involved in this operation will be rather exotic data processing equipment involving computers, automatic plotters, and displays. An extensive development effort of this complex will be required as shown in Figure 3-17 to provide an effective operation for both the astronomers and the orbiting MOT. Some minor modification to the existing MSC engineering data equipment operation is anticipated. These modifications will be primarily involved in ground computer data reduction and analysis programs recognizing MOT-unique telemetry calibrations. Also some minor modifications may be required at mission control to incorporate the experiment control subcenter inputs. The new equipment should be installed, checked, and verified prior to the launch of the MOT flight model.

Mission Update Modification — Updating modifications during the MOT mission will be developed to: (1) improve telescope and MOT-unique space station equipment operations, maintenance, and performance and (2) provide experiment flexibility by alteration or exchange of scientific instrumentation. A development flow of these modifications is shown in Figure 3-18. Prototype modifications will be developed on the MOT qualification model. After full development, flight model type kits will be verified for space installation and operation on the MOT qualification model prior to being sent by space transportation to the orbiting MOT.

3.1.4 Project Development Phase Equipment List

The type and quantity of hardware items required during the project development phase are identified in Table 3-1. The quantities shown include the

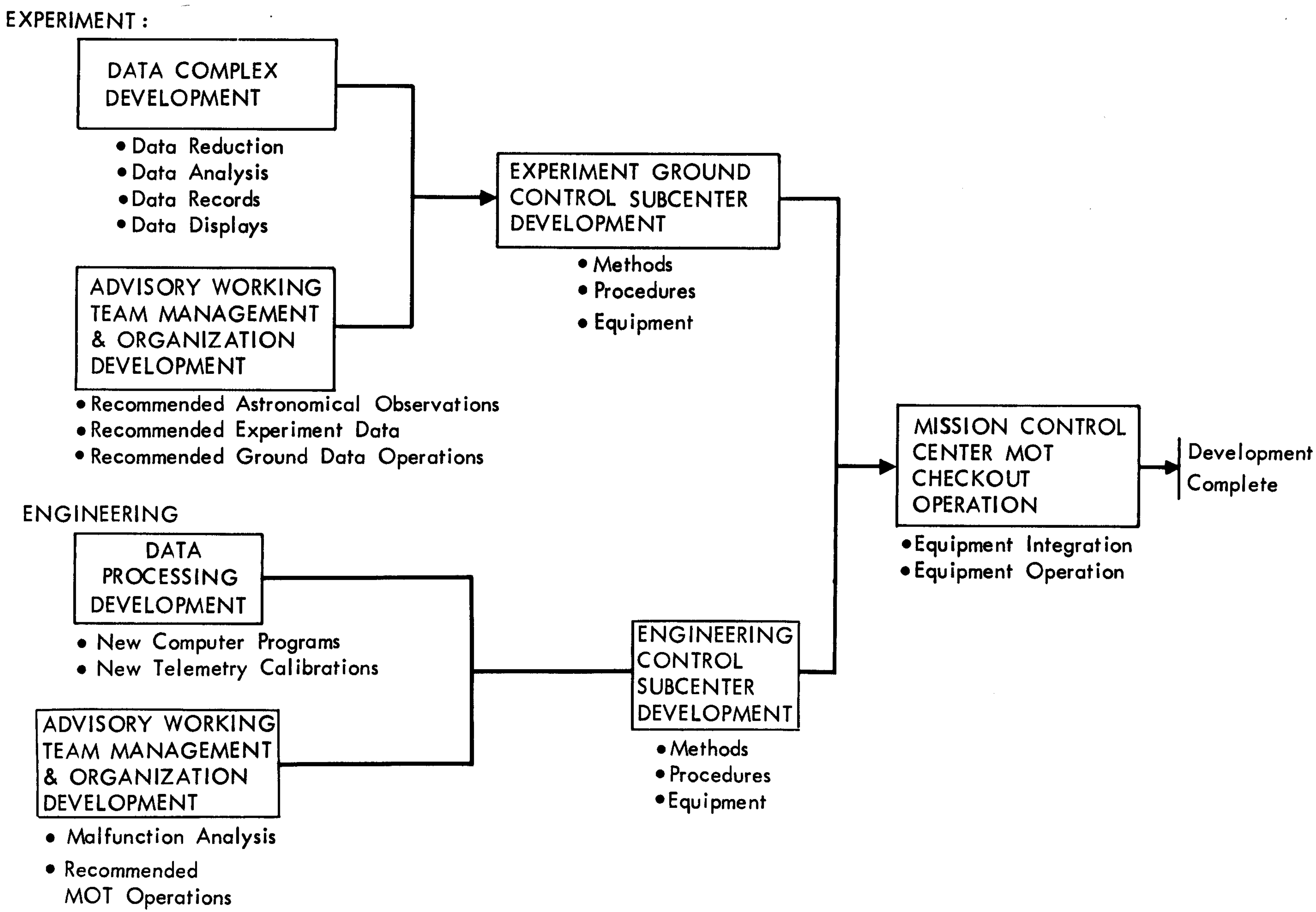


Figure 3-17: MISSION SUPPORT EQUIPMENT DEVELOPMENT — PROJECT DEVELOPMENT PHASE

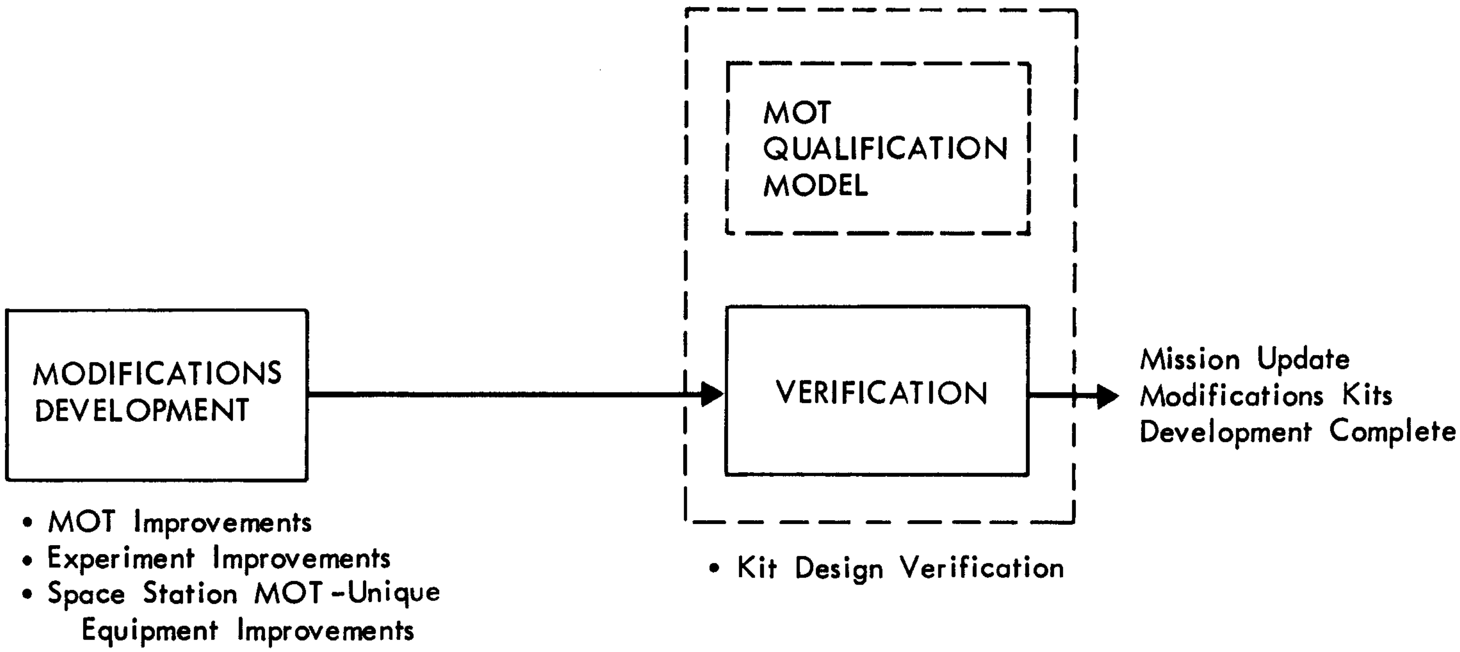


Figure 3-18: MISSION UPDATE MODIFICATION DEVELOPMENT — PROJECT DEVELOPMENT PHASE

Table 3-1: EQUIPMENT LIST — PROJECT DEVELOPMENT PHASE

MAJOR ELEMENT	SUBSYSTEMS	ASSEMBLIES	QUANTITY BREAD-BOARD	QUANTITY PROTO-TYPE	QUANTITY FLIGHT QUALITY
Telescope	Structures & Mechanism	Optics Support		1	2
		Scientific Instrument Support		1	2
		Telescope Tube Assembly		1	2
		Cabin		1	2
		Cabin-Tube Interface		1	2
		Telescope-Spacecraft Interface		1	2
		MOT-Shroud Attachment		1	2
	Optics	Primary Mirror (120-Inch)		1	1
		Secondary Mirror (32-Inch)		1	1
		Secondary Mirror (19-Inch)		1	1
		Folding Mirror Assemblies	2	4	4
		Secondary Mirror Alignment Assembly	1	2	2
		Secondary Mirror Interchange Assembly	1	2	2
	Attitude Control	Control Moment Gyro System	1	2	2
		Sensor System	1	2	2
		Electronics System	1	2	2
		Reaction Control System	1	2	2
		Inertial Reference (Sensor Gyro Pkg)	1	2	2
	Rendezvous	Propulsion System	2	4	2
		Communications & Control	1	2	2
		Electrical Power System	1	2	2
	Scientific Instruments	Wide-Field Cameras	1	1	1
		Large-Scale Cameras	1	1	1
		Photometers	2	2	2
		Spectrographs	2	2	2
		Spectrometers	3	3	3
	Flight Support Subsystems	Equipment Heat Transport	1	2	1
		Electric Power Distribution	1	2	1
		MOT-to-Spacecraft Audio Comm System	1	2	1
		Engineering Data System	1	2	1
		Cabin Atmosphere	1	2	1
		Telescope Operation Checkout Station	1	2	1
	Major Articles	Mockup	1		
		MOT Engineering Model		1	
		Project Verification Model		60%**	40%**
		Qualification Model			1
MOT-Unique Space Station Equipment	Rendezvous Control Station and Related Equipment		1	1	3
	MOT Operations & Control Station and Related Equipment*		1	1	3
	Electric Power Distribution		1	1	3
	Scientific Data Processing		1	1	3
Ground Support Equipment	Handling & Transportation			1	2
	System & Subsystem Checkout		1	1	3
	Service			1	2
Training	Part Task Simulators			18	
	Mission Simulator			1	
	Subsystem Trainers			1	
Mission Support Equipment	Experiment Data Center Equipment			1	
	MOT-Unique Mission Control Center Equipment			1	
	MOT-Unique Engineering Data Center Equipment			1	
Universal Shroud Assembly	Shroud Assembly	Shroud		2	
		Payload - Launch Vehicle Adapter		2	
	Ground Support Equipment	Handling & Transportation Equipment		1	
Launch System	Launch Vehicle	Launch Vehicle Modification-Equipment		1	
		Existing Ground Test Model		1	
	Ground Support Equipment (MOT-Unique Equip)	MOT Launch Vehicle Simulator		1	
Mission Update Modification Equipment	Telescope			1/MOD	1/MOD
	Scientific Instruments			1/MOD	1/MOD
	MOT Unique Subsystem Equipment			1/MOD	1/MOD

Subsystem Development Quantities

* Include Pump for Depressurizing MOT Cabin
** Obtained from Subsystem Development Quantities

items required for: (1) preliminary development and demonstration of functional characteristics (breadboard); (2) development of the first model designed to satisfy the subsystem requirements, including such factors as shape and installation limitations (prototype); and (3) fabrication and qualification of a final configuration unit (flight quality). In general, single breadboard, prototype, and flight quality items are required for development and qualification of each of the telescope subsystem assemblies. More than a single item per assembly is indicated for those items where the complexity or particular development and testing requirements so require. As practicable, the flight quality assemblies from the subsystem development program will be incorporated into the project verification model of the major articles, which in turn will be refurbished to provide a standby MOT for the initial flight during the operations phase.

3.1.5 Project Operation Planning

The project operation phase uses the facilities, equipment, people, and procedures developed and verified in the previous phase, to produce and operate a flight model MOT for 5 years in orbit. This phase is divided into three categories: factory, KSC, and mission operations. The operational flow illustrating the planning for this phase is shown by Figures 3-19 through 3-21. A requirement for factory operations for logistics support during the MOT lifetime is recognized. These operations pertain to the production of flight-model modification kits, spares, and supplies that are shipped by surface transportation to KSC for subsequent transportation to the MOT in space.

Since this study considers only one MOT being placed in orbit, a backup unit is included in the overall plan. This unit is completed at the factory and its further use is dependent on the success of transporting the original MOT into orbit. A backup model will provide insurance against the possibility that a near-complete loss of the project investment would occur by having to reactivate factory operations should a launch failure occur involving the principal flight model. In this study, the project verification model fromthe previous phase is refurbished with many new flight subsystems installed and used as the backup flight model.

3.1.6 Project Operations Phase Equipment List

The quantity and type of equipment required for orbital operations of the MOT are listed in Table 3-2. The quantities provide for a single MOT in orbit plus backup units for the items directly and uniquely related to the MOT system. The structures and mechanism and the flight support subsystem for the backup telescope will be obtained from the project verification model used in the project development phase. All other backup items will be newly manufactured.

3.2 CONCEPT DEVELOPMENT PLANNING

As a result of conducting the planning for the project development and project operation phases and based on the data obtained from the industrial survey,

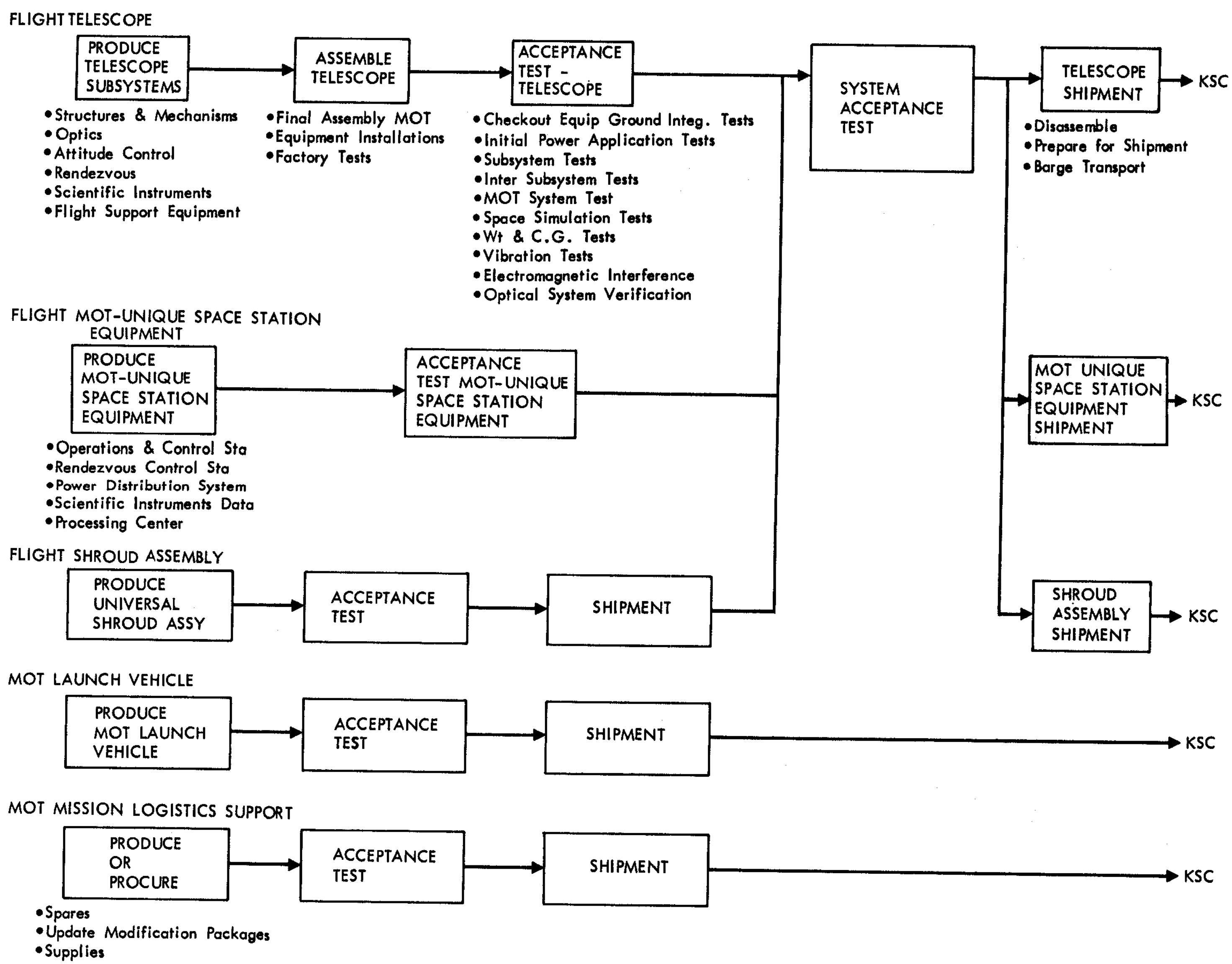


Figure 3-19: FACTORY OPERATIONS — PROJECT OPERATIONS PHASE

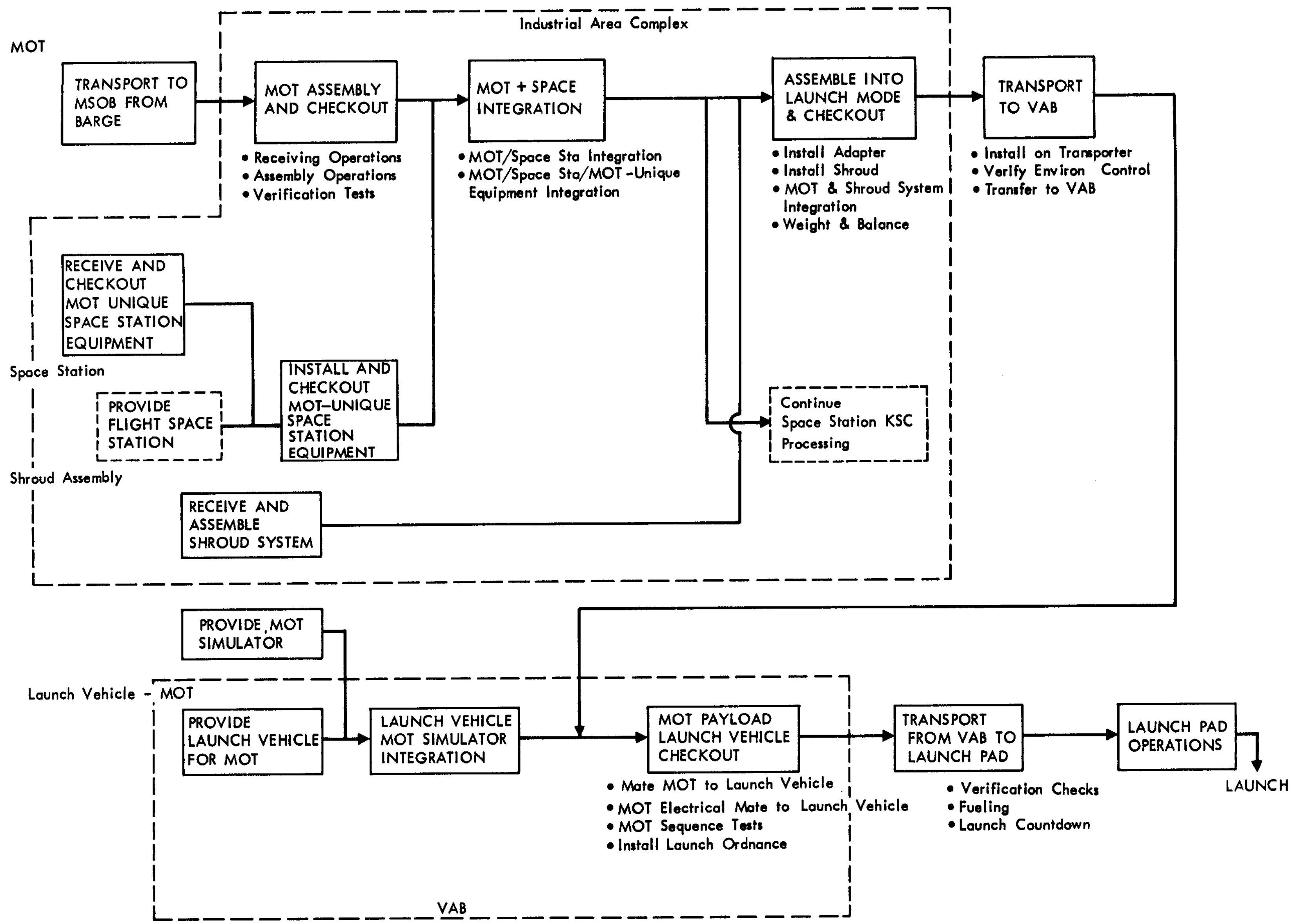


Figure 3-20: KSC OPERATIONS — PROJECT OPERATIONS PHASE

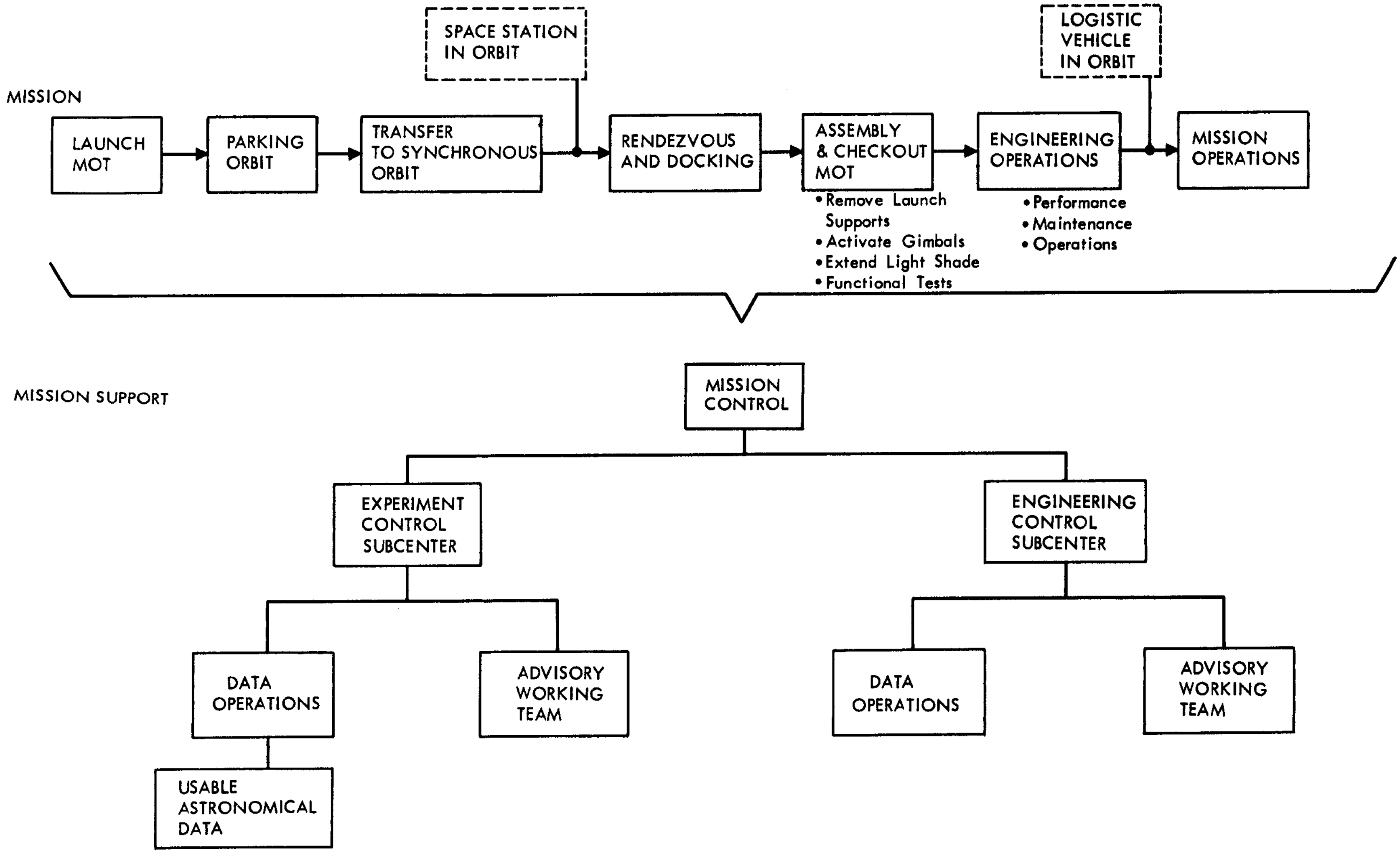


Figure 3-21: MISSION OPERATIONS — PROJECT OPERATIONS PHASE

Table 3-2: EQUIPMENT LIST — MOT PROJECT OPERATIONS PHASE

MAJOR ELEMENTS	SUBSYSTEM	QUANTITY	
		FLIGHT	BACKUP
MOT	Structures & Mechanisms Optics Attitude Control Rendezvous Scientific Instruments Flight Support Equipment	1 1 1 1 1 1	1
Adapter/Shroud (MOT)		1	1
MOT Unique Space Station Equipment	Remote Operations & Control Rendezvous Controls Power Distribution System - Inner & Intra Scientific Instruments Data Processing Center	1 1 1 1	1 1 1 1
Launch Vehicle - MOT		1	
MOT Mission Logistic Support Equipment 2	Spares Update Modifications Supplies	As Required	

1 Backup unit made by refurbishment of the Project Verification Model from the Project Development Phase.

2 This equipment will be sent to the orbiting MOT system on each logistic flight over a period of five years.

an evaluation was made regarding development risks and areas of improvements that will reduce the development complexity. This evaluation identified problem areas needing resolution to obtain an overall effective MOT program. Therefore, a third program structural element has been planned to provide resolutions of these problem areas. This program element is referred to as the concept development phase and will precede the two project phases. The basic purpose of this phase is to provide a high degree of confidence that the most effective MOT system concept will be selected for further development and that the development program can be conducted within a reasonable cost budget and specific time period. The basic output of this phase will be: (1) preliminary subsystem and system specifications, (2) preliminary detailed implementation plans, and (3) preliminary detail cost estimates.

The concept development phase is structured around two groups of primary and support investigations as illustrated in Figure 3-22. The primary investigations pertain to system-level activity; they provide inputs to and receive outputs from support investigations. The support investigations can be conducted as

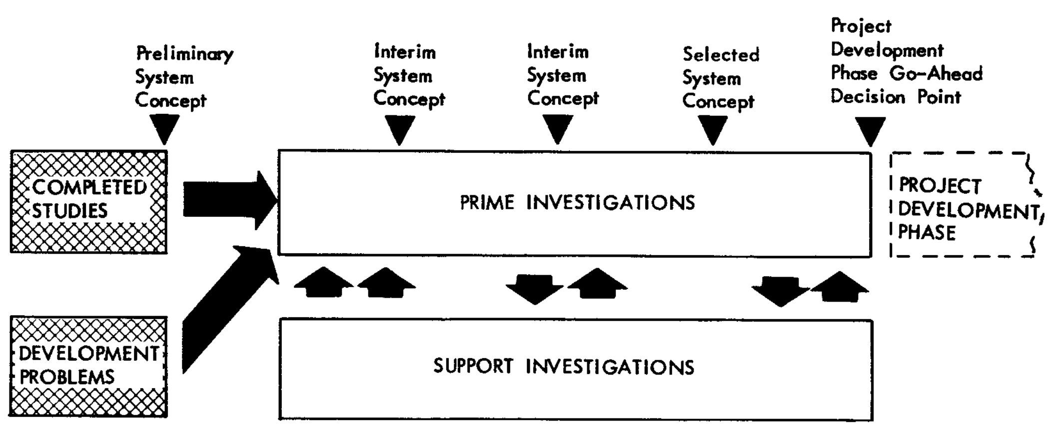


Figure 3-22: CONCEPT DEVELOPMENT PHASE STRUCTURE

single entities and place full emphasis on solving their respective problems. Some investigations include concept demonstrations using breadboard equipment to substantiate feasibility of critical concepts. In the prime investigations, three iterations of the system concept will be made, followed by the preparation of such data as specifications, implementation plans, and program costs. These data will then be used in the decision for follow-on program go-ahead.

3.2.1 Development Problems

The development problems identified from the evaluation of the preliminary MOT system concept development planning were assembled according to their commonality in the following categories: (1) MOT system, (2) system development facility complex, (3) development plans and costs, (4) telescope optics, (5) telescope pointing, (6) scientific instruments, and (7) scientific data system. The identified problems are described below.

MOT System

- Further conceptual development of the present MOT system concept should be conducted to provide sufficient confidence for proceeding into the project implementation stage.
- MOT system concept should be reviewed on the basis of the Saturn V synchronous-orbit payload capability. The present design concept uses only approximately 30,000 pounds of the approximately 80,000-pound Saturn V capability. Further design concept development should consider such factors as: (1) increasing telescope size, (2) launching a MOT space station and telescope together, (3) using excess payload for other purposes, and (4) using brute force telescope design to reduce cost and time.
- Future space programs planned for MOT time period and using Saturn V should be designed around a standard shroud system.
- Some MOT project activity should occur during development of the space station system, shroud system, and logistic vehicle system to ensure compatibility of the projects.
- Astronomer MOT interests should be investigated further to provide more confidence that the design will meet the users' desires.
- The preliminary MOT system concept structural intertie design for maintaining microalignment among the scientific instruments, folding mirrors, and primary mirror requires further study.
- Further thermal studies of the MOT system should evaluate the various potential mirror materials (with their different coefficients of thermal expansion) and determine the feasibility of minimizing the temperature spread between mirror fabrication and operation.

System Development Facility Complex

- The system development facility complex identified in the two previous phases is considered to be a major project item, warranting further investigation to more fully identify conceptual requirements.

Development Plans and Costs

- Program plans and costs should be maintained current with the MOT system concept iterations to provide (1) cost-effectiveness trades for configuration selections and (2) updated gross project schedules and funding planning.
- After selection of the final system concept and prior to initiation of project development, detailed preliminary implementation plans and detailed cost estimates should be prepared to provide a high degree of confidence that the program can be conducted within a reasonable cost budget and specific time span.

Telescope Optics

- The current lightweight mirror sturctural designs may not provide sufficient rigidity to achieve in-orbit accuracy after being subjected to handling and transportation load conditions.
- Thermal expansion of mirror materials may not allow precise prediction of the mirror optical shape and uniformity of optical surface at an operating temperature of -120°F after being fabricated at room temperature.
- Current beryllium material data indicates nonuniform volumetric thermal expansion and stress retention that will seriously degrade the mirror optical performance.
- Radiation resistance, reflective efficiency, and physical surface characteristics of typical MOT mirror material and finishes must be evaluated for use in establishing mirror conceptual configuration.
- Existing mirror finish measurement techniques should be upgraded to meet the MOT mirror finishing requirements.
- Many MOT mirrors are required for the project development and operations phases, justifying investigation into nonconventional fabrication methods, such as electroforming of the mirror surface and automated ionic polishing.
- A self-alignment system for the telescope optics will require extensive development to achieve the required MOT performance accuracies under operating conditions.
- Remote operation of the folding mirror assemblies for indexing and fine positioning of the light image with respect to the instruments is considered a critical function of the optical system, requiring early concept development.

Telescope Pointing

- The telescope's fine pointing system with the accuracy of ±0.01 arc-second requires detail concept development. The sensor system involved for obtaining this accuracy is considered to be the major item requiring development.
- Dynamic signature experimental data of men and equipment operating in a typical MOT and space station combination is required to adequately develop the telescope pointing concept.

Scientific Instruments

- Greater overall system gain might be realized from efforts expended on advanced scientific instrument concepts as contrasted with comparable expenditure of effort on improvement of telescope performance.

Scientific Data System

- Early definition of the scientific data handling concept is required since it will have a profound effect on the MOT ground and space operations. For example, direct transmission of data from scientific instruments to the ground might reduce the needs for ground-to-space logistics and man's space operational role.

3.2.2 Investigations

The investigations have been organized into effective, manageable work packages accounting for the identified development problems noted in Section 3.2.1. The prime investigations pertain to system-level activities and provide inputs to and receive outputs from the support investigations. The subject of each investigation and location of the corresponding investigation scope description are listed in Table 3-3. The program identification number for each of the investigation scope descriptions (A111, A112, etc.) is the same as that used to identify the corresponding item or task in the work breakdown structures and the cost estimates for the concept development phase. Additional investigations may be identified during the accomplishment of the concept development phase and should be considered in future planning activities. These investigations are further described in the following paragraphs and are listed in order of investigation number.

Table 3-3: CONCEPT DEVELOPMENT INVESTIGATIONS

Investigation	Identification Number
Prime Investigations	
System Concept	
System Concept Development	A111
System Operations Concept Review	A112
System Concept Interface Coordination	A113
Preliminary Specification Development	A114
System Development Complex Concept Evaluation	A115
Development Plans and Costs	
Development Implementation Plan	A121
Costing	A122
Support Investigations	
Optical Concept	
Mirror Surface Evaluation	A211
Mirror Assembly Concept Evaluation	A212
Mirror Assembly Concept Verification	A213
Optical Alignment Concept Evaluation	A214
Folding Mirror Assembly Concept Evaluation	A215
Pointing Concept	
Dynamic Signature Identification	A221
Space Station/MOT Interaction Evaluation	A222
MOT Pointing Concept Evaluation	A223
Scientific Instruments Concept	
Scientific Instruments Concept Evaluation	A231
Scientific Data System Concept	
Scientific Data System Concept Evaluation	A241

SYSTEM CONCEPT DEVELOPMENT

Purpose — To develop the most cost- and performance-effective MOT system concept to be used as a basis for: (1) detail design in the follow-on project phases and (2) providing control continuity over the other investigations conducted in the concept development phase.

Timing — Throughout the concept development phase.

Justification — The magnitude of the total MOT program requires considerable assurance that a sound conceptual design is selected prior to equipment development. This study has identified a number of significant development problems pertaining to the current preliminary system concept.

Description — This investigation satisfies the purpose of developing related major system concept aspects with support from other investigations and by providing continuity control over these support investigations. The related major system concept aspects are the overall system, configuration, structures, and thermal environment because they form the common or universal interfaces between the subsystem and system elements.

Overall System Concept — The overall system concept should be further developed and evaluated to cover such items as selection of the ideal orbit altitude and inclination, sizing of the MOT system to the launch vehicle system, determination of the proper MOT system concept to minimize logistics requirements, and selection of the optimum space station concept considering the MOT and other major NASA system requirements.

The preliminary system concept study was conducted at only two orbital altitudes: low (near-Earth) and synchronous orbit, both at a 28-degree inclination. Further study should be conducted to provide parametric data for selecting an orbital altitude and inclination that will provide the optimum system operation and performance. The preliminary system concept was developed for low-Earth orbit using a Saturn IB launch vehicle, and further study evaluated this design in a synchronous orbit condition. For this orbit condition, the required Saturn V launch vehicle has an 80,000-pound synchronous-orbit capability, whereas the MOT launch weight was estimated at 28,000 pounds. Should subsequent studies substantiate the need for a Saturn V synchronous-orbit operation, evaluation will be required to fully utilize this launch-vehicle payload capability. This evaluation should determine telescope size compatible with the launch vehicle payload size and weight capabilities. Also, consideration should be given to using this launch vehicle capability to transport an assembled MOT-and-space-station complex into orbit. Such a configuration would have the advantage of not requiring a telescope rendezvous and docking subsystem. Also, the space station might remain permanently attached to the launch vehicle third stage and use some of its electronics for telescope operations and its mass to dampen equipment and crew dynamics.

An extensive system concept study should be conducted to minimize the need for repetitive space logistics operations caused by the long MOT mission life. The preliminary system concept involved a ground-to-space logistics and crew transfer operation every 90 days. In this case, the data was physically returned by this logistics transportation system. Further study should evaluate a MOT system having both manned and automated capability. During the initial MOT space operation, man would be involved to check equipment and ensure proper system operation. The system could then be placed on automatic mode with operation and control accomplished on the ground and scientific data transmitted to the ground. Periodically, man would return to perform maintenance and directly operate the system for critical experiments requiring high resolution and physical return of data to the ground.

The space station concept selection should be evaluated so as to provide the most effective overall system operation and performance. The preliminary system concept assumed the use of a multipurpose MORL-type space station. Further space station selection studies should consider a single-purpose MOT station using multipurpose subsystems developed from other NASA programs. Such a concept may allow ground-to-space transportation of a completely assembled MOT-and-space-station combination, which might result in a more effective total system. Also, the combination may provide greater flexibility for experiment operation since it would not be involved in other multipurpose space station operations.

Configuration — Throughout this investigation, detail configuration data should be maintained to provide configuration constraints on other concept development investigations. Also, outputs from the other investigations will be assembled into a composite configuration definition by this activity, thereby ensuring continuous program continuity control. The configuration data should include drawings, equipment, concept descriptions, weight estimates, mission description (including timelines), and performance description. The performance description should include an analysis tree showing estimated performance tolerance distribution for each system element, thus defining the desired overall MOT system performance. Cost analysis should be maintained so that configuration elements versus cost trades may be evaluated continuously during this investigation.

The system concept configuration development should include consideration for locating the telescope electrical and electronic equipment in the inhabited area of the space station. Continuous shirtsleeve environment would then exist for equipment maintenance and troubleshooting functions, thereby providing more effective telescope operations. Also, the telescope thermal design would be simplified by not having to account for the heat load generated by this equipment.

Structures — A review of the structural concept should be made to ensure a sound configuration for the system concept. Areas that should be included in the review are: (1) the need for, and concept of, the primary mirror boost support structural system; (2) the structural intertie integrity of the in-orbit primary-mirror support structure and the scientific instrument support platen; (3) the need for, and the detail concept of, the soft-gimbal mount system; and (4) a system approach to critical material and processes relative to the structural aspects.

The preliminary system concept uses an air bag for protecting the primary mirror between launch to orbit achievement. During the industrial survey, several comments were made questioning the feasibility of this air bag system to provide proper support at the edges of the mirror. Therefore, depending on the mirror structural concept, a new boost support concept should be developed. This concept should then, because of its importance to the overall system, be demonstrated using a breadboard model. In developing the planning for this demonstration, it may be necessary to determine that this activity should be combined with the mirror concept demonstrations of Investigation A213. Completion of the demonstration should verify the feasibility of a boost support system for the primary mirror.

The in-orbit telescope operation for the preliminary system concept requires a microaccurate structural relationship among some of the scientific instruments, the folding mirrors, and the primary mirror. A question exists as to whether or not the structural configuration identified for this concept will meet the requirement. Structural intertie slippage between mirror and instruments due to telescope slewing action can result in relative permanent displacement affecting telescope operation. A review of this concept should be made to evaluate this structural and operational aspect. To obtain the required structural characteristics, it is believed that a single structural assemblage containing the primary mirror, folding mirror, and scientific instrument attachments is required as opposed to the composite structural assemblage in the preliminary system concept.

The preliminary system concept includes a gimbal mounting system between the telescope and the space station for fine pointing operations. This gimbal system is considered a high-risk development item and, if the requirement for the concept is reaffirmed as a result of the pointing concept investigation (A223), a conceptual investigation in greater depth than has been accomplished should be conducted. This investigation should include the dynamic and mechanical aspects of the design and may recommend the conduct of a concept demonstration.

The material used in the MOT has two basically unique requirements. These are an ability to support an expected 5-year operating life and the ability to maintain microdimensions on many of its parts during ground and space operation. A problem exists as to how confidence can be obtained in the material selection to meet these requirements in an economical and timely manner. An investigation in the early phase of the system study should be to develop a conceptual program on material selection. Such a program might include the feasibility of developing MOT material experiments for the AAP program.

An AAP-type experiment approach that should be investigated would be to prepare "time capsules" containing specimen materials. Some specimen materials might be small gage blocks of mirror material, such as quartz, crystalline glass, and beryllium; coupons of typical MOT organic and inorganic materials; and thermal control coatings. Several capsules vented to space may be included in forthcoming AAP manned spacecraft experiments. The capsules would be passive devices left on abandoned spacecraft and retrieved as an additional operation by other manned space operations occurring several years later. The material after being returned to the ground would be subjected to a thorough materials analysis. Characteristics, such as microcreep of the mirror material gage blocks, mirror surface contamination from organic materials outgassing, thermal control coating deterioration, and the effects on material properties of metals used in the telescope construction, could be determined. This capsule experiment aspect of the materials selection program might be reasonably low in cost and could provide confidence in the material selection prior to the MOT final development and operation. The cost of designing and fabricating the time capsules has not been included in this study since more definition is required.

Thermal Control — Due to the sensitive nature of the critical elements of the telescope, a precise thermal control system is necessary. Therefore, a conceptual study conducted in depth is required involving extensive thermal balance analysis. The investigation areas considered critical are maintaining a very uniform orbital thermal environment around the primary mirror and very constant thermal stability in the structure intertie system between the primary mirror, folding mirrors, and scientific instruments required to maintain microalignment accuracy. The thermal operational environment requirement for the optics must recognize: (1) the thermal characteristics of the selected mirror material; (2) the range between high fabrication temperatures and low operating temperatures; and (3) telescope infrared performance requirement on the operating temperature of the optics.

SYSTEMS OPERATION CONCEPT REVIEW

Purpose — To specifically define the required astronomical performance and capability of the MOT that will fully explore the spectrum from the near infrared through the visible and ultraviolet (0.08 to 100 microns).

Timing — In the first part of the concept development phase to provide timely inputs to MOT systems concept.

Justification — It is essential that the scientific community identify or confirm in more detail the intended use of the MOT system since this defines the basic design and operational features of the system.

Description — This performance and capability definition of the MOT will provide such data as the types of objects to be observed, the experiments to be performed, the types of instrumentation needed together with their wavelength range, the approximate percentages of time to be devoted to each type of experiment, and the desired degree of experiment operation flexibility. This data will then be used in establishing the operational concept of the MOT system and definition of the scientific instrumentation. An advisory MOT committee of astronomers should be established to provide consultation throughout the concept development of the system to ensure its applicability.

SYSTEM CONCEPT INTERFACE COORDINATION

Purpose — To provide technical interchange between the MOT system and other NASA-related space programs during the MOT concept development phase to ensure program compatibility.

Timing — Throughout the MOT concept development phase.

Justification — Final definition of the MOT system is dependent on the as yet undetermined characteristics of other prospective space systems that will supply operational support functions and subsystem hardware to the MOT system.

Description — During the MOT conceptual phase, other related MOT programs will probably be in their project development phase. It is necessary that the MOT requirements be recognized in the development of these related programs. It is also essential that the capability of the equipment in the related programs be recognized in the MOT conceptual design so that realistic system trades can be made.

To have an identity in this investigation, a document will be prepared identifying the program form, fit, and function interfaces. The performance capabilities and requirements for each interface and each program should be clearly presented. The document will then serve to clearly identify program relationships for both management and technical usage. Related programs that might be followed by this investigation are:

- Space Station
- Launch Vehicle
- Logistics Vehicle
- Subsystem Module
- Multipurpose Launch Protection Shroud
- Apollo Applications Program (AAP)
- Planned MSC and KSC modifications affecting MOT operations
- Orbital Astronomical Support Facility

PRELIMINARY SPECIFICATION DEVELOPMENT

Purpose — To define the selected MOT system and subsystem concepts in terms of preliminary specifications to be used for initiating the project development phase.

Timing — Toward the end of the concept development phase.

Justification — Preliminary specifications are required as a system of design goals and controls for initiating detailed definition of the MOT system during the project development phase.

Description — Preliminary MOT system and subsystems should be defined in the form of preliminary specifications at the end of the concept development phase. These should be in sufficient detail to form a sound basis for starting the preliminary design and development of hardware and software during early stages of the project development phase. Data from the support investigations and system-concept investigations should provide the necessary input for preparing the specification.

SYSTEM DEVELOPMENT COMPLEX CONCEPT EVALUATION

Purpose — To determine the concept of the most effective MOT system development complex.

Timing — Prior to the program planning and cost effort for the selected MOT system concept.

Justification — From the industrial survey conducted for this study, it became apparent that the MOT system development complex might require state-of-the-art advancement and be a major cost item. An evaluation in depth is required to determine the concept of the complex and its requirements.

Description — The investigation should establish the gross system requirements for development and production of the MOT. Possible geographical locations for the complex and whether individual complex elements are preferable to a single integrated complex should be determined. The complex concept should recognize at least: (1) optical system testing accuracy; (2) pointing system testing accuracy; (3) environmental test spectrum; (4) MOT test support system; and (5) test duration.

Test approach and cost aspects should be fundamental considerations in establishment of the development complex. To obtain the most effective requirements for the system development complex, the possibility of conducting MOT system-level ground-type tests to performance values somewhat less than the design should be evaluated. To establish confidence in system equipment capability prior to launch, analysis using analytical extrapolation might be performed involving below-subsystem-level and less-than-design-value system-level tests results. Final system acceptance could be made after initial use in orbit where the system performance under actual conditions would be demonstrated. An evaluation in depth of this approach may reveal that the system development complex may be of a simpler design with overall program cost savings.

DEVELOPMENT IMPLEMENTATION PLANNING

Purpose — To prepare the preliminary implementation plans required for making a go-ahead decision to initiate the project development and operation phases of the MOT program.

Timing — Near the end of the concept development phase, after the final MOT system concept has been defined.

Justification — To make the key decision of committing the remainder of the MOT program following concept development, preliminary detail planning and costs data are required to provide confidence in the prediction of program scope, duration, and costs.

Description — Preliminary detail plans for implementation of the project development and operation phases should be prepared during the latter part of the concept development phase. The plans will be used to obtain: (1) an understanding of the magnitude and timing for the succeeding phases and (2) a detailed cost estimate for the succeeding phases.

The method involved in accomplishing this investigation should be to first prepare a near-final MOT program plan and then prepare the supporting preliminary implementation plans. The program plan should be a major review and revision of the preliminary program plan prepared under this study and will be based on the final selected MOT concept. The completed program plan should form the basis and control for the preliminary supporting plans. These supporting plans should be prepared in detail for each of the following areas:

- Management
- Engineering
- Configuration Control
- Quality Assurance
- Testing
- Transportation
- Reliability
- Safety
- Manufacturing
- Facilities
- Logistics
- Training
- KSC Operations
- Mission Operations
- Experimentation

COSTING

Purpose — To provide: (1) parametric-type cost data for trade study analysis and gross program cost estimates during the system concept iteration activity and (2) detailed cost estimates on the final system concept for use in establishing a firm development budget.

Timing — To be accomplished throughout the MOT concept development phase.

Justification — Decisions made during the various system concept iterations must consider cost effectiveness and gross program costs. Also, prior to starting the project development phase, firm budgets for the succeeding phases must be established based on realistic cost estimates.

Description — Cost considerations based on parametric data should be included in the trade studies involved in the selection of the various system concepts. Gross program costs from the present study should be continuously updated to support the selection of various system concepts and to maintain long-range funding forecasts. For the selected system concept, detailed cost estimates should be prepared using the program definition developed in Investigation A121. These estimates should include individual task costs and time-phased funding.

MIRROR SURFACE EVALUATION—

Purpose — To obtain data on radiation resistance, reflective efficiency, and physical surface characteristics of typical MOT mirror surface configurations for use in selecting the final mirror configuration.

Timing — Early in the concept development phase.

Justification — Evaluation of MOT mirror performance requirements indicates a lack of basic mirror surface data. Establishment of the basic mirror surface early in the concept development program is considered necessary to allow orderly development leading to final mirror selection. From the industrial survey conducted under this study, surface irregularity problems were identified. These irregularities pertained to bubbles in quartz and Cer-Vit material and crazing-type defects in polished Kanigen nickel.

Description — The study will include physical surface characteristics, reflectance efficiencies, and radiation resistance of typical mirror specimens.

Physical Surface Characteristics — Photomicrographs should be made of typical MOT mirror specimens with sufficient magnification of the surface to permit measurement of the accuracy of the finish. These photomicrographs should be made during the various steps of fabrication to determine if final finish irregularities can be attributed to a specific step in the fabrication. In addition, these photomicrographs can be used in evaluating reflectance performance and radiation damage.

Reflectance Efficiencies — Spectral and diffuse reflectance measurements should be made on typical MOT mirror specimens, the data from which will be used in more accurately predicting MOT optical performance. These measurements should be made over the proposed MOT wavelength range of 0.08 to 100 microns. In addition, these measurements can be used in evaluating radiation damage.

Radiation Resistance — Radiation resistance evaluation of typical MOT mirror specimens recognizing a 5-year MOT operating life should be conducted. The tests should be conducted in a typical MOT operating environment, recognizing vacuum and thermal conditions. Damage assessment would be made by photomicrographs, reflectance measurement, and interferometric measurement.

Typical MOT Mirror Specimens — Two sets of specimens should be made representing the MOT primary and secondary mirror finishing ($\lambda/30$ rms and $\lambda/100$ rms, at 5000 Å). These specimens should be made of the following materials:

Vapor-Deposited Coatings

Blank Material	Substrate	Undercoat	Reflectance Coat	Overcoat
Beryllium	Kanigen		Al	MgF_2
Quartz			Al	MgF_2
Cer-Vit			Al	MgF_2
Beryllium	Kanigen	SiO	Al	MgF_2
Quartz		SiO	Al	MgF_2
Cer-Vit		SiO	Al	MgF_2
Beryllium	Kanigen	Chrome	Al	MgF_2
Quartz		Chrome	Al	MgF_2
Cer-Vit		Chrome	Al	MgF_2

MIRROR CONCEPT EVALUATION

Purpose — To develop primary and secondary mirror concepts involving material, design, fabrication, and measurement aspects.

Timing — Prior to the mirror concept demonstration in the latter portion of the concept development phase.

Justification — The present MOT concept uses mirrors of lightweight waffle-plate beryllium structure plated with Kanigen nickel. Recent investigations indicate that considerable problems exist with this design. These problems include the lack of stability and predictability of beryllium in the material micro-property range. In addition, Kanigen nickel has crazing characteristics that, during polishing, may seriously affect the final finish. The potential thermal problems associated with this metal mirror assembly being fabricated at 70°F and operating at -120°F requires considerably deeper investigation than has been accomplished to date. Other mirror materials, such as quartz and crystalline glass, being used today should be investigated. In summary, considerable assurance is believed necessary prior to the project development phase that the MOT requirements can be met for making primary and secondary mirrors of the desired size and figure accuracy ($\lambda/30$ rms for the 120-inch mirror and $\lambda/100$ rms for the 30- and 19-inch mirrors — all values determined at the 5000 Å level) and maintaining this accuracy in space.

Description — The configuration constraints and requirements on the mirror concept design will be obtained from the system concept investigation to ensure that the results of the mirror studies will be applicable to the system. Also, the method of mirror support (during boost) from the system concept investigation should be recognized in this mirror concept investigation.

Mirror Material — A detailed material properties analysis and evaluation should be made of candidate mirror materials throughout the ranges of the MOT thermal, vacuum, shock, and vibration environments. Mirror material properties should be investigated to evaluate the microuniformity of the thermal expansion characteristics that may be expected on a mirror of the MOT size and construction. Also, the effect of the mirror fabrication process on the material properties should be investigated. For instance, the magnesium-fluoride vapor coating over the aluminum vapor deposition may require a mirror temperature of about 400°F. The effect of this high-temperature fabrication operation, together with the low-temperature mission operations, should be evaluated from a material properties aspect. This phase of the investigation should result in recommendations for mirror-blank, plating, and vapor-deposition materials, as well as material processes.

Structural Concept — Results of the industrial survey indicate further concept effort should be expended on the structural aspects of the mirrors. This evaluation should consider how the mirror blank can be designed to be lightweight, sufficiently rigid to maintain the figure during the mirror's dynamic life and figure integrity over the thermal range of 70°F for figuring, 400°F for coating, and -120°F for mission operations. For instance, evaluations should be made of various structural configurations, such as honeycomb, egg-crate, and waffle-plate, for different single-material construction. Also, mirror blanks of composite-material construction should be evaluated; e.g. a lightweight metal honeycomb or fiberglass structural base of extreme stiffness with a ductile blanket bonded to the top of the base. This blanket might be of silicone rubber or similar ductile material on top of which a mirror plate is bonded. The mirror plate might be of solid quartz or crystalline glass of from 1 to 2 inches thick. Also, the mirror plate might be an electroformed metal, which is currently being developed under NASA contract. Favorable features of this potential mirror blank design are its ability to: (1) evenly distribute the stresses into and out of the mirror plate; (2) provide boost support to the mirror plate; (3) provide mirror plate attachment to the telescope during in-orbit operation; and (4) provide thermal insulation between the mirror plate and the cabin end of the telescope.

Fabrication Techniques — The fabrication process should be investigated for the recommended material and structural design from the above studies. This fabrication investigation should recognize not only the mirror accuracy and size requirements but also the number of development articles required during the project development phase. Fabrication methods, which, through accurate controls provide precise results, require identification. The new mirror surface finishing technique using ionic polishing should be investigated, including possible automation.

Mirror Measurement — Since MOT mirror surface irregularities from the design figure must be considerably smaller than those allowed in fabricating today's mirrors, a review of measurement techniques involved is necessary. A candidate technique that appears to have the required accuracy potential involves the use of improved laser interferometers. It is important to identify measuring systems that will be used during mirror fabrication since it forms such a fundamental control factor in the fabrication of a basic performance element of the telescope.

Concept Demonstration Definition — Since the mirror system is so significant to the MOT operation, a demonstration of the primary mirror concept is considered essential prior to starting the full MOT project program. The objective of this demonstration is to verify that the mirror assembly will have the required figure during in-orbit operations. An output of this investigation would be a specification for the follow-on mirror assembly concept verification (A213). The specification might require that several mirror blanks be fabricated of different designs and materials (such as beryllium, quartz, and crystalline glass). For this study, it is assumed that three different designs will be demonstrated.

These mirrors will be of full primary-mirror size since this was a strong recommendation of the various companies contacted in support of this study. The mirror blank should be figured to a spherical shape instead of the MOT parabolic shape, thus reducing fabrication costs and facilitating testing. The mirror finish will only be of sufficient quality to satisfy the test needs — not greater than 5000 Å. A very accurate measurement of each mirror surface should be made and then compared with similar measurements taken after various typical MOT environmental tests. The ability of the mirror assembly to maintain its original shape will determine the degree of acceptability.

MIRROR ASSEMBLY CONCEPT VERIFICATION

Purpose — To verify the mirror concept developed in the mirror assembly concept investigation (A212).

Timing — After the completion of the mirror assembly concept evaluation investigation (A212), after the MOT system concept development investigation (A111) has established the final size of the primary mirror, and prior to the start of the project development phase.

Justification — The ability to develop a mirror structural configuration to the MOT requirements is considered a high-risk item and requires concept demonstration prior to full MOT program implementation.

Description — Using the specifications from the mirror assembly concept evaluation investigation, a program should be conducted including the following major activities:

- Concept Demonstration Planning
- Test Mirror Assembly Designs
- Mirror Assembly Fabrication
- Mirror-Telescope Mount Fabrication
- Test Conduct
- Test Evaluation
- Final Mirror Structural Concept Selection

OPTICAL ALIGNMENT CONCEPT INVESTIGATION

Purpose — To establish confidence that a self-alignment system of the secondary mirror with respect to the primary mirror can be developed to the MOT accuracy and environmental requirements.

Timing — Prior to the selection of the final MOT system selection.

Justification — The ability of the telescope to perform adequately is highly dependent on how well the two basic optical elements are maintained in alignment. The present baseline has an actuator system that manipulates the secondary mirror based on outputs from sensors that are located on the primary mirror and looking at the secondary mirror. The ability to develop both the sensor and actuator systems to the required performance accuracy is considered a significant problem.

Description — The system concept development investigation will provide the mirror alignment requirements and constraints for this investigation. The method of micromovement of the secondary mirror, including the ability to survive the boost environment, should be investigated. The concept of the sensor system should be evaluated for its ability to accurately sense optical system misalignment under MOT environmental conditions.

Because of the sensitivity of the telescope design on the alignment subsystem, the alignment subsystem capabilities must be demonstrated. This demonstration will involve a laboratory model of the secondary-mirror actuator system, coupled with a typical sensor assembly installed on a simulated portion of the primary mirror. The output of this investigation will be the selection of a demonstrated optical alignment system concept.

FOLDING MIRROR ASSEMBLY CONCEPT EVALUATION

Purpose — To develop and demonstrate a concept of a folding-mirror actuating mechanism that will meet the MOT accuracy requirements.

Timing — After the folding mirror requirements have been established in the system concept development investigation.

Justification — The present system concept design requires that man remotely operate the MOT from the space station. This results in an additional requirement that the various scientific instruments be selected by rotating folding mirrors. The folding mirror assembly directs the light beam into each scientific instrument as selected. This assembly is required to support and orient the mirror so that the reflected image is repeatedly positioned and held within a fraction of an arc-second. A mechanism meeting this operating requirement and capable of surviving the transportation environment of launch to orbit is considered a significant problem requiring extensive concept development and demonstration.

Description — The requirement and constraints on the folding mirror assembly should be identified during the system concept study and should be based on realistic scientific instrument input requirements for dynamic stability and longitudinal-, rotational-, lateral-, and tilt-image inputs. Also, the inputs to this investigation should identify if the folding mirror assembly is to be used in the fine pointing system for the telescope (as determined from the pointing system concept investigation, A223).

Various concepts should be should be identified and evaluated to determine their ability to provide the required positioning accuracy. The most promising concept would be selected and a concept demonstration performed. This demonstration should be of sufficient sophistication to assess precision and repeatability under simulated space environments.

DYNAMIC SIGNATURE IDENTIFICATION

Purpose — To identify and establish dynamic signature criteria on typical MOT and space station operations of both man and equipment for developing the pointing system concept.

Timing — During the system concept development and the pointing concept evaluation investigations.

Justification — Presently available dynamic signature data on man and equipment operation is limited and not defined to the level necessary for design of the MOT. Realistic evaluations of the MOT pointing system concept are highly dependent on the use of valid signature data.

Description — A review and compilation of existing dynamic signature data and planned experiments on other programs should be made. From this review a set of experiments would be planned providing dynamic signature data to the magnitude and accuracy required for MOT. These experiments should be conducted on various AAP programs such as S-IVB workshop and ATM. The data from these experiments would then be analyzed, and the results used to establish the MOT dynamic signature criteria. These criteria should define the characteristics of various input disturbances, such as man's motions during various tasks and operation of rotating machinery, actuators, and thrustors, for use in the space station and MOT interaction evaluation investigation.

SPACE STATION/MOT INTERACTION EVALUATION

Purpose — To determine and analyze the influence of pertinent space station operations on the MOT pointing concept.

Timing — During the MOT pointing concept evaluation.

Justification — Since the mission of the MOT is accomplished by the combined operations of the space station and the telescope, an optimum division of pointing control between the two is desirable. Therefore, the capability of the space station to contribute to this requirement is necessary for definition of a control concept. During periods of astronomical observation, disturbances generated within the space station (to which the telescope is attached) may seriously degrade the telescope's resolution. The pattern and magnitude of these space station motions must therefore be investigated.

Description — The quantity and distribution of the space station mass should be defined as a basic input to the analysis of the space station and telescope dynamic responses and the development of a pointing concept. Dynamic disturbances emanating from the space station that influence the telescope pointing system requirements, including crew movements, rotating machinery, and actuation equipment, should be defined. The space station control system performance should be analyzed as to its ability to accomplish, or contribute to, the pointing and stabilization of the telescope. The general requirements of the telescope pointing and attitude stability system should be determined by deletion of the functions performed by the space station from the overall pointing and attitude requirements of the orbital telescope.

MOT POINTING CONCEPT EVALUATION

Purpose — To establish a MOT pointing system concept that has a high probability of being developed with reasonable expenditures of effort and time.

Timing — The preferred pointing concept should be identified prior to the final system concept selection; the pointing concept should be verified before the end of the concept development phase.

Justification — MOT attitude control investigations performed to date have been necessarily limited in scope because of the preliminary conceptual nature of the MOT studies. Stabilization of the telescope pointing to ±0.01-arc-second accuracy is considered to be a high-risk area of development. More detailed definition of the requirements and characteristics of this principal subsystem are necessary for further refinement of the MOT configuration and operations.

Description — Concept requirements will be identified, leading to extended evaluation and demonstration of the MOT pointing concept.

Concept Requirements Identification — The MOT pointing system performance requirements and operating constraints should be further defined on the basis of the astronomical observation resolution and pointing position requirements. Man's functional participation in the overall pointing system should be considered in the identification of the pointing system requirements. The requirements should recognize that the fine pointing sensor should not remove a significant amount of light from the telescope optical output and must have microaccuracy sensing capability.

Pointing System Concept — Investigation of the preliminary system concept of the pointing and attitude stability system, which involves pointing and stabilizing the entire telescope, should be extended into a greater depth of detail beyond the scope of the past conceptual studies. In addition, alternate concepts should be investigated in an attempt to simplify the system and to reduce the requirements of the subsystem equipment. Alternate techniques to be considered include such approaches as: (1) use of man for initial target acquisition and tracking, (2) use of low-thrust reaction jets instead of control moment gyros, (3) reduction or limitation of the requirement for fine stabilization of the entire telescope through the use of quick-response adjustable optics, and (4) use of pointing sensors located within the scientific instruments as a source of input to the pointing system electronics.

Utilization of man should be considered for initial target acquisition and tracking to reduce equipment complexity if the preferred system concept requires man in orbit during telescope operation. Also, the feasibility of using a reference-gyro-type platform system, patterned after those developed in the ballistic missile field, should be explored for use in coarse and intermediate slewing operation instead of the preliminary system concept star tracking system.

Since the inception of the preliminary system concept study, advances have been made in low-thrust, high-specific-impulse mass-expulsion systems, such as subliming solids, resistojets, and ion engines. The feasibility of using such devices instead of control moment gyros as a primary torque source for fine pointing control should be investigated.

Fine control of the telescope pointing axis by means of rapid but accurate adjustment of the optical configuration may be a possible alternative to fine control of the entire telescope. Since it is desirable that the geometric relationship between the primary and secondary mirrors and the instrumentation be maintained constant during an observation, adjustment of the folding mirror for fine control of the light beam appears to be the most promising. Investigation of interferometric techniques for position sensing and the possible actuation of the mirror by piezoelectric effects should be included.

The influence on the pointing system of a soft-spring, gimbaled connection between the telescope and the space station during observation periods requires further investigation. Future analyses should result in refinement beyond that accomplished in earlier studies, which were limited to a single degree of freedom. In addition, the alternate concept of rigid attachment of the telescope to the space station and a Saturn IV-B spent stage should be considered.

NASA study and development programs related to this investigation include the following:

- Control Moment Gyros
- Apollo Telescope Mount
- Microactuators
- Segmented Mirror Control
- Saturn IV-B Space Applications
- Crew Activity Vehicle Disturbances

Concept Demonstration — Due to the significance of the pointing function on the overall telescope performance, a concept demonstration should be conducted. The demonstration should verify the potential performance and development feasibility using breadboard models. The output of the demonstration should be the final pointing system concept selection.

SCIENTIFIC INSTRUMENT CONCEPT EVALUATION

Purpose — To identify and evaluate new conceptual types of scientific instruments which might relieve the telescope performance requirements or improve the telescope capability.

Timing — During the system concept development investigation.

Justification — The present telescope performance is greatly determined by the needs of the scientific instruments (such as the spectrograph requiring location of the image in a microsize slot over extended periods of time). Such requirements on the telescope may be relieved by other instrument concepts.

Description — An extensive survey of industrial and scientific activity in the area of scientific instrumentation should be conducted to determine the present state of development. Potential areas may be found in image amplifiers and holograph activities. Holographs, requiring an estimated 30 minutes for each exposure, have been advocated as a replacement for spectrographs requiring exposure periods of many hours. The performance capability of instrument concepts should be evaluated for providing outputs in electrical form adaptable for direct transmission to the ground. Evaluation of each instrument should be made to determine if telescope pointing system inputs can be more advantageously obtained by sensor outputs located in the instruments. The output of this investigation would be the identification of the current and projected instrumentation concept and recommended instrumentation concepts that should be pursued for use in the MOT system concept.

SCIENTIFIC DATA SYSTEM CONCEPT EVALUATION

Purpose — To develop an automatic data system concept capable of data transmission from the scientific instrument output to the ground with the required quality for the MOT experiments.

Timing — After start of the scientific instrument concept evaluation.

Justification — The current MOT data system concept records all scientific data in the MOT and space station complex and returns this data to the ground by logistics vehicle operation every 90 days. Shielding is required to protect the unexposed photographic film used extensively as a recording medium. A data system, using either photoelectric detection techniques in place of film or automated photographic data readout systems, should be investigated as possibly providing a simpler MOT design and operations concept.

Description — From the scientific instrument concept investigation, the instrument outputs should be identified as to type and quality. An analysis should then be made as to methods of instrument output conversion to electrical signals. In particular, photoelectric imaging systems, including those now under development by other government agencies, should be analyzed to establish if these can provide the desired resolution and coverage. An evaluation of photographic data obtained by using digital computer techniques should be made to establish the extent to which this technique might be adapted to the MOT, providing real-time data analysis and immediate operational correction. This data automation concept could possibly reduce the logistic-vehicle requirements, simplify the in-orbit handling operations, provide faster data analysis response both on the ground and in space, and increase the effective MOT output.

It is visualized that the ideal mission operation might be to first check and initially operate the MOT by man for 3 months after orbit insertion. The system would then be put into automatic mode and operated from the ground. This automatic operation might be conducted for 9 months of each year, obtaining that type of astronomical data capable of automation. Man might then return to the MOT for 3 months each year for maintenance, equipment modification, and to conduct those experiments requiring accuracy and resolution that cannot be automated. This type of operation has the potential of providing a significant savings by eliminating three of the four logistic operations per year as required in the present system concept.

3.2.3 Equipment List — Concept Development Phase

The items of equipment identified in Table 3-4 are required to support demonstrations of the concepts selected from the concept development phase investigations.

Table 3-4: EQUIPMENT LIST — CONCEPT DEVELOPMENT PHASE

PRIMARY MIRROR BOOST SUPPORT STRUCTURE CONCEPT DEMONSTRATION (Prime Investigation A111)
- Breadboard Primary Mirror Boost Support Structure Test Article
- Test Equipment and Facilities are Considered Existing Aerospace Capability
- Miscellaneous Jigs, Fixtures, and Instrumentation

MIRROR SURFACE EVALUATION (Support Investigation A211)
- About 50 Mirror Test Specimens of about 1 inch in Diameter
- Test Equipment and Facilities are Considered Existing Aerospace Capability

MIRROR CONCEPT DEMONSTRATION (Support Investigation A212)
- Three Full-Size Breadboard-Type MOT Primary Mirrors Finished to a Spherical Shape and to a $\lambda/4$ or less Finishing Tolerance. Might be of Beryllium, Quartz, and Crystalline Glass Material.
- $\lambda/100$ or Better Mirror-Measurement Equipment
- Miscellaneous Test Jigs, Fixtures, and Instrumentation
- Environment Test Facilities are Considered Existing Aerospace Capability

OPTICAL ALIGNMENT CONCEPT DEMONSTRATION (Support Investigation A214)
- Breadboard Secondary Mirror Alignment Assembly
- Breadboard Alignment Sensor Assembly
- A Test Jig Simulating the Primary and Secondary Mirror Support Structure
- Alignment Micromeasurement Equipment

FOLDING MIRROR CONCEPT DEMONSTRATION (Support Investigation A215)
- Breadboard Folding Mirror Actuation System
- Miscellaneous Test Jigs and Fixtures
- Test Measurement Equipment to a Microcapability

POINTING CONCEPT DEMONSTRATION (Support Investigation A223)
- Fine Pointing System Breadboard to Demonstrate a ±0.01-Arc-Second Capability
- Seismic Test Stand Including Air Bearing System
- Micromeasurement Equipment Capable of Measuring to an Accuracy of ±0.01 Arc-Second
- Miscellaneous Test Jigs and Fixtures

3.3 TASK SEQUENCING AND SCHEDULE PLANNING

This planning involves preparing work breakdown structures (WBS), sequence networks, and schedules for each of the three phases and then preparing a total MOT program schedule. The work breakdown structures were developed by analyzing the previous planning effort for specific program tasks and then arranging these tasks in logical building-block matrixes. Each task on the WBS has been assigned an accounting number, which is used for cross-correlation throughout this report.

Program networks were prepared using the WBS data and the planning data in other sections of the report. This data was analyzed as to the sequence of accomplishment and then arranged into sequence network charts. Schedules were then prepared using the WBS's, sequence networks, and industry experience. The charts that present the task sequence and schedule planning for the MOT program are as follows:

- Concept Development Phase
  - Work Breakdown Structure . . . . Figure 3-23
  - Task Sequence Network . . . . Figure 3-24
  - Schedule . . . . Figure 3-25
- Project Development Phase
  - Work Breakdown Structure . . . . Figure 3-26
  - Task Sequence Network . . . . Figure 3-27
  - Schedule . . . . Figure 3-28
- Project Operation Phase
  - Work Breakdown Structure . . . . Figure 3-29
  - Task Sequence Network . . . . Figure 3-30
  - Schedule . . . . Figure 3-31
- MOT Program Schedule Figure 3-32

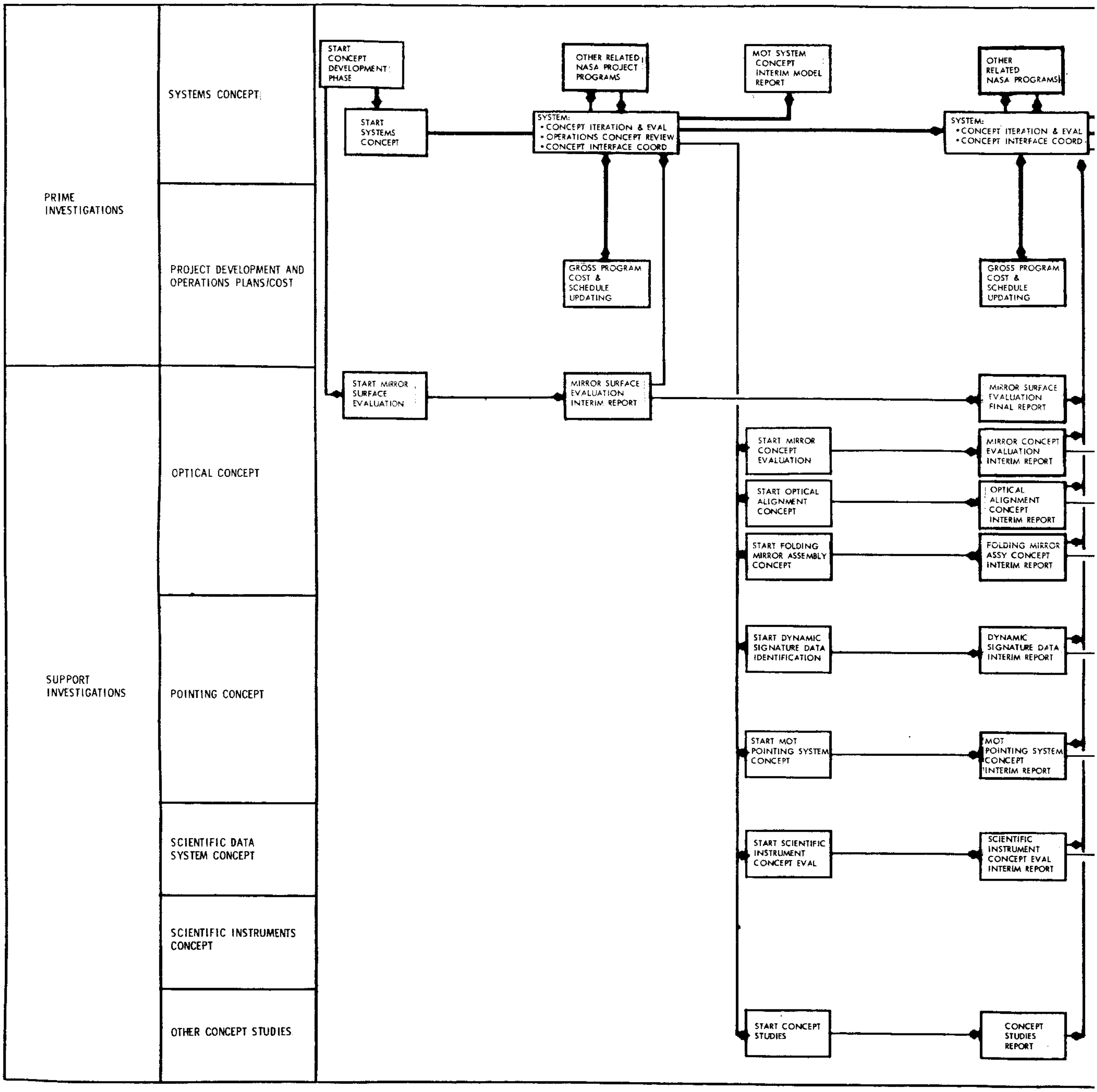
The wide schedule bars shown in the project development and operation phase schedules represent the critical program path around which the other schedule elements were constructed. The principal element contributing to these critical program paths is the development and production activities associated with the primary mirror. Since a mirror of this size and performance for space application is unique, a significant time-consuming development effort is required. To minimize this time requirement, the schedule planning has considered (1) less than final finish on the first unit, (2) no learning curve, since the quantity involved is small, (3) multifinishing facility capability, and (4) multishift finishing operation. Excessive mirror fabrication time should be avoided since this can

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3
			A111 SYSTEM CONCEPT DEVELOPMENT THERMAL STRUCTURES PERFORMANCE CONFIGUATION MISSION
			A112 SYSTEM OPERATIONS CONCEPT REVIEW ASTRONOMERS INPUT-OUTPUT DESIRES MAN'S TELESCOPE OPERATION ROLE
		SYSTEM CONCEPT A110	A113 SYSTEM CONCEPT INTERFACE COORDINATION OASF SYSTEM MULTIPURPOSE SHROUD SYSTEM SPACE STATION SYSTEM LOGISTIC VEHICLE SYSTEM MOT LAUNCH VEHICLE SYSTEM SUBSYSTEM MODULE SYSTEM
			A114 PRELIMINARY SPECIFICATION DEVELOPMENT PRELIMINARY SUBSYSTEM SPECIFICATION PRELIMINARY SYSTEM SPECIFICATION
	PRIME INVESTIGATIONS A100		A115 SYSTEM DEVELOPMENT COMPLEX CONCEPT EVALUATION SYSTEM TESTING PRELIMINARY REQUIREMENTS SYSTEM TESTING EQUIPMENT CONCEPT SYSTEM TESTING FACILITY CONCEPT
		DEVELOPMENT PLANS AND COST A120	A121 DEVELOPMENT IMPLEMENTATION PLANNING PROGRAM PLAN PRELIMINARY MANAGEMENT PLAN PRELIMINARY ENGINEERING PLAN PRELIMINARY CONFIGURATION CONTROL PLAN PRELIMINARY RELIABILITY PLAN PRELIMINARY SAFETY PLAN PRELIMINARY MANUFACTURING PLAN PRELIMINARY QUALITY ASSURANCE PLAN PRELIMINARY TEST PLAN PRELIMINARY TRANSPORTATION PLAN PRELIMINARY LOGISTIC PLAN PRELIMINARY TRAINING PLAN PRELIMINARY MISSION OPERATION PLAN PRELIMINARY FACILITY PLAN
			A122 COSTING FUNDING BREAKDOWN COST ESTIMATE
			A211 MIRROR SURFACE EVALUATION RADIATION RESISTANCE REFLECTIVITY EFFICIENCY PHYSICAL SURFACE CHARACTERISTICS EVALUATION SURFACE MATERIAL RECOMMENDATION
			A212 MIRROR ASSEMBLY CONCEPT EVALUATION CONCEPT REQUIREMENTS IDENTIFICATION STRUCTURAL CONCEPTUAL DESIGN NEW MIRROR FABRICATION TECHNIQUES EVALUATION (ELECTRICAL FORMING, IONIC POLISHING, ETC.) MATERIAL EVALUATION MOT MIRROR FINISHING MEASUREMENT SYSTEM EVALUATION IN ORBIT ATTACHMENT CONCEPT MIRROR CONCEPT DEMONSTRATION SPECIFICATION
MOT CONCEPT A000			A213 MIRROR ASSEMBLY CONCEPT VERIFICATION TEST MIRROR DESIGN TEST MIRROR FABRICATION

	SUPPORT INVESTIGATIONS A200	OPTICAL CONCEPT A210	TEST CONDUCT TEST EVALUATION MIRROR MATERIAL SELECTION ESTABLISHMENT OF MIRROR ENVIRONMENT REQUIREMENTS PRELIMINARY SPECIFIC ION INPUTS
			A214 OPTICAL ALIGNMENT CONCEPT EVALUATION CONCEPT REQUIREMENTS IDENTIFICATION MECHANISM CONCEPT (MICRO ACT. DEV.) ALIGNMENT SENSOR CONCEPT CONTROL CONCEPT (POINTING SYSTEM-ALIGN. SYSTEM CROSS COUPLING EFFECT) ALIGNMENT SYSTEM DYNAMICS MICRO ACTUATOR DEVELOPMENT CONCEPT DEMONSTRATION CONCEPT EVALUATION AND SELECTION PRELIMINARY SPECIFICATION INPUT
			A215 FOLDING MIRROR ASSEMBLY CONCEPT EVALUATION CONCEPT REQUIREMENTS IDENTIFICATION MECHANISM CONCEPT CONTROL CONCEPT CONCEPT DEMONSTRATION CONCEPT EVALUATION PRELIMINARY SPECIFICATION INPUT
		POINTING CONCEPT A220	A221 DYNAMIC SIGNATURE IDENTIFICATION DEFINE TYPICAL MOT/SPACE STATION MAN AND EQUIPMENT DYNAMIC OPERATIONS DEFINE DYNAMIC SIGNATURE SPACE EXPERIMENTS CONDUCT SPACE EXPERIMENTS ANALYZE AND EVALUATE DATA ESTABLISH MOT/SPACE STATION DYNAMIC SIGNATURE CRITERIA
			A222 SPACE STATION/MOT INTERACTION EVALUATION SPACE STATION MASS IDENTIFICATION GENERATED DYNAMICS REACTION CONTROL SYSTEM CAPABILITY POINTING CAPABILITY SPACE STATION/MOT POINTING INTERRELATIONSHIPS
			A223 MOT POINTING CONCEPT EVALUATION CONCEPT REQUIREMENTS IDENTIFICATION POINTING SYSTEM CONCEPT MODE CONCEPT REACTION CONCEPT SENSOR CONCEPT CONTROL CONCEPT MOT/SPACE STATION INTERCONNECT CONCEPT CONCEPT DEMONSTRATION PROGRAM PLAN CONCEPT DEMONSTRATION CONCEPT EVALUATION AND SELECTION PRELIMINARY SPECIFICATION INPUT
		SCIENTIFIC INSTRUMENTS CONCEPT A230	A231 SCIENTIFIC INSTRUMENTS CONCEPT EVALUATION CONCEPT REQUIREMENT IDENTIFICATION REVIEW CURRENT & INDICATIONS OF POTENTIAL INSTRUMENTS EVALUATE CONCEPTS TO IDENTIFY LESS SEVERE TELESCOPE SYSTEM REQUIREMENTS IDENTIFY RECOMMENDED CONFIGURATIONS PRELIMINARY SCIENTIFIC INSTRUMENTS SPECIFICATION INPUT
		SCIENTIFIC DATA SYSTEM CONCEPT A240	A241 SCIENTIFIC DATA SYSTEM CONCEPT EVALUATION CONCEPT REQUIREMENT IDENTIFICATION EVALUATE R-F TRANSMISSION VS DIRECT RETURN SPACE STATION DATA CENTER CONCEPT EVALUATION GROUND DATA CENTER CONCEPT EVAL. (COMPUTERIZED PHOTO ANALYSIS, DEGREE OF AUTOMATION, OUTPUT TO ASTRONOMERS) MOT DIRECT READOUT CONCEPT CONCEPT EVALUATION AND SELECTION PRELIMINARY DATA SYSTEM SPECIFICATION INPUT
		ADDITIONAL CONCEPT STUDIES A250	A251 TO BE DEFINED DURING CONCEPTUAL PHASE

REVISED 11-10-66

Figure 3-23: WORK BREAKDOWN STRUCTURE — CONCEPT DEVELOPMENT PHASE


PRIME INVESTIGATIONS
SUPPORT INVESTIGATIONS
SYSTEMS CONCEPT
PROJECT DEVELOPMENT AND OPERATIONS PLANS/COST
OPTICAL CONCEPT
POINTING CONCEPT
SCIENTIFIC DATA SYSTEM CONCEPT
SCIENTIFIC INSTRUMENTS CONCEPT
OTHER CONCEPT STUDIES
START CONCEPT DEVELOPMENT PHASE
START SYSTEMS CONCEPT
OTHER RELATED NASA PROJECT PROGRAMS
SYSTEM: •CONCEPT ITERATION & EVAL •OPERATIONS CONCEPT REVIEW •CONCEPT INTERFACE COORD
MOT SYSTEM CONCEPT INTERIM MODEL REPORT
OTHER RELATED NASA PROGRAMS
SYSTEM: •CONCEPT ITERATION & EVAL •CONCEPT INTERFACE COORD
GROSS PROGRAM COST & SCHEDULE UPDATING
GROSS PROGRAM COST & SCHEDULE UPDATING
START MIRROR SURFACE EVALUATION
MIRROR SURFACE EVALUATION INTERIM REPORT
MIRROR SURFACE EVALUATION FINAL REPORT
START MIRROR CONCEPT EVALUATION
MIRROR CONCEPT EVALUATION INTERIM REPORT
START OPTICAL ALIGNMENT CONCEPT
OPTICAL ALIGNMENT CONCEPT INTERIM REPORT
START FOLDING MIRROR ASSEMBLY CONCEPT
FOLDING MIRROR ASSY CONCEPT INTERIM REPORT
START DYNAMIC SIGNATURE DATA IDENTIFICATION
DYNAMIC SIGNATURE DATA INTERIM REPORT
START MOT POINTING SYSTEM CONCEPT
MOT POINTING SYSTEM CONCEPT INTERIM REPORT
START SCIENTIFIC INSTRUMENT CONCEPT EVAL
SCIENTIFIC INSTRUMENT CONCEPT EVAL INTERIM REPORT
START CONCEPT STUDIES
CONCEPT STUDIES REPORT

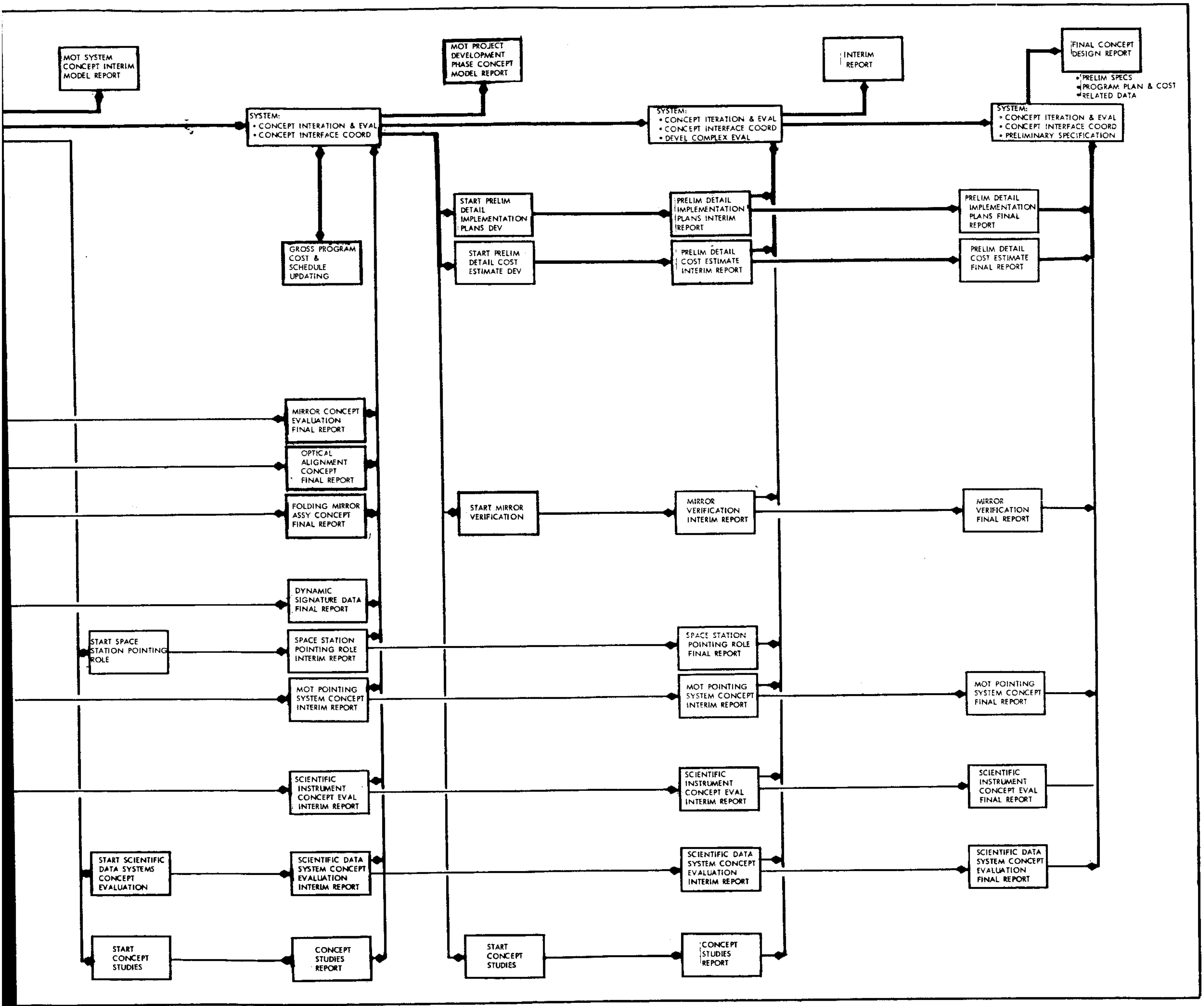


Figure 3-24: TASK SEQUENCE NETWORK- CONCEPT DEVELOPMENT PHASE

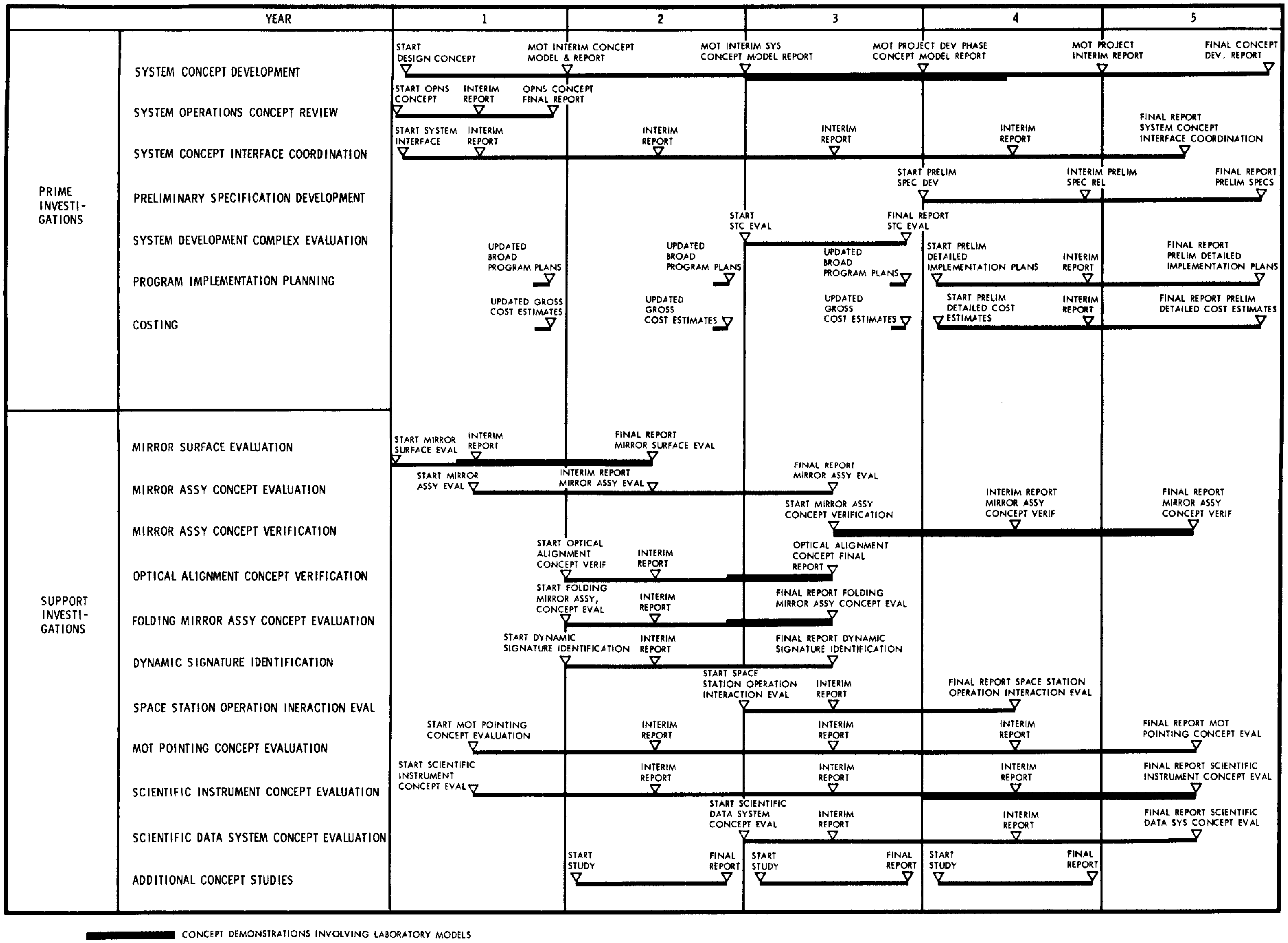


Figure 3-25: SCHEDULE-MOT CONCEPT DEVELOPMENT PHASE

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
	MOT SYSTEM B100	TELESCOPE B110	STRUCTURE & MECHANISMS B111	OPTICS SUPPORT	PRIMARY MIRROR ATTACHMENTS INNER SHELL SUPPORT BASE SECONDARY MIRROR SUPPORT STRUCT. PRIMARY MIRROR BOOST SUPPORT ASSY. PRIMARY MIRROR COVER DOORS.
				TUBE	INNER SHELL-OPTICAL SYSTEM SUPPORT OUTER SHELL-METEOROID & THERMAL EXTENDABLE SHADE
				CABIN	CABIN (SUBSYSTEMS MODULE) CABIN/OUTER SHELL CONNECTIONS FLIGHT SUPPORT SYSTEMS ATTACHMENTS THERMAL PROTECTION ISOLATION BELLOWS
				MOT - SHROUD BOOST ATTACHMENT	MOT BOOST SUPPORT STRUCTURE
				CABIN /TUBE INTERFACE	3 TO 6 POINT TRUSS CONNECTING TRUSS ATTACHMENTS
				TELESCOPE/SPACE STATION INTERFACE	SOFT GIMBAL MOUNT ASSY EXTENDABLE ACCESS TUNNEL ATTACHMENT STRUTS
				SCIENTIFIC INSTRUMENTS SUPPORT	PLATEN & CLOSURE DOOR. PLATEN BOOST SUPPORT STRUCTURE PLATEN SUPPORT TUBE
			OPTICS B112	120" PRIMARY MIRROR, 32' SECONDARY MIRROR 19" SECONDARY MIRROR	
				FOLDING MIRROR ASSEMBLIES	PRINCIPAL FOLDING MIRROR ASSEMBLY SUPPLEMENTARY FOLDING MIRROR ASSEMBLY
				SECONDARY MIRROR ALIGNMENT ASSY	SECONDARY MIRROR LINKAGE - DRIVE SYSTEM POSITIONING SENSOR SYSTEM ALIGNMENT FIXTURE POSITIONING SYSTEM ELECTRONICS
				SECONDARY MIRROR INTERCHANGE ASSY	PIVOT STRUCTURE SUBASSY ACTUATOR SUBASSY LATCHING SUBASSY
			ATTITUDE CONTROL B113	CONTROL MOMENT GYROS	X - AXIS - CONTROL MOMENT GYRO Y - AXIS - CONTROL MOMENT GYRO Z - AXIS - CONTROL MOMENT GYRO
				SENSORS	COARSE GUIDANCE STAR TRACKERS INTERMEDIATE GUIDANCE STAR TRACKER FINE GUIDANCE SENSORS
				INERTIAL REF. ELECTRONICS	
				REACTION CONTROL SYSTEM	ENGINES PROPELLANT TANKS PRESSURIZATION SYSTEM
				INERTIAL REF. (SENSOR-GYROS)	
			RENDEZVOUS	PROPULSION SYSTEM	ENGINES PROPELLANT TANKS PRESSURIZATION SYSTEM
				COMMUNICATIONS & CONTROL	COMMAND RECEIVER COMMAND DECODER RADAR TRANSPONDER

MOT PROJECT B000			B114		ANTENNAS
				ELECTRICAL POWER SYSTEM	BATTERIES INVERTERS VOLTAGE REGULATORS
			SCIENTIFIC INSTRUMENTS B115	LOW DISPER. UV SPECTROMETER LOW DISPER. SPECTROGRAPH WIDE FIELD CAMERA HIGH DISPER. UV SPECTROMETER THERMOELECTRIC PHOTOMETER PHOTOELECTRIC PHOTOMETER HIGH DISPERSION SPECTROGRAPH LARGE SCALE CAMERA HIGH DISPER. IR SPECTROMETER	
			FLIGHT SUPPORT SUBSYSTEMS B116	ELECTRICAL POWER DISTRIBUTION ACTIVE EQUIPMENT HEAT TRANSPORT SYSTEM AUDIO INNERCOMMUNICATIONS	
				ENGINEERING DATA SENSORS	SENSORS (TEMP , PRESS., STRAIN, POSITION, ETC.) SIGNAL CONDITIONERS INDICATORS ENG DATA INTERCOMMUNICATIONS
				CABIN ATMOSPHERE SYSTEM	DUCTS AND VALVES CABIN CIRCULATION ASSY
				TELESCOPE OPERATION CHECKOUT STATION	TV CAMERAS TELESCOPE CONTROLS SCIENTIFIC INST CONTROLS
			MAJOR ARTICLES B117	MOCKUP MOT ENGINEERING MODEL PROJECT VERIFICATION MODEL QUALIFICATION MODEL	
		MOT-UNIQUE SPACE STATION EQUIPMENT B120	MOT OPERATIONS & CONTROL STATION B121 RENDEZVOUS CONTROL STATION B122 POWER DISTRIBUTION SYS — INTERNAL & EXTERNAL B123		
		GROUND SUPPORT EQUIPMENT B130	HANDLING & TRANSPORTATION EQUIPMENT B131	INTRAFACILITY INNERFACILITY	
			CHECKOUT EQUIPMENT B132	MOT CHECKOUT EQUIPMENT	SUBSYSTEM CHECKOUT EQUIPMENT SPACE STATION SIMULATOR MOT-UNIQUE SPACE STATION SIMULATOR LAUNCH VEHICLE SIMULATOR MISSION OPERATIONS SIMULATOR TEST CONTROL CENTER
				MOT-UNIQUE SPACE STATION EQUIPMENT CHECKOUT EQUIPMENT	MOT OPERATIONS & CONTROL CHECKOUT EQPMT RENDEZVOUS CONTROL STATION CHECKOUT EQPMT POWER DISTRIBUTION SYSTEM CHECKOUT EQPMT
				OTHER CHECKOUT EQUIPMENT	MOT SIMULATOR - SPACE STATION CONTRACTOR MOT SIMULATOR - LAUNCH VEHICLE CONTRACTOR
			SERVICING EQUIPMENT B133	MOT SERVICING EQUIPMENT S/C MOT-UNIQUE EQUIPMENT	
		TRAINING EQUIPMENT B140	PART TASK SIMULATOR B141		
			MISSION SIMULATOR B142		
			SUBSYSTEM TRAINERS B143		
		MISSION SUPPORT EQUIPMENT B150	EXPERIMENT CONTROL CENTER EQUIP. B151		
			MOT-UNIQUE MISSION CONTROL CENTER EQUIPMENT B152		
			MOT-UNIQUE ENGINEERING DATA CENTER EQUIPMENT B153		
	B200 UNIVERSAL SHROUD ASSEMBLY	SHROUD ASSEMBLY B210	SHROUD B211		
			PAYLOAD - LAUNCH VEHICLE ADAPTER B212		
		GSE B220	HANDLING & TRANSPORTATION EQUIP B221		
	B300 LAUNCH VEHICLE SYSTEM	LAUNCH VEHICLE B310	MODIFICATIONS B311		
			EXISTING GROUND TEST MODEL B312		
		GSE (MOT PECULIAR EQ.) B320	MOT/LAUNCH VEHICLE SIMULATOR (USAGE) B321		
	MISSION UPDATE MODS B400	TELESCOPE B410			
		SCIENTIFIC INSTRUMENT B420			
		MOT UNIQUE SUBSYSTEM EQPMT B430			

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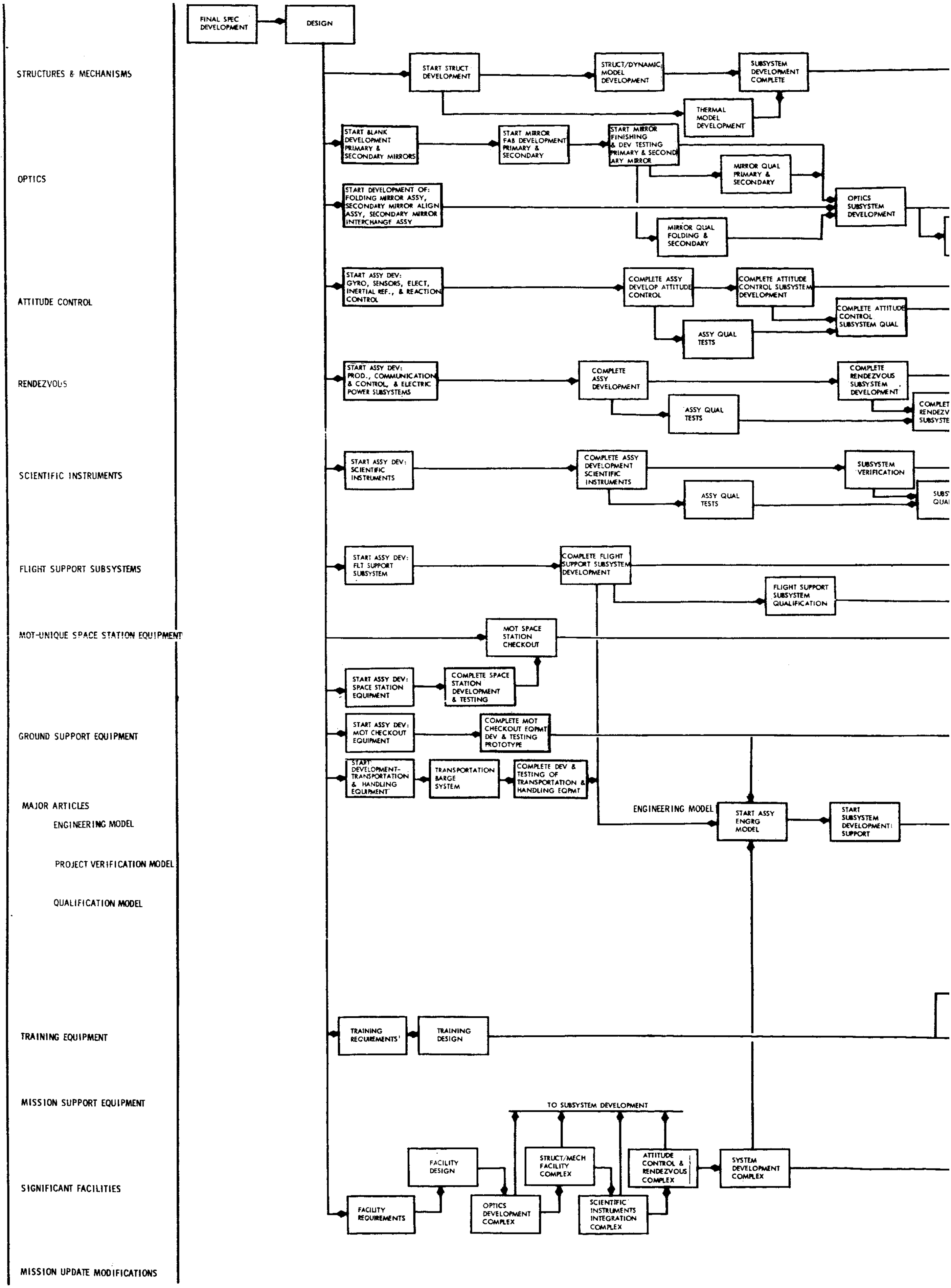
Figure 3-26: WORK BREAKDOWN STRUCTURE — PROJECT DEVELOPMENT PHASE

87-2


STRUCTURES & MECHANISMS
OPTICS
ATTITUDE CONTROL
RENDEZVOUS
SCIENTIFIC INSTRUMENTS
FLIGHT SUPPORT SUBSYSTEMS
MOT-UNIQUE SPACE STATION EQUIPMENT
GROUND SUPPORT EQUIPMENT
MAJOR ARTICLES
ENGINEERING MODEL
PROJECT VERIFICATION MODEL
QUALIFICATION MODEL
TRAINING EQUIPMENT
MISSION SUPPORT EQUIPMENT
SIGNIFICANT FACILITIES
MISSION UPDATE MODIFICATIONS
FINAL SPEC DEVELOPMENT
DESIGN
START STRUCT DEVELOPMENT
STRUCT/DYNAMIC MODEL DEVELOPMENT
SUBSYSTEM DEVELOPMENT COMPLETE
THERMAL MODEL DEVELOPMENT
START BLANK DEVELOPMENT PRIMARY & SECONDARY MIRRORS
START MIRROR FAB DEVELOPMENT PRIMARY & SECONDARY
START MIRROR FINISHING & DEV TESTING PRIMARY & SECONDARY MIRROR
MIRROR QUAL PRIMARY & SECONDARY
START DEVELOPMENT OF: FOLDING MIRROR ASSY, SECONDARY MIRROR ALIGN ASSY, SECONDARY MIRROR INTERCHANGE ASSY
OPTICS SUBSYSTEM DEVELOPMENT
MIRROR QUAL FOLDING & SECONDARY
START ASSY DEV: GYRO, SENSORS, ELECT, INERTIAL REF., & REACTION CONTROL
COMPLETE ASSY DEVELOP ATTITUDE CONTROL
COMPLETE ATTITUDE CONTROL SUBSYSTEM DEVELOPMENT
COMPLETE ATTITUDE CONTROL SUBSYSTEM QUAL
ASSY QUAL TESTS
START ASSY DEV: PROD., COMMUNICATION & CONTROL, & ELECTRIC POWER SUBSYSTEMS
COMPLETE ASSY DEVELOPMENT
COMPLETE RENDEZVOUS SUBSYSTEM DEVELOPMENT
ASSY QUAL TESTS
START ASSY DEV: SCIENTIFIC INSTRUMENTS
COMPLETE ASSY DEVELOPMENT SCIENTIFIC INSTRUMENTS
SUBSYSTEM VERIFICATION
ASSY QUAL TESTS
START ASSY DEV: FLT SUPPORT SUBSYSTEM
COMPLETE FLIGHT SUPPORT SUBSYSTEM DEVELOPMENT
FLIGHT SUPPORT SUBSYSTEM QUALIFICATION
MOT SPACE STATION CHECKOUT
START ASSY DEV: SPACE STATION EQUIPMENT
COMPLETE SPACE STATION DEVELOPMENT & TESTING
START ASSY DEV: MOT CHECKOUT EQUIPMENT
COMPLETE MOT CHECKOUT EQPMT DEV & TESTING PROTOTYPE
START DEVELOPMENT-TRANSPORTATION & HANDLING EQUIPMENT
TRANSPORTATION BARGE SYSTEM
COMPLETE DEV & TESTING OF TRANSPORTATION & HANDLING EQPMT
ENGINEERING MODEL
START ASSY ENGRG MODEL
START SUBSYSTEM DEVELOPMENT SUPPORT
TRAINING REQUIREMENTS
TRAINING DESIGN
TO SUBSYSTEM DEVELOPMENT
FACILITY DESIGN
STRUCT/MECH FACILITY COMPLEX
ATTITUDE CONTROL & RENDEZVOUS COMPLEX
SYSTEM DEVELOPMENT COMPLEX
FACILITY REQUIREMENTS
OPTICS DEVELOPMENT COMPLEX
SCIENTIFIC INSTRUMENTS INTEGRATION COMPLEX

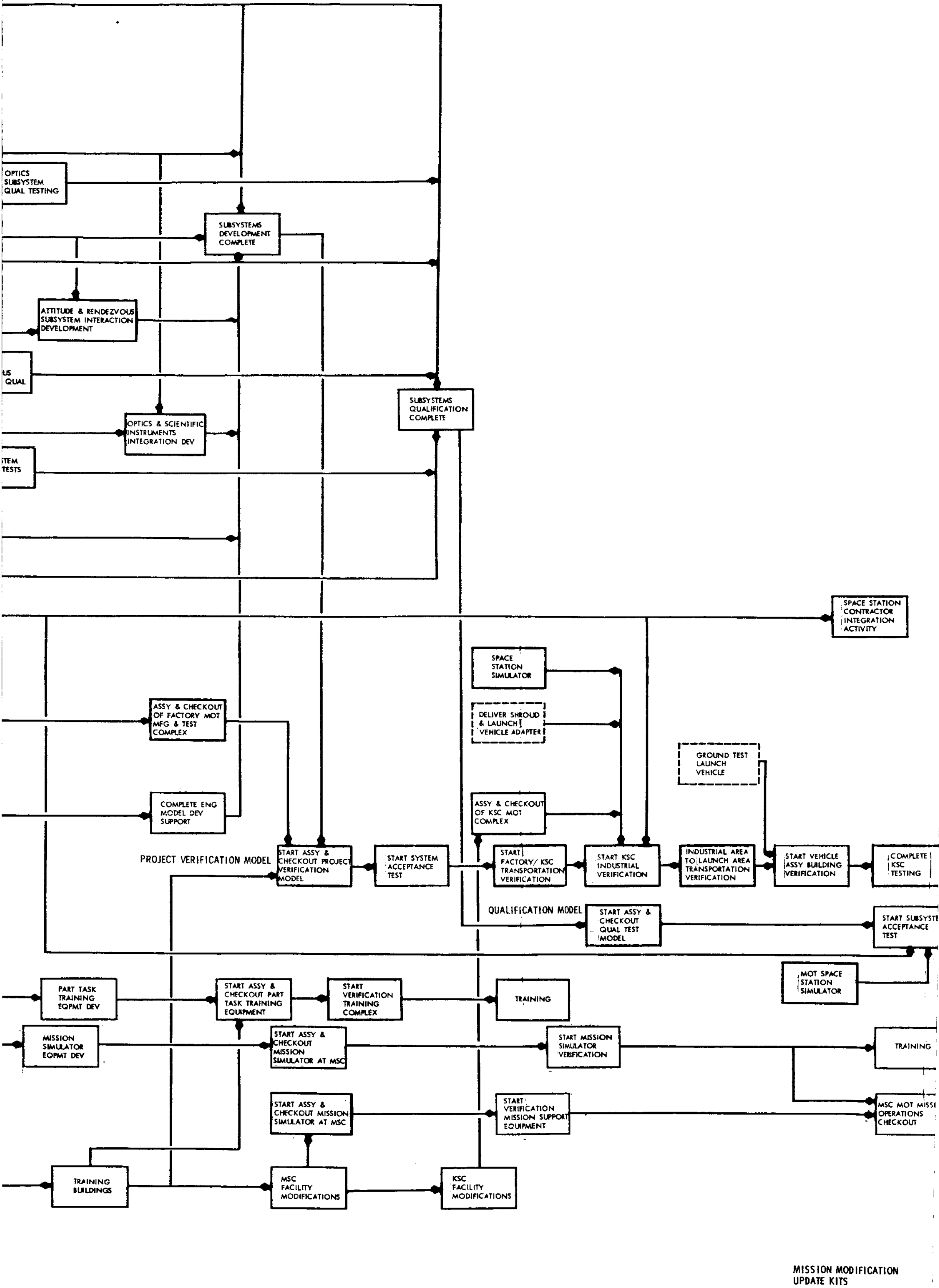
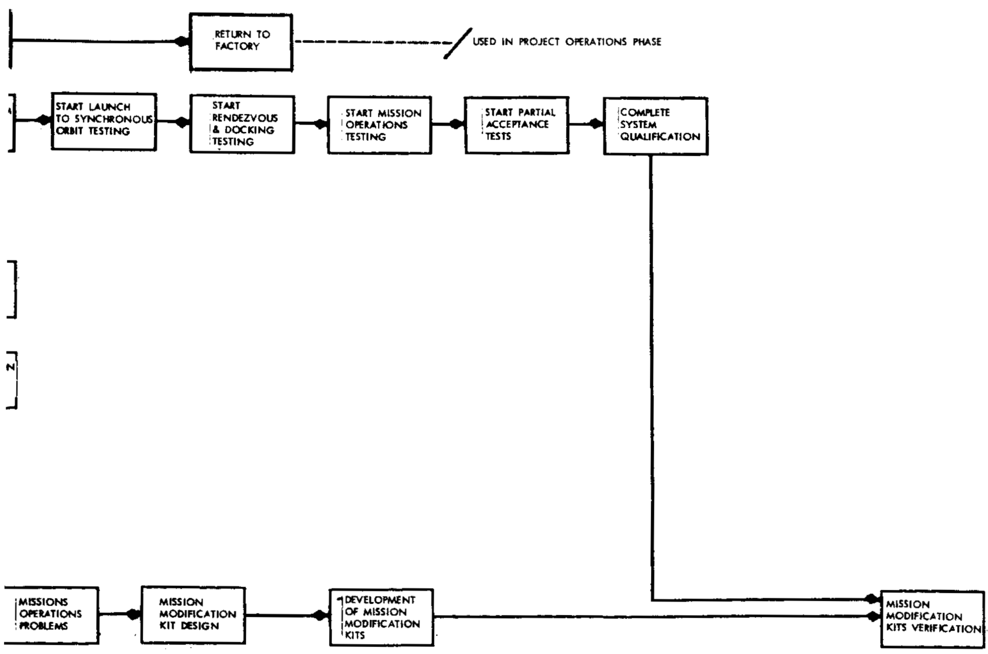
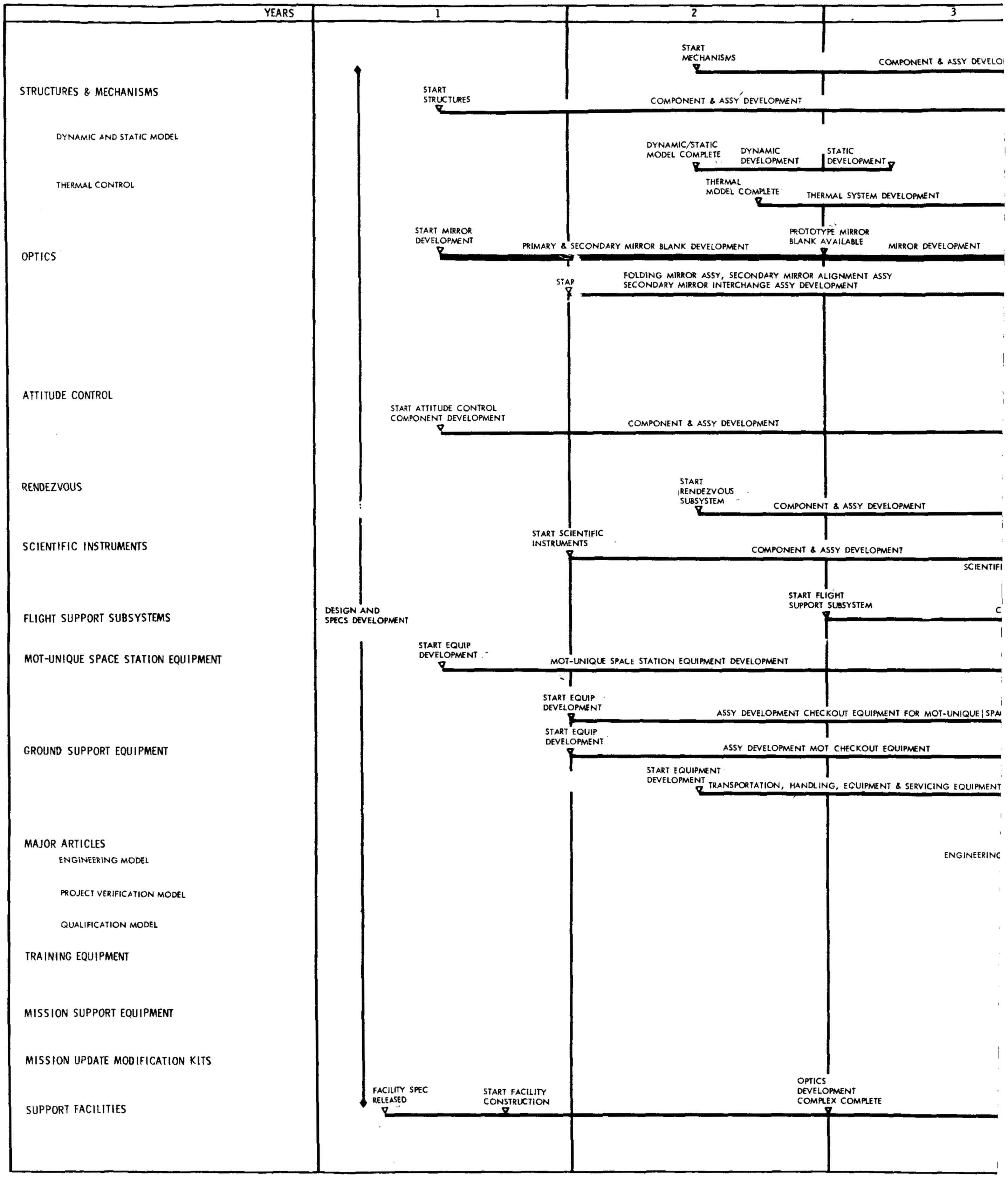

OPTICS SUBSYSTEM QUAL TESTING
SUBSYSTEMS DEVELOPMENT COMPLETE
ATTITUDE & RENDEZVOUS SUBSYSTEM INTERACTION DEVELOPMENT
QUAL
SUBSYSTEMS QUALIFICATION COMPLETE
OPTICS & SCIENTIFIC INSTRUMENTS INTEGRATION DEV
TESTS
SPACE STATION CONTRACTOR INTEGRATION ACTIVITY
SPACE STATION SIMULATOR
ASSY & CHECKOUT OF FACTORY MOT MFG & TEST COMPLEX
DELIVER SHROUD & LAUNCH VEHICLE ADAPTER
GROUND TEST LAUNCH VEHICLE
COMPLETE ENG MODEL DEV SUPPORT
ASSY & CHECKOUT OF KSC MOT COMPLEX
PROJECT VERIFICATION MODEL
START ASSY & CHECKOUT PROJECT VERIFICATION MODEL
START SYSTEM ACCEPTANCE TEST
START FACTORY/ KSC TRANSPORTATION VERIFICATION
START KSC INDUSTRIAL VERIFICATION
INDUSTRIAL AREA TO LAUNCH AREA TRANSPORTATION VERIFICATION
START VEHICLE ASSY BUILDING VERIFICATION
COMPLETE KSC TESTING
QUALIFICATION MODEL
START ASSY & CHECKOUT QUAL TEST MODEL
START SUBSYSTE ACCEPTANCE TEST
MOT SPACE STATION SIMULATOR
PART TASK TRAINING EQPMT DEV
START ASSY & CHECKOUT PART TASK TRAINING EQUIPMENT
START VERIFICATION TRAINING COMPLEX
TRAINING
MISSION SIMULATOR EQPMT DEV
START ASSY & CHECKOUT MISSION SIMULATOR AT MSC
START MISSION SIMULATOR VERIFICATION
TRAINING
START ASSY & CHECKOUT MISSION SIMULATOR AT MSC
START VERIFICATION MISSION SUPPORT EQUIPMENT
MSC MOT MISSI OPERATIONS CHECKOUT
TRAINING BUILDINGS
MSC FACILITY MODIFICATIONS
KSC FACILITY MODIFICATIONS
MISSION MODIFICATION UPDATE KITS

Figure 3-27:



TASK SEQUENCE NETWORK — PROJECT DEVELOPMENT PHASE

88-3


YEARS
1
2
3
STRUCTURES & MECHANISMS
DYNAMIC AND STATIC MODEL
THERMAL CONTROL
OPTICS
ATTITUDE CONTROL
RENDEZVOUS
SCIENTIFIC INSTRUMENTS
FLIGHT SUPPORT SUBSYSTEMS
MOT-UNIQUE SPACE STATION EQUIPMENT
GROUND SUPPORT EQUIPMENT
MAJOR ARTICLES
ENGINEERING MODEL
PROJECT VERIFICATION MODEL
QUALIFICATION MODEL
TRAINING EQUIPMENT
MISSION SUPPORT EQUIPMENT
MISSION UPDATE MODIFICATION KITS
SUPPORT FACILITIES
START MECHANISMS
COMPONENT & ASSY DEVELO
START STRUCTURES
COMPONENT & ASSY DEVELOPMENT
DYNAMIC/STATIC MODEL COMPLETE
DYNAMIC DEVELOPMENT
STATIC DEVELOPMENT
THERMAL MODEL COMPLETE
THERMAL SYSTEM DEVELOPMENT
START MIRROR DEVELOPMENT
PRIMARY & SECONDARY MIRROR BLANK DEVELOPMENT
PROTOTYPE MIRROR BLANK AVAILABLE
MIRROR DEVELOPMENT
START
FOLDING MIRROR ASSY, SECONDARY MIRROR ALIGNMENT ASSY
SECONDARY MIRROR INTERCHANGE ASSY DEVELOPMENT
START ATTITUDE CONTROL COMPONENT DEVELOPMENT
COMPONENT & ASSY DEVELOPMENT
START RENDEZVOUS SUBSYSTEM
COMPONENT & ASSY DEVELOPMENT
START SCIENTIFIC INSTRUMENTS
COMPONENT & ASSY DEVELOPMENT
SCIENTIFI
START FLIGHT SUPPORT SUBSYSTEM
DESIGN AND SPECS DEVELOPMENT
START EQUIP DEVELOPMENT
MOT-UNIQUE SPACE STATION EQUIPMENT DEVELOPMENT
START EQUIP DEVELOPMENT
ASSY DEVELOPMENT CHECKOUT EQUIPMENT FOR MOT-UNIQUE SPA
START EQUIP DEVELOPMENT
ASSY DEVELOPMENT MOT CHECKOUT EQUIPMENT
START EQUIPMENT DEVELOPMENT
TRANSPORTATION, HANDLING, EQUIPMENT & SERVICING EQUIPMENT
ENGINEERING
FACILITY SPEC RELEASED
START FACILITY CONSTRUCTION
OPTICS DEVELOPMENT COMPLEX COMPLETE

89-1

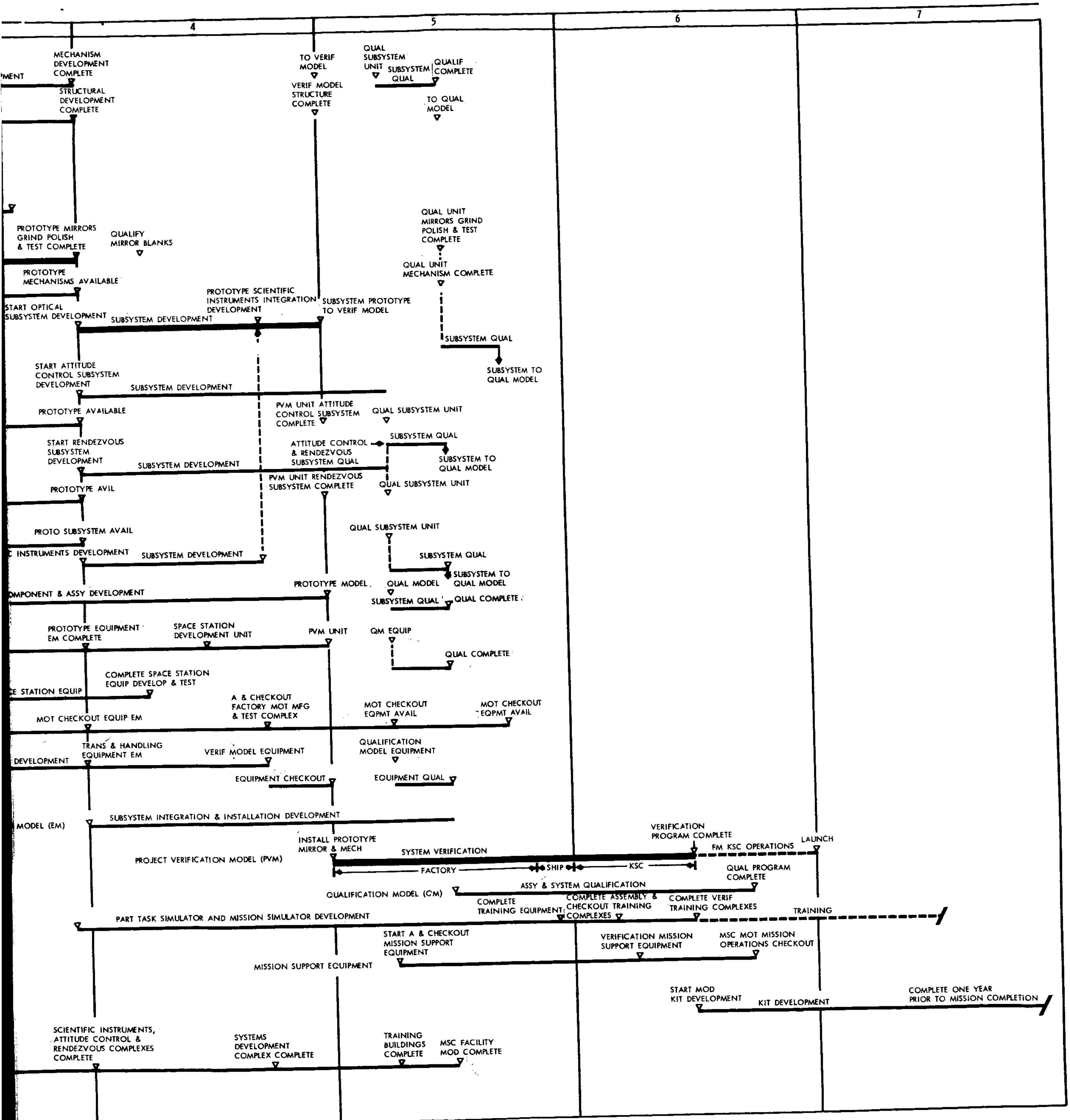
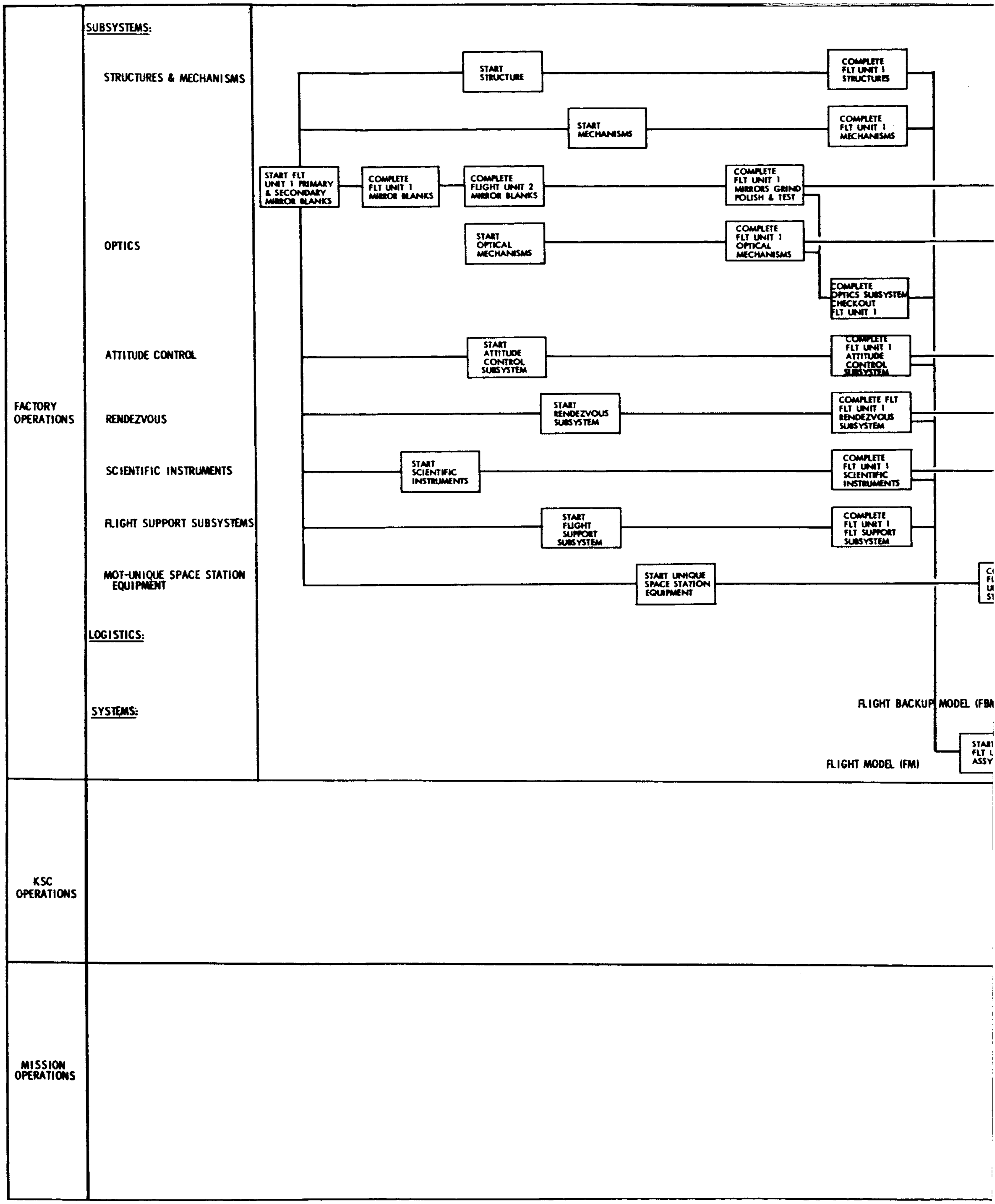
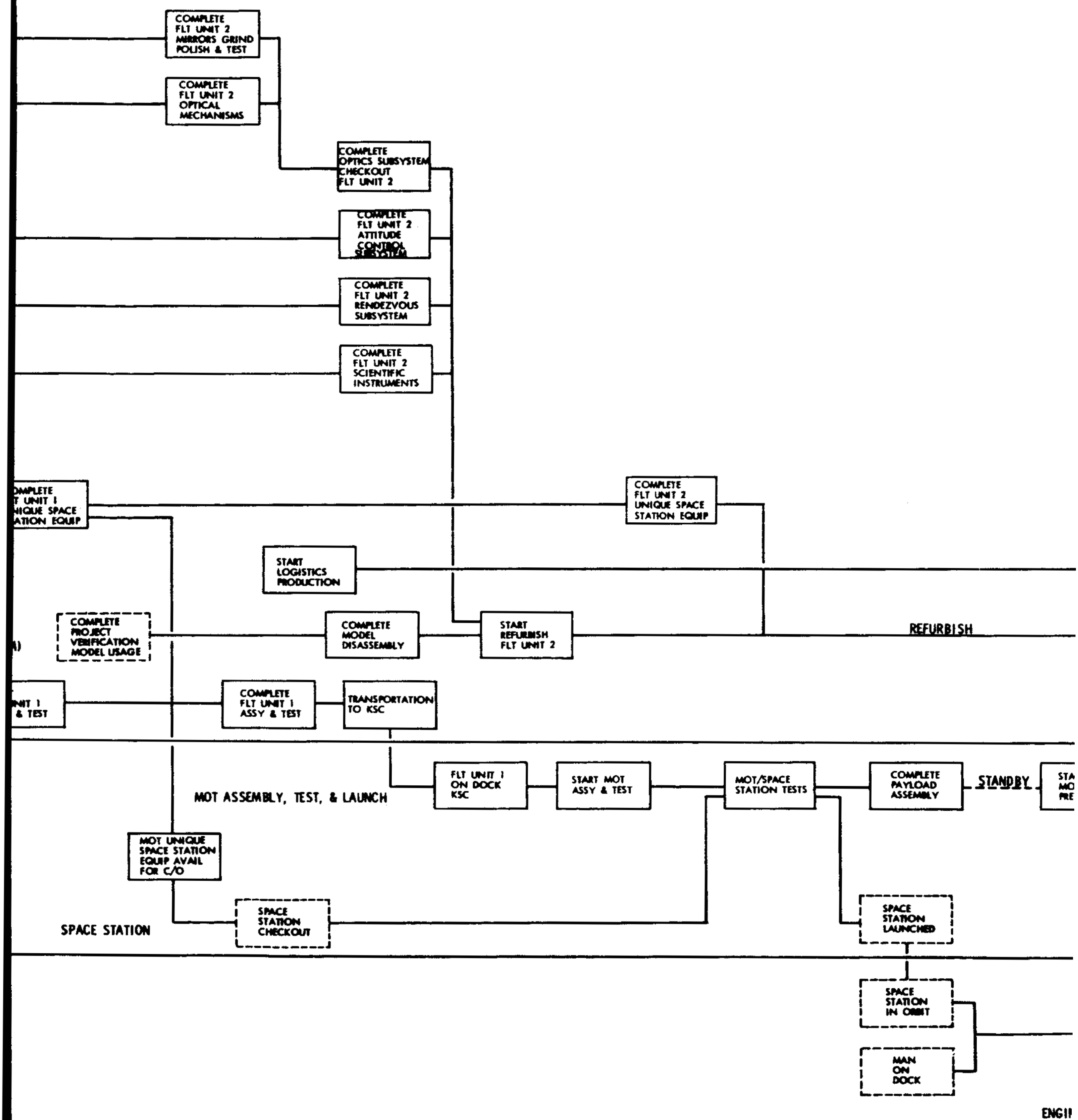


Figure 3-28: MOT PROJECT DEVELOPMENT PHASE SCHEDULE

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3
MOT PROJECT C000	FACTORY C100	MOT C110	C111 STRUCTURES & MECHANISMS C112 OPTICS C113 ATTITUDE CONTROL C114 RENDEZVOUS C115 SCIENTIFIC INSTRUMENTS C116 FLIGHT SUPPORT EQUIPMENT
		SHROUD ASSEMBLY C120	
		MOT UNIQUE SPACE STA EQ C130	C131 MOT OPERATIONS & CONTROL STATION C132 RENDEZVOUS CONTROL STATION C133 POWER DISTRIBUTION SYSTEM - INNER & INTRA C134 SCIENTIFIC INSTRUMENTS DATA PROCESSING CENTER.
		LAUNCH VEHICLE - MOT C140	
		MOT MISSION LOGISTIC SUPPORT C150	C151 SPARES C152 UPDATE MODIFICATIONS C153 SUPPLIES
	KSC C200	MOT OPERATIONS C210	C211 MOT ASSEMBLY & CHECKOUT C212 SPACECRAFT/MOT UNIQUE EQUIPMENT ASSY & C/O C213 MOT/SPACECRAFT INTEGRATION C214 SHROUD ASSEMBLY & CHECKOUT C215 MOT/SHROUD INTEGRATION C216 LAUNCH VEHICLE/MOT SIMULATOR INTEGRATION C217 MOT - SHROUD - LV INTEGRATION C218 LAUNCH PAD OPERATIONS
		MOT LAUNCH VEHICLE - OPERATIONS C220	
	MISSION SUPPORT C300	ENGR. OPERATIONS (0 - 89 DAYS) C310	C311 MISSION CONTROL (ENGINEERING PRIME - EXPERIMENT SUPPORT) C312 ENGINEERING DATA CENTER OPERATIONS C313 EXPERIMENT DATA CENTER OPERATIONS
		EXPERIMENT OPERATIONS (90 DAYS & ON) C320	C321 MISSION CONTROL (EXPERIMENT PRIME - ENGINEERING SUPPORT) C322 EXPERIMENT DATA CENTER OPERATIONS C323 ENGINEERING DATA CENTER OPERATIONS

Figure 3-29: WORK BREAKDOWN STRUCTURE — PROJECT OPERATIONS PHASE


FACTORY OPERATIONS
SUBSYSTEMS:
STRUCTURES & MECHANISMS
OPTICS
ATTITUDE CONTROL
RENDEZVOUS
SCIENTIFIC INSTRUMENTS
FLIGHT SUPPORT SUBSYSTEMS
MOT-UNIQUE SPACE STATION EQUIPMENT
LOGISTICS:
SYSTEMS:
START STRUCTURE
COMPLETE FLT UNIT 1 STRUCTURES
START MECHANISMS
COMPLETE FLT UNIT 1 MECHANISMS
START FLT UNIT 1 PRIMARY & SECONDARY MIRROR BLANKS
COMPLETE FLT UNIT 1 MIRROR BLANKS
COMPLETE FLIGHT UNIT 2 MIRROR BLANKS
COMPLETE FLT UNIT 1 MIRRORS GRIND POLISH & TEST
START OPTICAL MECHANISMS
COMPLETE FLT UNIT 1 OPTICAL MECHANISMS
COMPLETE OPTICS SUBSYSTEM CHECKOUT FLT UNIT 1
START ATTITUDE CONTROL SUBSYSTEM
COMPLETE FLT UNIT 1 ATTITUDE CONTROL SUBSYSTEM
START RENDEZVOUS SUBSYSTEM
COMPLETE FLT FLT UNIT 1 RENDEZVOUS SUBSYSTEM
START SCIENTIFIC INSTRUMENTS
COMPLETE FLT UNIT 1 SCIENTIFIC INSTRUMENTS
START FLIGHT SUPPORT SUBSYSTEM
COMPLETE FLT UNIT 1 FLT SUPPORT SUBSYSTEM
START UNIQUE SPACE STATION EQUIPMENT
FLIGHT BACKUP MODEL (FBM
FLIGHT MODEL (FM)
KSC OPERATIONS
MISSION OPERATIONS



COMPLETE FLT UNIT 2 MIRRORS GRIND POLISH & TEST
COMPLETE FLT UNIT 2 OPTICAL MECHANISMS
COMPLETE OPTICS SUBSYSTEM CHECKOUT FLT UNIT 2
COMPLETE FLT UNIT 2 ATTITUDE CONTROL SUBSYSTEM
COMPLETE FLT UNIT 2 RENDEZVOUS SUBSYSTEM
COMPLETE FLT UNIT 2 SCIENTIFIC INSTRUMENTS
COMPLETE FLT UNIT 2 UNIQUE SPACE STATION EQUIP
START LOGISTICS PRODUCTION
COMPLETE PROJECT VERIFICATION MODEL USAGE
COMPLETE MODEL DISASSEMBLY
START REFURBISH FLT UNIT 2
REFURBISH
COMPLETE FLT UNIT 1 ASSY & TEST
TRANSPORTATION TO KSC
MOT ASSEMBLY, TEST, & LAUNCH
FLT UNIT 1 ON DOCK KSC
START MOT ASSY & TEST
MOT/SPACE STATION TESTS
COMPLETE PAYLOAD ASSEMBLY
STANDBY
MOT UNIQUE SPACE STATION EQUIP AVAIL FOR C/O
SPACE STATION CHECKOUT
SPACE STATION
SPACE STATION LAUNCHED
SPACE STATION IN ORBIT
MAN ON DOCK

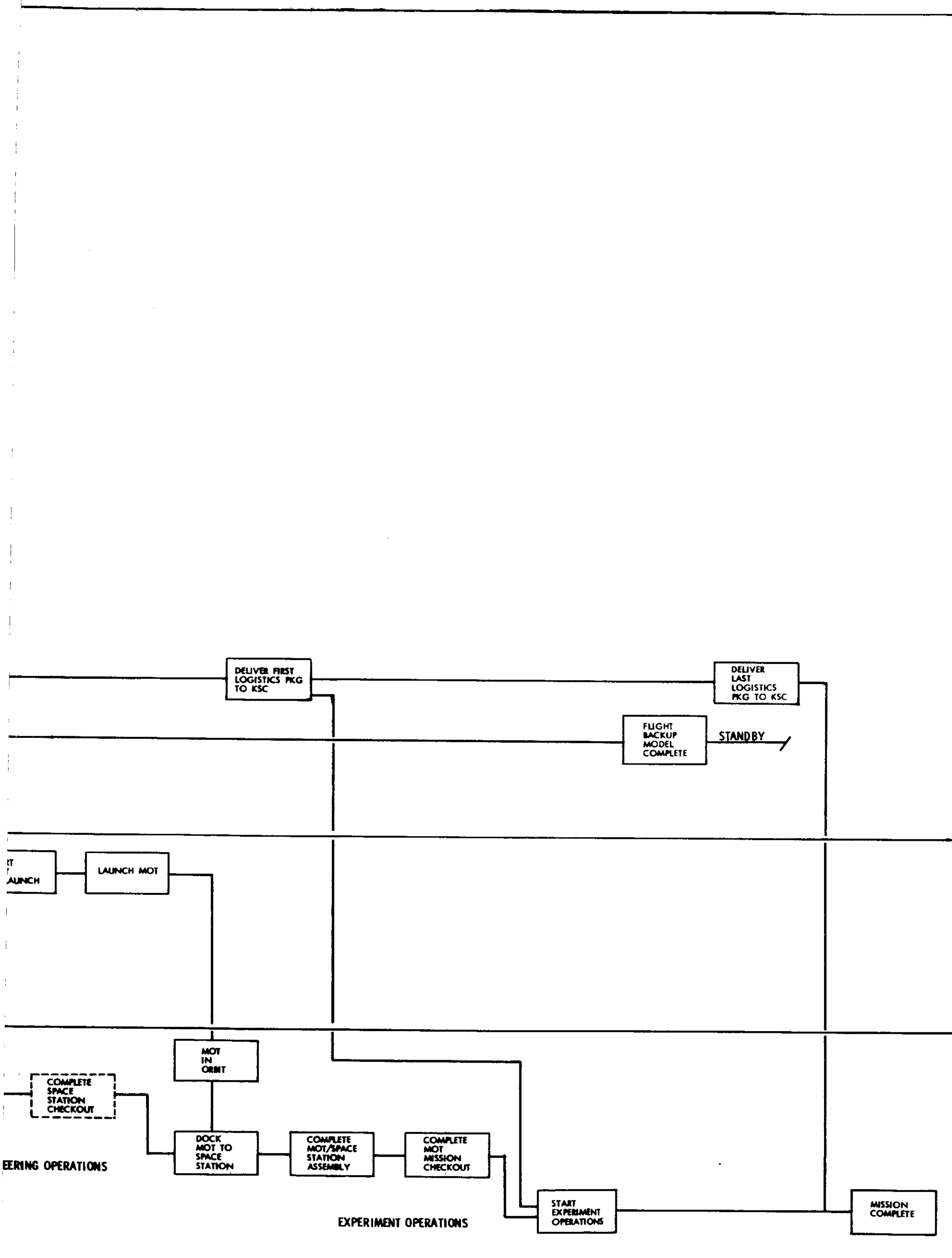


Figure 3-30: TASK SEQUENCE NETWORK — PROJECT OPERATIONS

91-3

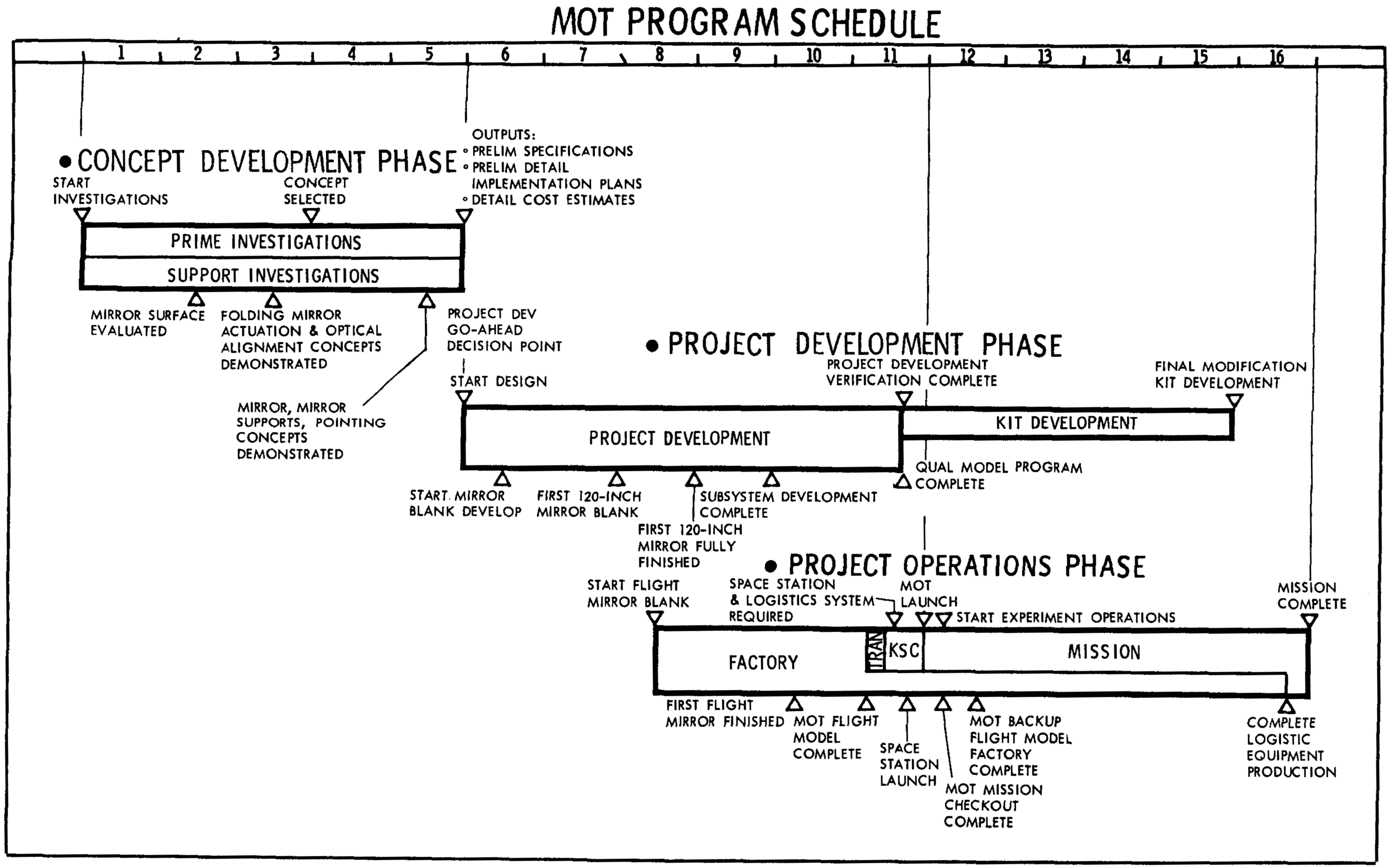


Figure 3-32: MOT PROGRAM SCHEDULE

result in less than optimum program efficiency due to difficulty of controlling the numerous other program elements over such a long time span. Facility schedule planning has been included in the project development phase schedule based on the requirements presented in Section 4.0 of this report.

The MOT program schedule is a summary of the three program phases and covers a 16-year total time span. This top schedule reflects only major milestones such as concept selection occurring 3 years after program start, and launch occurring 11 years after program start.

4.0 FACILITY PLANNING

The facility planning identifies the significant MOT-unique facilities assumed to be beyond industry's funding interests and added to the government's facility inventory. Facilities not specifically identified are considered to be industry-provided and are not considered to be of major proportion. No significant facilities are required for the concept development phase since the facility requirements will be met by industry capability. The facilities identified in this section are those required to develop the MOT equipment in the project development phase and, in turn, used to conduct the project operation phase.

The significant program facilities identified for this program are:

- System Development Complex (New)
- Optical Development Complex (New)
- Attitude Control and Rendezvous Development Complex (New)
- Scientific Instrument Integration Complex (New)
- Structural Development Facilities (Existing)
- Training Facilities (New)
- Mission Control Complex (Some Addition)
- KSC Facilities (Existing)

Geographical and common functional subsystem entities were considered in assembling the above facilities. The system development complex was considered to be location sensitive due to the constraints of surface transportation to KSC of the complete telescope. Also, the optical development complex should be located to allow proper transportation of the primary mirror to the system development complex, commensurate with its size and delicate nature.

Of the five new complexes, the system development complex is considered the largest requirement and, correspondingly, the most expensive. This requirement stems from the traditional conservative requirement of proving full system operation on the ground under simulated space operating conditions prior to actual flight. To provide a test complex that will simultaneously provide thermal space environment, seismic isolation, vacuum space environment, very accurate stellar simulation to demonstrate the optics to their design limit, and a gimbal test system to allow the MOT fine guidance system to be demonstrated to the design limit of ± 0.01 arc-second accuracy will entail a very large resource expenditure.

The scheduling of the design and development of facilities is presented in Section 3.3. The requirements for these facilities are described in detail in the following text.

4.1 SYSTEM DEVELOPMENT COMPLEX

The complex shown in Figure 4-1 is used to assemble, check, and test the MOT at the system level. Primary facility areas are:

- Receiving and Shipping
- Assembly and Disassembly
- General Test
- Electromagnetic Screen Room
- Vibration Test
- Acoustical Test
- Coarse and Intermediate Guidance Test
- System Test

The coarse and intermediate guidance test area involves a mechanical gimbal system to support the MOT; it is capable of allowing the operation of reaction control jets and contains a large travel stellar simulator.

The system test area involves a vacuum chamber in which the MOT will be suspended on a highly sensitive gimbal test system supported by a seismic base. Within the chamber, looking down at the telescope, will be a test telescope (of the same size but greater accuracy than the MOT) for stellar simulation. The chamber will be cryogenically cooled to simulate space and will have a solar simulator to simulate the Sun's radiation on the side of the telescope.

For optimum program efficiency, this facility should be one integrated building complex. For this study, it is assumed to be located in the Michoud area in Louisiana. This assumption was made for two reasons: first, the primary mirror can be shipped by waterway to this location from the major industrial areas of the country. Water shipment is preferred because of the mirror size, and it would keep the dynamic transportation loads minimized. The second reason for the site selection was to avoid a duplication of this facility at KSC. The philosophy used in the development planning was that after the factory completed the MOT, it would be shipped to KSC as intact as practicable and in a manner that would not materially reduce the confidence established in the factory. The telescope must be shipped in a manner that keeps the dynamic transportation loads to a minimum and maintains a controlled atmosphere environment. Therefore, water transportation, using the Saturn IC barge or an equivalent, was selected to ship the MOT by water from Michoud to KSC.

4.2 OPTICAL DEVELOPMENT COMPLEX

This optical subsystem complex, which is shown in Figure 4-2, is used in converting the MOT mirror blanks into finished mirrors and then to integrate these mirrors with the secondary-mirror alignment assembly, the folding-mirror

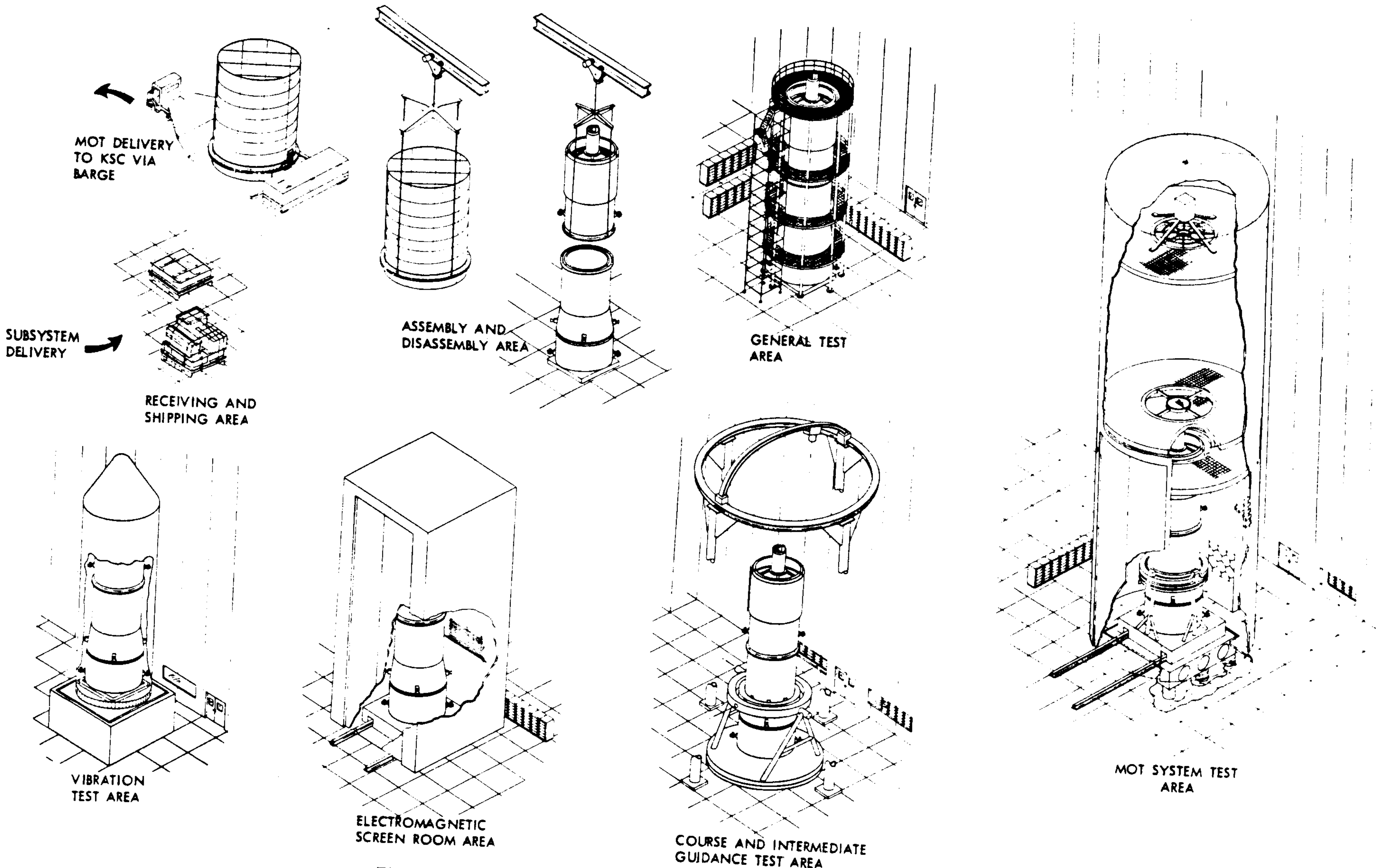


Figure 4-1: SYSTEM DEVELOPMENT COMPLEX

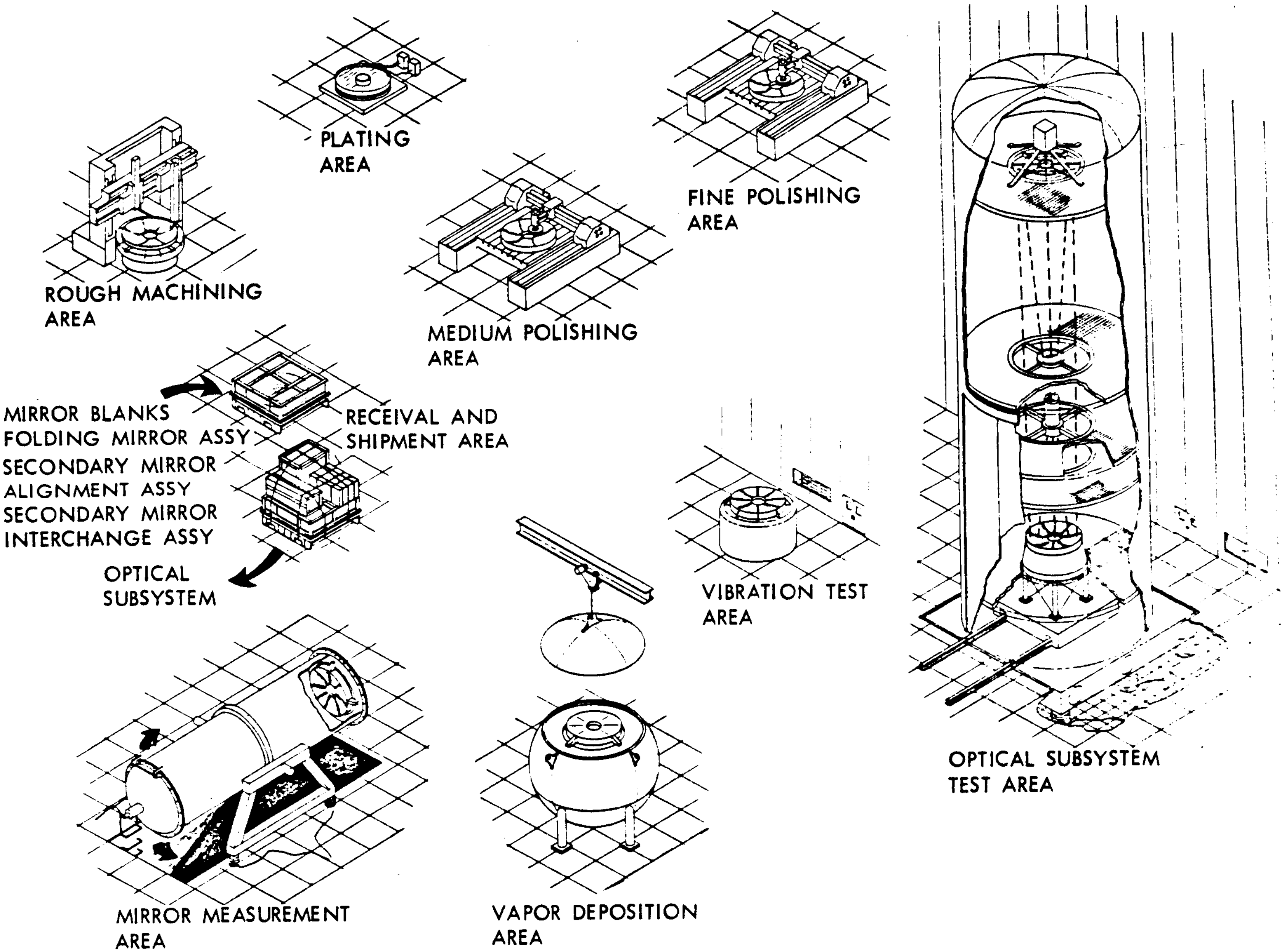


Figure 4-2: OPTICAL DEVELOPMENT COMPLEX

assemblies, and the secondary-mirror interchange assembly. The principal facility areas are:

- Blank rough machining
- Blank nickel plating (required only for beryllium blank)
- Blank medium polishing area
- Blank fine polishing area
- Blank optical measurement (including a vacuum chamber with low-temperature capability)
- Vapor deposition area
- Optical subsystem test
- Vibration test
- Receiving and shipment

The optical subsystem test area includes a seismic support of a large, long tubular low-vacuum chamber having low-temperature control. The MOT optics components would be mounted in a vertical MOT test fixture and directly overhead would be a test telescope looking at the MOT optics so as to represent a stellar input. The test telescope would have primary and secondary mirrors of about the same size as those in the MOT, but finished to a greater accuracy.

Since the MOT optics subsystem has such very high accuracy requirements, an integrated single-building complex with the above principal areas is considered necessary. Design of the complex should include the necessary fabrication and quality control features to ensure product accuracy. The location of the facilities has not been identified in the study other than being near water transportation routes leading to the MOT system development complex.

4.3 ATTITUDE CONTROL AND RENDEZVOUS DEVELOPMENT COMPLEX

This facility, as shown in Figure 4-3, is used to develop the attitude control and rendezvous subsystem except for the propulsion assembly. The principal areas of this complex are the coarse and medium guidance test area and the fine guidance test area.

The coarse and medium guidance test area contains a MOT test fixture on which are mounted the coarse and medium guidance equipment and the rendezvous electrical and electronic equipment. This simulated MOT is mounted in a vertical position on a mechanical gimbal system that allows a large angular movement. A simulated stellar source is mounted above the simulated telescope. This stellar source can be moved over a spherical segment area to demonstrate guidance tracking ability. The reaction jets are operated to produce typical MOT operations.

The fine guidance test area also has a MOT test fixture on which is mounted the fine guidance system. A movable stellar source is mounted above the MOT simulator and feeds directly into the fine guidance sensor system. The simulator

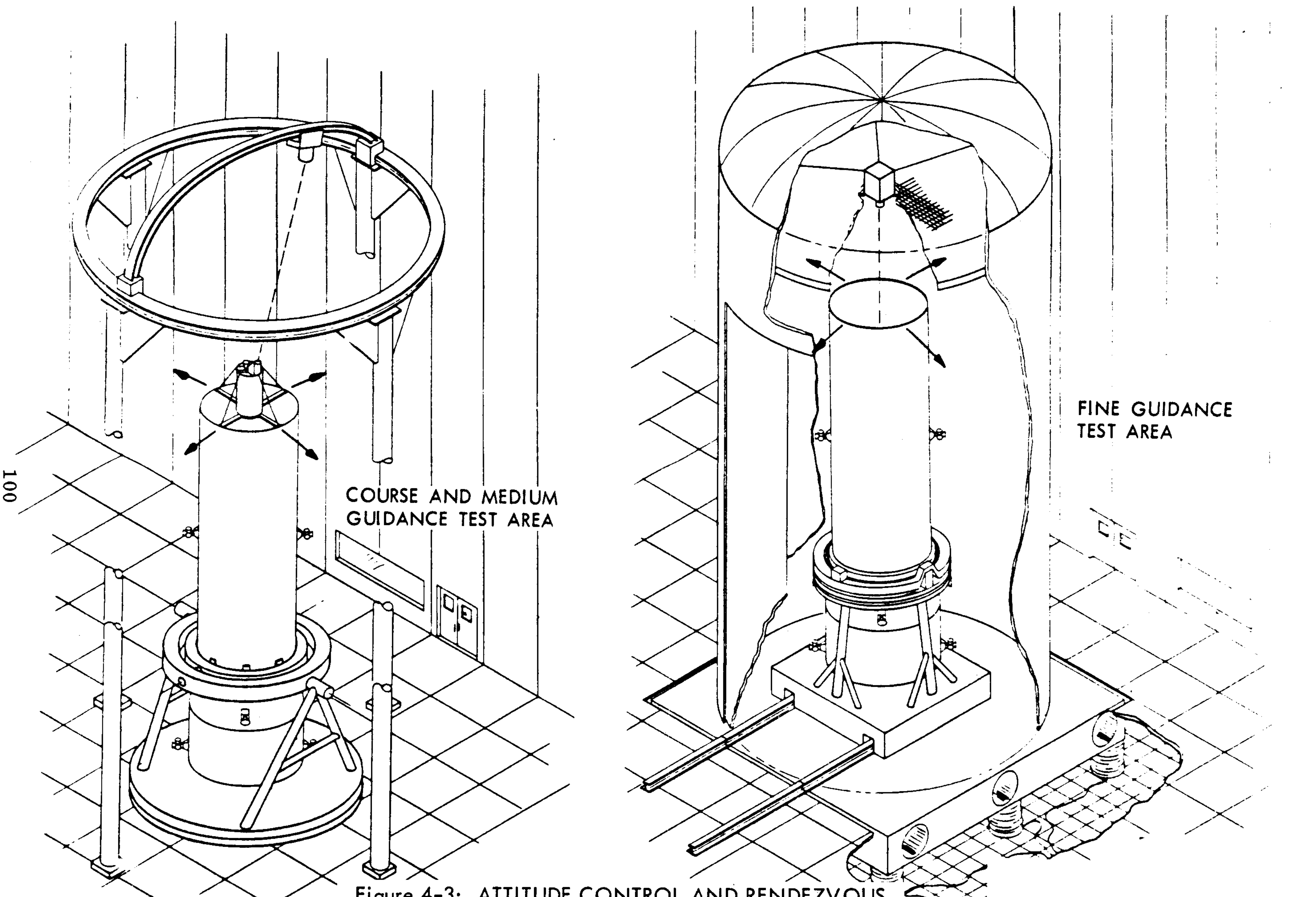


Figure 4-3: ATTITUDE CONTROL AND RENDEZVOUS DEVELOPMENT COMPLEX

is mounted on a test gimbal suspension system that provides a small travel and is located in a test chamber. This suspension system is, in turn, mounted on a seismic support base. The test chamber should be capable of providing a low vacuum and expected orbital thermal conditions. This complex may be located anywhere in the United States on the assumption that the MOT subsystem equipment is readily transported with proper packaging.

4.4 SCIENTIFIC INSTRUMENT INTEGRATION COMPLEX

This facility, shown in Figure 4-4, is required to ensure that the instruments are developed to a common integrated operational concept. The subsystem test area contains a simulated MOT cabin and a telescope image simulator mounted in a test chamber. The instruments are mounted on the platen in the cabin. The chamber is mounted on a seismic base and capable of providing vacuum and low-temperature conditions. Also included in the facility are separate areas for vibration test, receiving and shipment, general test, and processing of the scientific instrument data.

4.5 STRUCTURAL DEVELOPMENT FACILITIES

These facilities will be needed early in the project development phase and before the system development complex facilities will be available. Existing facilities at MSC could be used, as could other existing aerospace industry facilities, for structural development. The significant requirements are for a dynamic test facility capable of testing the full-scale MOT structures, and a vacuum chamber capable of simulating thermal and solar environment for the testing of the full-scale MOT thermal model. No additional facilities for these functions are considered required.

4.6 TRAINING FACILITIES

The facilities shown in Figure 4-5 are principally the brick and mortar for the part task training complex and the mission simulator training complex. The training equipment will have been developed and produced as a part of the project program and then assembled and checked for training use in these buildings.

4.7 MISSION CONTROL COMPLEX

Some facility additions are visualized for this complex. An experiment control and data facility will be tied to the mission control center by communications. A rather extensive data center is visualized, considering the type of mission and the duration of 5 years or more. The complexity of the experiment control center will depend on whether or not the telescope is remotely controlled from the ground. In the preliminary system concept used in this study, the telescope is not controlled from the ground. Therefore, this control center will perform a manned advisory operation for mission control. Some minor equipment modification may be required in the existing mission control and engineering data center.

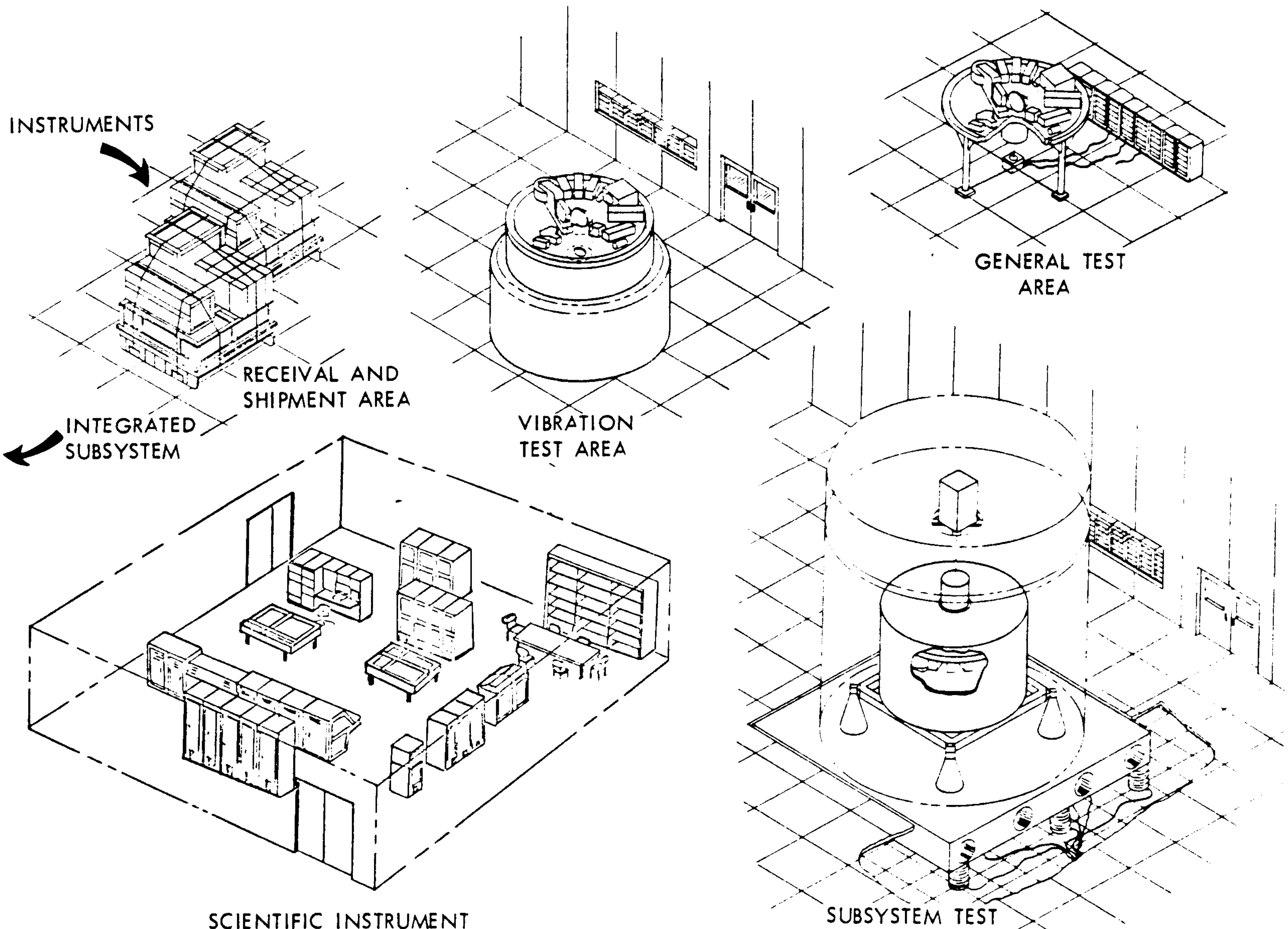


Figure 4-4: SCIENTIFIC INSTRUMENT INTEGRATION COMPLEX

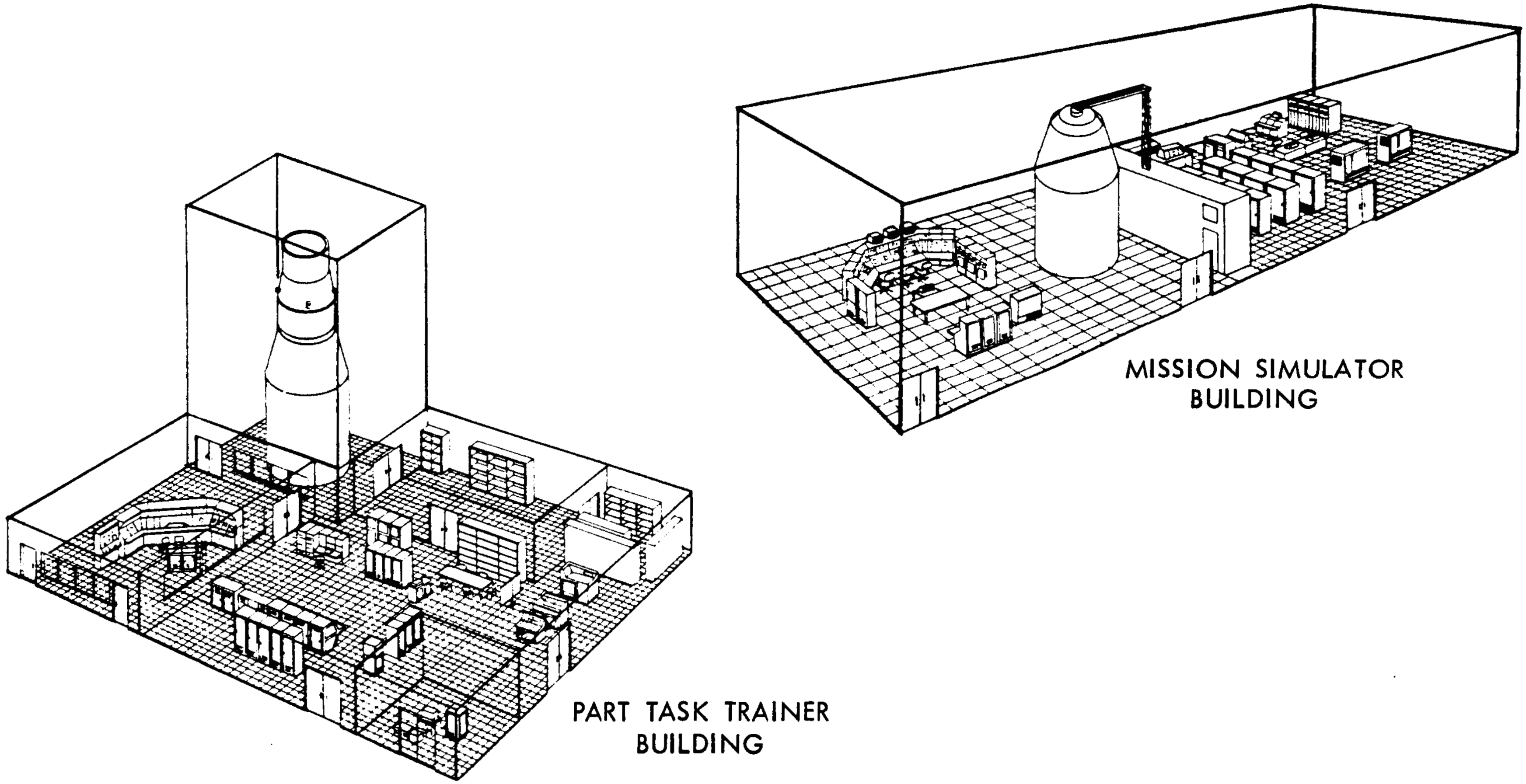


Figure 4-5: TRAINING FACILITIES

4.8 KSC FACILITIES

The Apollo and Saturn V facilities at KSC were reviewed as to their capability to handle the MOT. From this review it was determined that these existing facility complexes would adequately handle the MOT, particularly in regard to length and weight as illustrated below:

	Height (feet)	Weight (tons)
MOT (Launch Mode with Shroud)	62	15

	Hook Height (feet)	Hoist Capability (tons)
Existing Facilities Characteristics		
o Manned Space Operation Bldg. (MSOB)	85	25
• Vertical Assembly Bldg. (VAB)	140*	250
• Mobile Launcher	100*	12 to 25

* Hook height above Saturn V

5.0 MOT PROGRAM COSTS

This section contains cost estimates for the various phases and total MOT program. In structuring the program, the nonrecurring costs were recognized by the establishment of the concept development and project development phases, whereas the recurring costs for multiunit MOT's were recognized by the project operations phase. To allow cross correlation, the common program task numbers have been used in the cost tabulations as were used in the program planning data in Section 3.0. Costs have been prepared for each program task as identified in the work breakdown structure (WBS), then time phased and assembled into yearly funding tabulations. Because of the level of estimating, no resource cost breakdowns are presented. However, a ratio of resources may be applied to the tasks of the latter two program phases of about 42% for engineering labor; 25% for nonengineering labor; and 33% for material, purchased parts, and provided items. Specific conditions used as a basis for cost estimating are:

1) All costs in 1966 dollars;
2) Costs include fee;
3) Telescope cabin basic structure considered developed in another program;
4) Shroud assembly considered developed in another program;
5) Saturn V ground test vehicle operation costs assumed to be $10 million;
6) Saturn V flight vehicle costs assumed to be $70 million and launch operation costs $30 million;
7) Space station costs not included except for MOT-unique equipment;
8) Cost of facility lands not included;
9) Flight crew training costs not included;
10) Costs of government-owned ground equipment operations involved in launch and during the mission not included;
11) Space logistics costs not included.

5.1 TASK COSTS

The concept development phase involved in developing and verifying an effective MOT system concept, including the planning of the related development program, costs $57,200,000 as shown in Table 5-1 and represents about 4% of the total MOT program costs. This cost includes conducting approximately 18 investigations involving six concept demonstrations using breadboard models. The concept demonstration verifying the primary-mirror structural concept (A213) represents 44% of the costs for this phase. This cost includes the structural evaluation testing under typical MOT environmental conditions of three types of full-size MOT primary mirrors with a low finish on each mirror.

Table 5-1: TASK COSTS — CONCEPT DEVELOPMENT PHASE

(Dollars in Thousands)

	Work Breakdown Structure Level			
	0	1	2	3
MOT Concept Development A000	57,200			
Prime Investigations A100		7,850		
System Concept A110			7,250	
System Concept Development A111				5,700
System Operations Concept Review A112				300
System Concept Interface Coordination A113				650
Preliminary Specification Development A114				400
System Development Complex Concept Evaluation A115				200
Development Plans and Cost A120			600	
Support Investigations A200		49,350		
Optical Concept A210			33,700	
Mirror Surface Evaluation A211				300
Mirror Assembly Concept Evaluation A212				1,400
Mirror Assembly Concept Verification A213				25,000
Optical Alignment Concept Evaluation A214				3,500
Folding Mirror Assembly Concept Evaluation A215				3,500
Pointing Concept A220			9,700	
Dynamic Signature Identification A221				400
Space Station/MOT Interaction Evaluation A222				300
MOT Pointing Concept Evaluation A223				9,000
Scientific Instruments Concept A230			950	
Scientific Instruments Concept Evaluation A231				950
Scientific Data System Concept A240			2,000	
Scientific Data System Concept Evaluation A241				2,000
Additional Concept Studies A250			3,000	
To be defined during conceptual phase				3,000

The project development phase, involved in the development and verification of the entire MOT project, costs $1 billion (B000) as shown in Table 5-2, and represents 77% of the total program costs. Of the six major telescope subsystems, the structure and mechanisms subsystem has the highest development costs, representing 35% of the total telescope subsystem costs. Three major costs of the structural subsystem development are the static, dynamic, and thermal development tests on the full-size MOT structure. The major articles and their integration use (B117) represent 40% of the development costs of the telescope. The largest cost item of this phase is the telescope (B110), representing 45%. The significant new facilities and associated equipment for this phase costs $113 million, as shown in Table 5-3, or 11% of the total project development phase costs. The facilities that have been developed and priced in this phase are also used in the factory operation portion of the project operation phase.

Cost of the project operation phase is $244 million (C000), or 19% of the total MOT program, as shown in Table 5-4. The factory operation involving production of two flight models (C100) where one is used as backup, and production of mission logistics material represents 74% of the phase costs. The KSC MOT flight model and launch vehicle operations (C200) represent 18% of the phase costs. The ground mission support activity at MSC mission control, involving engineering and experiment aspects of the technical advisory, and data operations (C300) represent 8% of the phase costs. The recurring costs for each succeeding MOT system, including factory, KSC, and mission support operations is approximately $217 million.

5.2 YEARLY FUNDING COSTS

Using the task costs, yearly funding cost data for the total MOT program and the individual phases was prepared and is shown in Table 5-5. Throughout the program duration of 16 years, the maximum funding of $253 million occurs in the eighth year. From this funding data, it can be determined that $22 million is required to obtain selection of an effective MOT system concept, with an additional $35 million required for concept verification and planning of the related development program. This data also shows that a program expenditure of $1,150,000,000 is required to place the first MOT in orbit.

5.3 TELESCOPE PERFORMANCE AND SIZE PARAMETRIC COSTS

Since telescope size and performance are significant development and operational parameters, a gross relationship with costs is considered significant for program analysis purposes. Therefore, parametric data has been assembled for these two parameters. Size-versus-cost data shown in Table 5-6 was determined using the two principal factors considered to be cost sensitive — optics size and telescope weight. The optics cost factor is considered to be a function of the primary-mirror diameter cubed, based on analysis of optical industry performance. An analysis of the configuration was made, identifying equipment weights that vary with telescope size, and results of this analysis were used to determine the changes in telescope costs due to weight.

Table 5-2: TASK COST ESTIMATES PROJECT DEVELOPMENT PHASE

	(DOLLARS IN THOUSANDS)				
WBS LEVEL	0*	1*	2*	3*	4
MOT PROJECT DEVELOPMENT B000	1,000,000				
MOT SYSTEM B100		714,000			
Telescope B110			454,000		
Structures and Mechanisms B111				79,500	
Optics Support					8,680
Tube					20,600
Cabin					2,670
MOT Shroud-to-Booster Attachment					1,020
Cabin and Telescope Tube Interface					3,350
Telescope and Space Station Interface					7,410
Scientific Instrumentation Support					5,050
Optics B112				56,300	
120-Inch Primary Mirror					20,200
32-Inch Secondary Mirror					7,150
19-Inch Secondary Mirror					3,610
Folding Mirror Assemblies					7,390
Secondary Mirror Alignment Assembly					14,100
Secondary Mirror Interchange Assembly					1,300
Attitude Control B113				36,400	
Control Moment Gyros					4,530
Sensors					19,000
Inertial Reference Electronics					829
Reaction Control System					2,710
Inertial Reference (Sensor-Gyros)					1,790
Rendezvous B114				11,700	
Propulsion System					3,370
Communications and Control					5,630
Electrical Power System					2,260
Scientific Instruments B115				30,400	
Low-Dispersion UV Spectrometer					4,900
Low-Dispersion Spectrograph					4,500
Wide-Field Camera					1,700
High-Dispersion UV Spectrometer					5,300
Thermoelectric Photometer					1,200
Photoelectric Photometer					1,600
High-Dispersion Spectrograph					6,400
Large-Scale Camera					800
High-Dispersion IR Spectrometer					3,700
Flight Support Subsystems B116				9,770	
Electrical Power Distribution					1,400
					1,570

108-1

Active Equipment Heat Transport System				[illegible]
Audio Innercommunications				37
Engineering Data Sensors				3,840
Cabin Atmosphere System				1,790
Telescope Operations Checkout Station				866
Major Articles B117			181,000	
Mockup				672
MOT Engineering Model Program				39,200
Project Verification Model Program				69,400
Qualification Test Model Program				65,200
MOT Unique Space Station Equipment B120		38,600		
MOT Operations and Control Station B121			20,600	
Rendezvous Control Station B122			5,920	
Power Distribution System - Internal and External B123			2,160	
Ground Support Equipment B130		60,500		
Handling and Transportation Equipment B131			9,000	
Checkout Equipment B132			40,500	
Servicing Equipment B133			6,000	
Training Equipment B140		77,000		
Part Task Simulator B141			39,500	
Mission Simulator B142			24,500	
Subsystem Trainers B143			8,500	
Mission Support Equipment B150		19,500		
Experiment Control and Data Center Equipment B151			16,000	
MOT-Unique Mission Control Center Equipment B152			1,500	
MOT-Unique Engineering Data Center Equipment B153			1,000	
UNIVERSAL SHROUD ASSEMBLY B200	1,180			
Shroud Assembly B210		1,060		
Shroud B211			700	
Payload-to-Launch-Vehicle Adapter B212			300	
GSE B220		100		
Handling and Transportation Equipment B221				
LAUNCH VEHICLE SYSTEM B300	15,900			
Launch Vehicle B310		14,800		
Modifications B311			4,100	
Existing Ground Test Model B312			10,000	
GSE (MOT-Unique Equipment) B320		100		
MOT and Launch Vehicle Simulator (Usage) B321				
MISSION UPDATE MODS B400	90,000			
Telescope B410		45,000		
Scientific Instrument B420		25,000		
MOT Unique Subsystem Equipment B430		10,000		
SIGNIFICANT FACILITIES	113,000			

* The costs shown for this WBS level represent the total of the next lower level, plus the integration costs.

WBS = Work Breakdown Structure

108-2

Table 5-3: SIGNIFICANT FACILITIES COSTS — PROJECT DEVELOPMENT PHASE

(Dollars in Thousands)

	Building	Equipment	Total
System Development Complex	11,000	45,000	56,000
Optical Development Complex	6,000	28,000	34,000
Attitude Control and Rendezvous Development Complex	3,000	8,000	11,000
Scientific Instrument Development Complex	1,500	8,000	9,500
Training Equipment Complex			
Mission Simulator	500	(1)	500
Part Task Trainer	500	(1)	500
Mission Control Facility Additions	1,500	(2)	1,500
Total	24,000	89,000	113,000

1. Training equipment cost included in project development phase task costs (B140).
2. Mission support equipment cost included in project development phase task costs (B150).

Table 5-4: TASK COSTS — PROJECT OPERATIONS PHASE

(Dollars in Thousands)

	Work Breakdown Structure Level (1)			
	0	1	2	3
MOT Project Operations C000	244,000			
Factory C100		171,000		
MOT C110 (FM = 33,900; BFM = 23,700)			57,600	
Structures and Mechanisms C111				3,520 (2)
Optics C112				7,950 (2, 3)
Attitude Control C113				8,760 (2, 3)
Rendezvous C114				1,630 (2, 3)
Scientific Instruments C115				18,800 (2, 3)
Flight Support Equipment C116				1,040 (2)
Shroud Assembly C120			1,000	
MOT-Unique Space Station Equipment C130			7,030 (2,3)	
Launch Vehicle/MOT C140			70,000	
MOT Mission Logistic Support C150			26,500	
Spares C151				17,300
Update Modifications C152				9,000
Supplies C153				174
KSC C200		41,900		
MOT Operations C210			8,000	
MOT Launch Vehicle Operations C220			30,000	
Mission Support C300		18,900		
Engineering Operations (0 to 89 Days) C310			1,440	
Mission Control (Engineering Prime-Experiment Support) C311				46
Engineering Data Center Operations C312				279
Experiment Data Center Operations C313				1,120
Experiment Operations (90 Days and On) C320			15,200	
Mission Control (Experiment Prime-Engineering Support) C321				697
Experiment Data Center Operations C322				12,000
Engineering Data Center Operations C323				1,950

(1) The costs shown for each level represent the total of the next lower level plus integration costs.
(2) FM = Flight Model
(3) BFM = Backup Flight Model

Table 5-5: YEARLY FUNDING COSTS — MOT PROGRAM

(Dollars in Thousands)

Year	Concept Development Phase	Project Development Phase	Project Operations Phase	MOT Program
1	1,400			1,400
2	7,000			7,000
3	13,800			13,800
4	21,300			21,300
5	13,700			13,700
6		49,700		49,700
7		183,000		183,000
8		239,000	13,900	252,900
9		191,000	38,700	229,700
10		163,000	63,400	226,400
11		77,500	71,900	149,400
12		43,800	22,900	66,700
13		28,000	10,400	38,400
14		16,500	9,320	25,820
15		8,500	8,020	16,520
16			5,460	5,460
Total	57,200	1,000,000	244,000	1,301,200*

*Round off to $1,300,000 for program cost.

Table 5-6: TELESCOPE PERFORMANCE AND SIZE PARAMETRIC COST DATA

SIZE VS COST
(Constant Mirror Finish and Pointing Stability)

				$ in Millions				
Primary Mirror Diameter (Inches)	Changing Telescope Weight (Pounds)	Relative Weight Factor	Relative Optics Factor (d^3)*	Weight Costs Change	Optics Costs Change	Total Costs Change	Total Program Costs	Relative Cost Factor
200	33,000	1.65	5.2	+180	+200	380	1,680	1.29
120	20,000	1.00	1.0	0	0	0	1,300	1.00
80	13,000	0.65	0.33	- 95	- 35	-130	1,170	0.90
60	10,000	0.50	0.14	-140	- 40	-180	1,120	0.86

PERFORMANCE VS COST
(Constant 120-Inch-Diameter Size)

					$ in Millions				
Relative Performance Value	Optical** Finish	Optical Finish Cost Factor	Pointing Stability (Arc- Sec)	Pointing Cost Factor	Optical Finish Cost Change	Pointing Cost Change	Total Cost Change	Total Program Costs	Relative Cost Factor
1.29	Ideal	∞	---	---	∞	---	∞	∞	∞
1.04	λ/85	4.0	0.01	1.90	+9	+61	+70	1,370	1.05
1.00	λ/53	0	0.02	1.00	0	0	0	1,300	1.00
0.80	λ/28	0.66	0.03	0.64	-1	-25	-26	1,270	0.98
0.44	λ/10	0.50	0.06	0.26	-1.5	-51	-53	1,250	0.96
0.10	λ	0.30	0.30	0.04	-2.0	-66	-68	1,230	0.95

* d Primary Mirror Diameter
** Primary, Secondary, and Folding Mirrors

Performance parameter data presented in Table 5-6 recognizes the finish of the mirrors and the pointing system operations as the significant performance-sensitive cost elements. Mirror finishing involves a small number of personnel working over a relatively long period of time and, therefore, the finishing cost factor does not become significant until a near perfect finish is required. The preliminary system concept pointing requirement of ±0.01 arc-second, used as the basis for cost comparison, represents at this time a significant state-of-the-art advancement. Greater pointing requirements will result in significantly increased pointing system costs.