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# SOLID-BOOSTED NOVA VEHICLE SYSTEM STUDY (U)

Document D2-22431

VOLUME IV

- Operations, Manufacturing, and Facilities
- Reliability and Development Plan
- Advanced Technology
- Costing and Funding

April 1963

GEORGE C. MARSHALL SPACE FLIGHT CENTER
National Aeronautics and Space Administration

FINAL REPORT

Prepared Under Contract Number NAS8-2438
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By

THE BOEING COMPANY
Aero-Space Division
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## 3.3 OPERATIONS

### 3.3.1 Introduction

This section describes the studies performed to define operation of the T65D launch system. Studies were directed towards definition of:

- The number and schedule of launches required in support of the NOVA mission model furnished by MSFC
- Functional flow of vehicle major components from factory to delivery at AMR
- Effects of launch schedule on production rates and storage requirements
- Liquid stage acceptance captive firing tests and test facilities
- Transportation requirments and equipment for major vehicle components
- Launch facilities and operation at AMR

Work was done in sufficient detail to determine basic requirements, establish feasibility of logistic concepts, handling procedures, and equipment, and to define operations, facilities, and equipment for use in establishment of system costs.

The information presented on launch facilities and operation was provided by Martin-Denver, as a summary of work being done under a NASA contract for the study of NOVA launch facilities at AMR. This work has been published in detail in Martin-Denver report "NOVA Launch Facility Study," NASA-CR-63-7, March 1963.

### 3.3.2 Summary

#### 3.3.2.1 Mission Models and Launch Schedules

Mission requirements for the T65 vehicle system are based on the "NOVA Operational Mission Model Ground Rules" published by the NASA Future Projects Office on January 18, 1963. These ground rules require consideration of four basic missions:

- Manned Mars Mission
- Mars Ship Development
- Lunar-Base Supply
- Earth-Orbital Space Station

Two levels of effort are required on both the manned Mars mission and the lunar-base supply. This requires consideration of four mission schedules as follows.

| Mission | Number of Mars Ships | Lunar Base | Total No. of Launches | Peak Launch Rate (6 months) |
|---|---|---|---|---|
| 1 | 4 | 50 men | 79 | 11 |
| 2 | 4 | 20 men | 60 | 11 |
| 3 | 3 | 50 men | 71 | 8 |
| 4 | 3 | 20 men | 53 | 8 |

Reliability growth of the T65 vehicle was used in determining the total number of launches. Peak launch rate was dictated by the requirements of the manned Mars mission. Lunar-base missions were scheduled to obtain the most nearly uniform launch rate consistent with Mars-mission and lunar-supply requirements. Four space-station launches were also used to level launch rates as much as possible.

The 1975 launch window was selected as the earliest date for a Mars mission consistent with a conservative development schedule. Two other Mars missions were scheduled for the 1977 and 1981 launch windows.

The requirements of the Mars mission dictate high peak launch rates. This imposes a requirement for a high production rate prior to these missions or a level production rate with a large launch vehicle component storage capability. The high peak launch rate also determines the number of launch facilities required.

### 3.3.2.2 Supporting Operations

Functional flow diagrams were developed for the solid-first-stage motors, cluster structure, and components (Figure 3.3.4-1) and for the liquid second-stage (Figure 3.3.4-2).

There is a requirement for a solid substage assembly facility for installation of lower skirts, subsystem components, and instrumentation packages on the solid motors. This requirement is based on the need to minimize assembly time at the launch building. The facility may be located adjacent to the solid-motor manufacturing plant or at some location between the plant and AMR. The facility is not located at AMR because of limitations on available real estate. Storage for solid-motor substage assemblies is required for periods up to 9 months to permit support of Mars-mission peak launch rates with uniform production rates.

All liquid-engine second stages require stage-acceptance tests at the Mississippi Test Facility (MTF). Following acceptance tests, they are returned to the manufacturing facility for refurbishment prior to delivery at AMR.

The relationship between launch schedule requirements and production rates was analyzed. It was determined that:

- Peak production rate for solid motors is five per month
- Peak storage requirement is for 39 motors
- Peak production rate for second stages is ten per year
- Both solid motors and second stages must be capable of being stored for periods up to 9 months.

### 3.3.2.3 Stage-Acceptance Static Test

All liquid-engine stages require an acceptance static firing test to detect and correct any deficiencies related to stage performance while operating in the environment imposed by firing of the engines. It is assumed that the M-1 engine can be fired under sea-level conditions without altitude-compensating devices.

Acceptance firing tests of the second stage will be performed at MTF. Acceptance firing tests of the transtage will be accomplished at the manufacturer's facility.

Complete checkout of the stage will be accomplished before firing. This will include functional tests, RFI and electrointerference tests, and leak tests of the $LO_2$ and $LH_2$ tankage.

Static firings will include short-duration and full-duration firings. All systems will be operating to determine performance in the engine operating environment. After firing tests are completed, the stage will be returned to the factory for refurbishment.

The static-firing test complex will consist of three identical stage-test stands and one stand for the testing of individual M-1 engines.

In addition to the test stands, acceptance-firing test facilities will include:

- Control centers
- Data acquisition facilities
- Instrumentation towers
- Observation bunkers
- Communications, instrumentation, and test control facilities
- Tunnels
- Cryogenic servicing
- High-pressure industrial water system
- High-pressure gas storage and transfer system

- Electrical power
- Transportation

The static test stand for the second stage will consist of reinforced concrete substructure, two main support piers, steel-framed stage-support and thrust frame, water-cooled single-direction flame deflector, and a steel superstructure for access and handling equipment. Nominal thrust rating will be 7,500,000 pounds to allow for growth. Barge docking facilities will be located adjacent to the stand. The stage will be brought to the vicinity of the test stand by barge and unloaded by wheeled transporters attached to the stage-transportation pallet. The stages will be removed from the pallet and placed on the test stand by a crane located on the superstructure. Supply barges will be used to service the stage with cryogenics.

The M-1 engine test stand — nominally rated at 1,500,000 pounds thrust — will be used to trouble shoot and evaluate performance for engines that do not perform adequately during stage static firing. The stand will consist of a concrete substructure, support piers, and superstructure on which the engine will be mounted. Mounting attachments will accommodate both fixed and gimbaled engines. The stand will be provided with a water-cooled one-way flame deflector. A complete cryogenic supply and feed system, including storage tanks, will be provided.

### 3.3.2.4 Transportation

Water transportation of major vehicle components (solid motors, first-stage cluster structure, second stage, and transtage) is required because of size.

Special ocean-going barges will be required for solid motors and second stages. Port facilities and access waterways at MTF and AMR must be sized to allow movement of these barges from the ocean to unloading facilities.

Cross-beam cluster structure and transtage will be transported by existing commercial water transportation. Other vehicle components may be shipped by road, rail, water, or air as required.

The transportation and handling concept for the solid motors involves the use of a full-length strongback to prevent case buckling and local bearing failures. This is required because the high fineness ratio of the motor precludes the use of simple end supports. The motor will remain in the strongback for all operations, including propellant casting, until the motor is rotated to vertical for emplacement on the launch platform. Special tracked ground transporters designed to pick up the strongback will be used for local transportation on specially prepared roadbeds and for loading and unloading barges. The transporter will also be used with a heavy lift crane to rotate the motor to the vertical for erection on the launch platform. Identical transporter units will be used at all manufacturing and operational areas.

The transportation and handling concept for the second stage involves the use of a handling pallet that supports the stage in the vertical position at all times. The pallet will be used for all prelaunch operations involving the second stage, except final assembly and static firing tests. Transportation will be accomplished by the use of four-wheeled semi-independent tractors that engage each corner of the handling pallet. The tractors will be pneumatic-tired self-powered units equipped with hydraulic cylinders to lift the pallet from the ground for transport. Power and steering control design will permit control of transport operations by one operator. Identical tractors will be used at all manufacturing and operational areas.

#### 3.3.2.5 Launch Facilities and Equipment

The hybrid launch facility concept has been selected for the T65 vehicle because analyses to date have indicated that this concept is the least expensive. For the T65 vehicle this concept is characterized by:

- Off-pad checkout of liquid second stage, transtage, and payload .
- Off-pad assembly of second stage and transtage.
- On-pad assembly and checkout of solid-motor first stage.
- On-pad assembly of first stage, second stage-transtage combination, and payload.

The number of launch buildings required is a function of the maximum launch rate required for the Mars missions. Four buildings are required for the three-ship Mars mission and six buildings for the four-ship Mars mission.

Two types of launch control centers have been considered. One type is a soft installation using microwave data-transmission links. The other is a hardened center connected to the launch building by hardline. For the purposes of this study, Martin has selected a centralized soft launch control center for the four-launch-building complex. The six-building complex is provided with three hardened centers, each serving a pair of launch buildings.

### 3.3.3 Mission Models and Operational Launch Schedules

Mission requirements for the study were established by the "NOVA Operational Mission Model Ground Rules," published by the NASA Future Projects Office on January 18, 1963. These ground rules include four space programs: manned Mars missions, Mars vehicle development, Earth-orbital space stations, and lunar-base-supply missions. NOVA mission requirements are the sum of these four programs.

Alternate levels of program requirements are considered for the Mars missions and the lunar-base-supply missions. Three Mars missions are specified in a 10-year operational period. The Mars flight will have either a three-ship

or a four-ship convoy. The lunar-base-supply flights will be for supply of either a 20-man base or a 50-man base. These two programs, which require two levels of operation each are combined with the Mars vehicle development and Earth-orbital space station programs to form four different combinations of NOVA mission requirements.

The ground rules indicate the general requirements for time period and quantities of payloads. A preliminary phasing schedule was developed that would meet these requirements and was commensurate with time necessary for T65D vehicle development. Mars-mission timing is fixed with respect to a choice of launch window. The lunar-base-supply and Earth-orbital space station programs were scheduled to provide as efficient an operational and production program as possible without interfering with the Mars program. The preliminary model showing the successful launches (plus 10-percent spares for Mars missions) required for the four combinations of mission is tabulated in Table 3.3.3-1.

### 3.3.3.1 NOVA Operational Ground Rules

The ground rules supplied by NASA for the basic mission are summarized below.

Mars Missions — During the 10-year operational program, three manned Mars missions will be attempted. The missions will be timed to minimize the energy necessary for the round trip. The earliest attempt to be investigated is the 1973 Mars window because of the pacing developments needed for a Mars mission. Other possible Mars windows used in the NOVA mission plan are 1975, 1977, 1981, and 1983. The 1979 window is not considered because of its higher energy requirements and the increased solar activity at that time.

The manned Mars mission will require several ships each weighing about 1,500,000 pounds in Earth orbit, assuming nuclear propulsion for orbit departure. Each ship consists of 2 packages assembled in a 567-kilometer orbit. Each package is placed in orbit using a NOVA vehicle with a minimum payload capacity of 910,000 pounds. This payload capacity is adequate to provide reserve for rendezvous and assembly of the 1,500,000-pound Mars vehicle.

Two levels of Mars mission were to be studied. These are represented by a four-ship mission and a three-ship mission. The four-ship mission will require 6 million pounds in orbit. The three-ship mission will require 4.5 million pounds in orbit. The buildup in orbit will take place in a 6-month period preceding the orbital departure date.

A spares factor of 10-percent of payload weight is required at orbital rendezvous. This factor accounts for payload successfully delivered to orbit but which must be replaced. It also covers such things as payload failures, damage during docking, replacement of various components, etc. Only whole numbers of launches were considered when computing NOVA launches necessary to provide for spares.

**MISSION MODEL**

**NOVA PAYLOAD QUANTITIES**

| MISSIONS | | 1973 | | | | 1974 | | | | 1975 | | | | 1976 | | | | 1977 | | | | 1978 | | | | 1979 | | | | 1980 | | | | 1981 | | | | 1982 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Space Station | | | | | | | | | | | 2 | | | 1 | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| | Mars Development | 1 | | 2 | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Mars 4 Ship | | | | | | | | 5 | 4 | | | | | | | | 5 | 4 | | | | | | | | | | | | | | | | | 5 | 4 | | | | |
| | 50 Man Base | | | | 1 | | 1 | | 1 | | 1 | | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 |
| 2 | Space Station | | | | | | | | | | | 2 | | | 1 | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| | Mars Development | 1 | | 2 | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Mars 4 Ship | | | | | | | | 5 | 4 | | | | | | | | 5 | 4 | | | | | | | | | | | | | | | | | 5 | 4 | | | | |
| | 20 Man Base | | | | | 1 | | | | 1 | | | 1 | | | 1 | | | 1 | | 1 | | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | | 1 | | 1 | 1 |
| 3 | Space Station | | | | | | | | | | | 2 | | | 1 | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| | Mars Development | 1 | | 2 | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Mars 3 Ship | | | | | | | | 4 | 3 | | | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | 4 | 3 | | | | |
| | 50 Man Base | | | | 1 | | 1 | | 1 | | 1 | | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 |
| 4 | Space Station | | | | | | | | | | | 2 | | | 1 | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| | Mars Development | 1 | | 2 | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Mars 3 Ship | | | | | | | | 4 | 3 | | | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | 4 | 3 | | | | |
| | 20 Man Base | | | | | 1 | | | | 1 | | | 1 | | | 1 | | | 1 | | 1 | | | 1 | | 1 | | | 1 | | 1 | | 1 | | 1 | | | 1 | | 1 | 1 |
| Yearly Quarter | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Year | | 1973 | | | | 1974 | | | | 1975 | | | | 1976 | | | | 1977 | | | | 1978 | | | | 1979 | | | | 1980 | | | | 1981 | | | | 1982 | | | |

Table 3.3.3-1

Mars Vehicle Development — Since the Mars ship cannot be defined in detail at this time, the vehicle size required for its development cannot be determined. For this mission model, it is assumed that the number of successful NOVA launches is equal to twice the number of packages per ship plus one. This means that the equivalent of two Mars ships plus a spare package are used for the development program.

The Mars-mission ship-development launches are scheduled over a 2-year period prior to the first Mars window to be used for a mission attempt. The schedule provides 1.5 years between the NOVA operational availability and the start of launches for the first Mars attempt.

Lunar Base — Two levels of operation were considered for NOVA support of the lunar program. These are based on establishing and maintaining either a 20-man or a 50-man base. Establishing the lunar-base can involve either the initial lunar base installation or addition to a base established by some Saturn V based mode of transportation. The lunar base launchings take place over a full 10-year operational period, but on a noninterference basis with the Mars mission attempts. The lunar mission launches start as soon as a particular NOVA configuration is operational and continue until a Mars mission is approached. There is then a break in the lunar flights while the Mars-mission attempt is made. However, the launch rate for the lunar base is selected so that the lunar supply is always greater than required, even during the Mars-mission attempts.

Lunar-base-support payload requirements are shown in Figures 3.3.3-1 and -2. The lunar payload is expressed as equivalent payload in a 225-kilometer circular orbit. One pound of payload is a 225-kilometer orbit is required to deliver 0.145 pounds of payload on the lunar surface. Figure 3.3.3-1 also includes a 0.9 reliability factor to account for losses from the 225-kilometer orbit to the lunar surface.

Space Station — During the 10-year operational program, three large space stations will be placed in a 567-kilometer orbit using the NOVA launch vehicle. The time of launching these stations is to be scheduled to help level the annual NOVA launch rates. Weight of the space station will correspond to NOVA capacity. A total of four NOVA launch vehicles is planned for this mission over the 10-year program plan. Two of these are to be available for the first space-station launch to allow for possible failure.

### 3.3.3.2 Development of the Model

Model Description — A definitive model was established to meet the mission requirement ground rules and fit both T65D-launch-vehicle and Mars-vehicle development requirements. The model defines the schedule of T65D launch attempts necessary to provide the required payloads in orbit. The reliability growth curves (see Section 3.5) were used in determining the required number of launches.

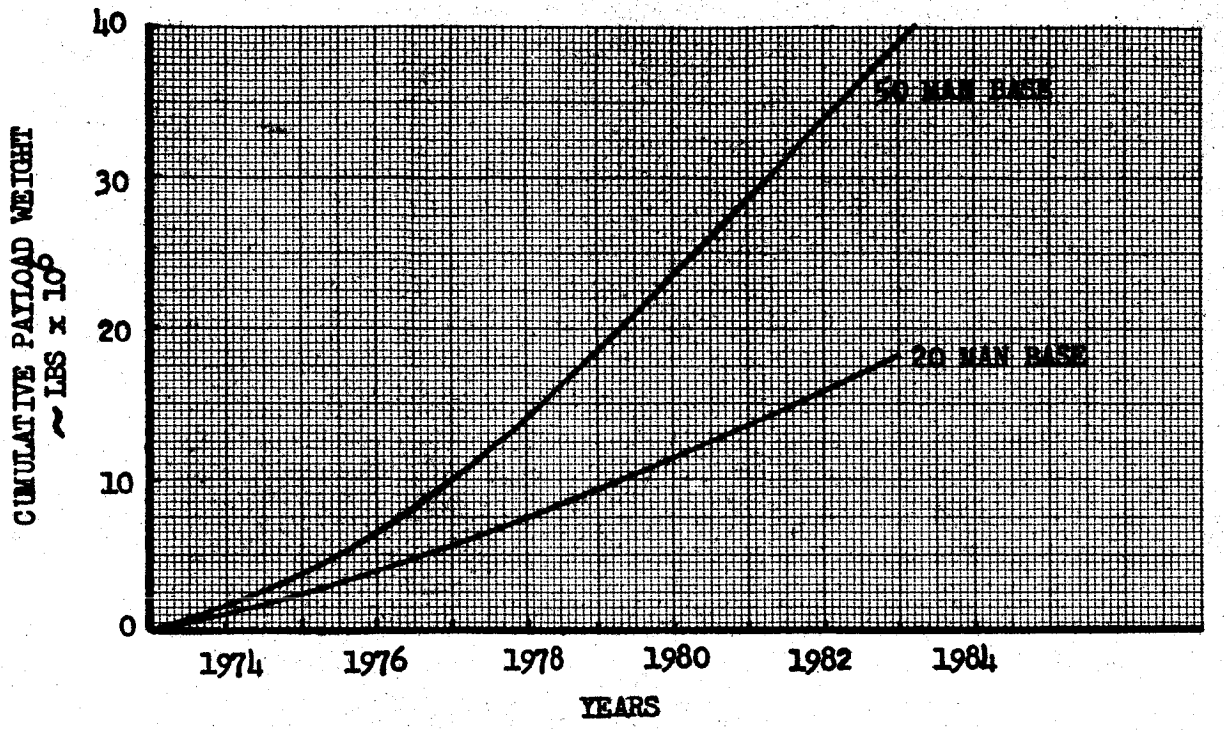


Figure 3.3.3-1 PAYLOADS FOR LUNAR SUPPLY

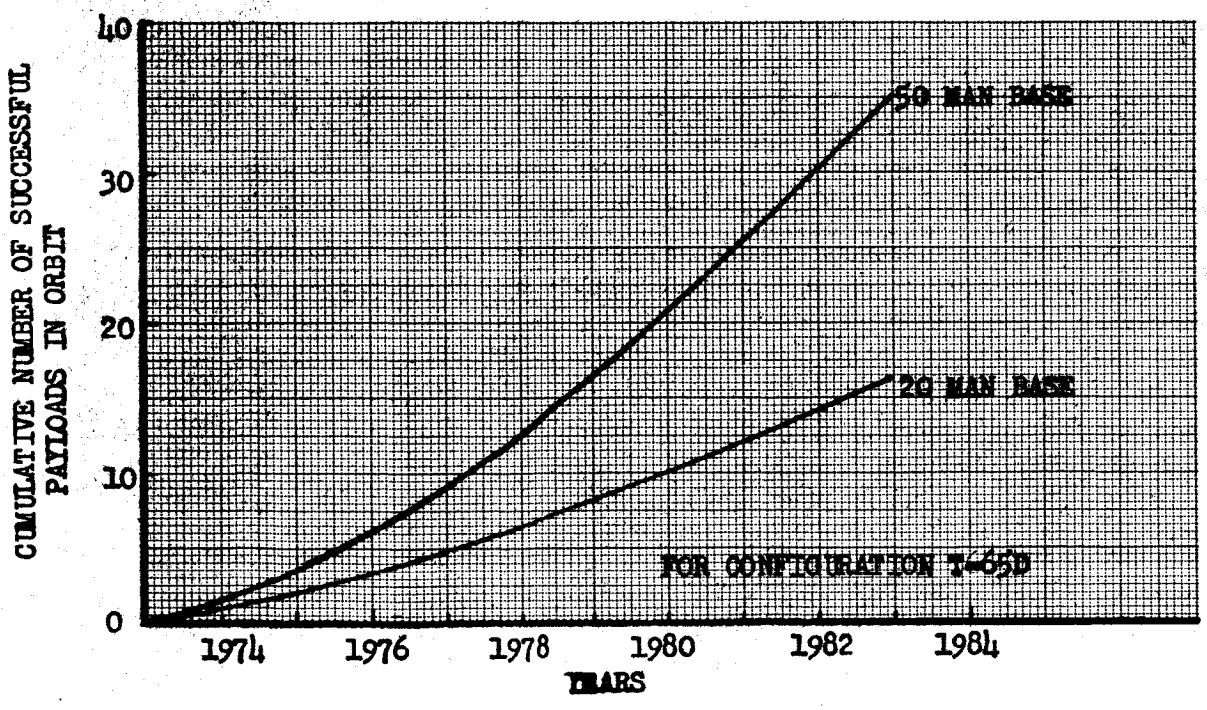


Figure 3.3.3-2 PAYLOADS FOR LUNAR SUPPLY

Launch schedules for this model are shown in Tables 3.3.3-2, -3, -4, and -5, as indicated below.

| Mission Number | Number of Mars Ships | Lunar Base | Table Number |
|---|---|---|---|
| 1 | 4 | 50 men | 3.3.3-2 |
| 2 | 4 | 20 men | 3.3.3-3 |
| 3 | 3 | 50 men | 3.3.3-4 |
| 4 | 3 | 20 men | 3.3.3-5 |

Schedules are developed by quarterly increments.

The Mars mission windows are the primary constraint on the definition of a mission model. Five launch windows are of interest, with the first occurring in 1973. Three Mars missions are required using any three of the five windows. Early Mars missions appear desirable for national prestige and because of velocity increment is slightly lower for the early windows. However, T65D launch-system availability on a normal-work-week basis prevents meeting the 1973 window. A moderate program for development of the launch vehicle results in operational availability of the vehicle by mid-1972. One and one-half years are necessary to develop a Mars vehicle for use with a NOVA booster. One-half year is necessary to build up Mars ships in orbit. Therefore, the 1975 Mars window is the earliest that can be attempted without a high-priority development and production program. The number of launches necessary to achieve the required payloads was estimated for the Mars missions and Mars-vehicle development using both the reliability growth curves and the spares factor.

The launches needed for lunar-supply missions and orbital stations were estimated and scheduled for noninterference with the Mars missions. The number of successful launches for lunar supply is shown in Figure 3.3.3-2. This is based on the baseline T65C configuration, which has a payload capacity of approximately 1,120,000 pounds in a 225-kilometer orbit. The launch schedule was established so that the cumulative weight of payload to the moon always exceeds the curve. This requires stock piling of supplies on the lunar surface for use during the Mars buildup period.

The space-station launches were scheduled during periods of low launch activity, without regard to availability for support of the first Mars mission. If early availability of the space station is considered desirable, this could be achieved by scheduling two space-station launches during the 6-month slack period between completion of the R&D flight-test program for T65D in mid-1972 and the start of the operational program in 1973. A program with space-station support for the Mars mission that also allows for more unform launch rates and slower production buildup could be achieved by attempting the first Mars mission in 1977. However, this program was not selected because of the desirability of an earlier Mars mission.

# LAUNCH SCHEDULES

| MISSIONS | SCHEDULE 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lunar Base Supply 50 Man | | 1 | 1 | 2 | | 1 | | | | | | 2 | 2 | 1 | 2 | 1 | | | | | 2 | 1 | 1 | 1 | 1 | 2 | | 2 | 2 | 2 | 2 | 2 | | | | | 1 | 2 | 1 | 2 | 37 |
| Space Station | | | | | | | | | | | 2 | | | 1 | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | 4 |
| Mars Vehicle Development | 1 | 1 | 2 | 1 | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 |
| Mars Mission 4 Ship | | | | | | | | 6 | 5 | | | | | | | | 5 | 5 | | | | | | | | | | | | | | | | | 5 | 5 | | | | | 31 |
| Yearly Quarter | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | |
| Launches Per Year | 9 | | | | 9 | | | | 9 | | | | 7 | | | | 10 | | | | 5 | | | | 6 | | | | 8 | | | | 10 | | | | 6 | | | | 79 |
| Year | 1973 | | | | 1974 | | | | 1975 | | | | 1976 | | | | 1977 | | | | 1978 | | | | 1979 | | | | 1980 | | | | 1981 | | | | 1982 | | | | |

Table 3.3.3-2

| MISSIONS | SCHEDULE 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lunar Base Supply 20 Man | | 1 | 1 | 1 | | | 1 | | | | | | 2 | | 1 | 1 | | | | | | 1 | 1 | | 1 | | | 1 | | 1 | | 1 | | | | | 1 | | 1 | 2 | 18 |
| Space Station | | | | | | | | | | | 2 | | | 1 | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | 4 |
| Mars Vehicle Development | 1 | 1 | 1 | 2 | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 |
| Mars Mission 4 Ship | | | | | | | | 6 | 5 | | | | | | | | 5 | 5 | | | | | | | | | | | | | | | | | 5 | 5 | | | | | 31 |
| Yearly Quarter | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | |
| Launches Per Year | 8 | | | | 9 | | | | 7 | | | | 5 | | | | 10 | | | | 2 | | | | 3 | | | | 2 | | | | 10 | | | | 4 | | | | 60 |
| Year | 1973 | | | | 1974 | | | | 1975 | | | | 1976 | | | | 1977 | | | | 1978 | | | | 1979 | | | | 1980 | | | | 1981 | | | | 1982 | | | | |

Table 3.3.3-3

## LAUNCH SCHEDULES

| MISSIONS | SCHEDULE 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LUNAR BASE SUPPLY 50 MAN | | | 1 | 1 | 1 | 1 | | | | 1 | | 2 | 2 | 2 | 2 | | | | | | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | | | | | 1 | 1 | 1 | 2 | 36 |
| SPACE STATION | | | | 2 | | | | | | | | | | 1 | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | 4 |
| MARS VEHICLE DEVELOPMENT | 1 | 2 | 1 | 1 | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 |
| MARS MISSION 3 SHIP | | | | | | | | 4 | 4 | | | | | | | | 4 | 4 | | | | | | | | | | | | | | | | | 4 | 4 | | | | | 24 |
| YEARLY QUARTER | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | |
| LAUNCHES PER YEAR | 9 | | | | 8 | | | | 7 | | | | 7 | | | | 8 | | | | 6 | | | | 6 | | | | 7 | | | | 8 | | | | 5 | | | | 71 |
| YEAR | 1973 | | | | 1974 | | | | 1975 | | | | 1976 | | | | 1977 | | | | 1978 | | | | 1979 | | | | 1980 | | | | 1981 | | | | 1982 | | | | |

Table 3.3.3-4

| MISSIONS | SCHEDULE 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LUNAR BASE SUPPLY 20 MAN | | 1 | | 1 | | 1 | | | | | | 1 | 1 | | 2 | 1 | | | | | | | 1 | | 1 | | | 1 | | 1 | 1 | 1 | | | | | 1 | | 2 | 1 | 18 |
| SPACE STATION | | | | | | | | | | | 2 | | | 1 | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | 4 |
| MARS VEHICLE DEVELOPMENT | 1 | 1 | 2 | 1 | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 |
| MARS MISSION 3 SHIP | | | | | | | | 4 | 4 | | | | | | | | 4 | 4 | | | | | | | | | | | | | | | | | 4 | 4 | | | | | 24 |
| YEARLY QUARTER | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | |
| LAUNCHES PER YEAR | 7 | | | | 7 | | | | 7 | | | | 5 | | | | 8 | | | | 2 | | | | 2 | | | | 3 | | | | 8 | | | | 4 | | | | 53 |
| YEAR | 1973 | | | | 1974 | | | | 1975 | | | | 1976 | | | | 1977 | | | | 1978 | | | | 1979 | | | | 1980 | | | | 1981 | | | | 1982 | | | | |

Table 3.3.3-5

Reliability Estimates — The number of launches necessary to achieve the mission requirements was developed from the reliability estimates shown for the T65C launch vehicle, which are the same as shown for the T65D vehicle in Section 3.5. The number of launches necessary for the operational programs is derived from the reliability growth curve by quarterly increments so that reliability growth effects are reflected in each program. Fractional values from the curve are taken to the next higher integral number.

Production and Launch Effects — A moderate production buildup and a uniform launch rate are desirable for best efficiency and economy of operation. The requirements of the Mars mission dictate high peak launch rates. This imposes a requirement for a high production rate prior to these missions or a level production rate with a large launch-vehicle-component storage capability. The high peak launch rate also determines the number of launch facilities required (see Section 3.3.7).

The space-station and lunar-base-supply launches have been scheduled, as far as possible, to provide more uniform launch and production rates. The requirements for lunar supply are shown in Figure 3.3.3-1. These curves show the minimum pounds of payload required to the moon at any time. Earlier deliveries are permissible. Therefore, launch schedules have been adjusted to obtain the most nearly uniform launch rate consistent with Mars-mission and lunar-supply requirements.

### 3.3.4 Supporting Operations

This section outlines the operational flow sequence for T65D stages and components from shipment at the factory to delivery at AMR. The interrelationship between mission launch rate requirements, production schedules, transportation, and storage requirements is described.

#### 3.3.4.1 Guidelines and Assumptions

To remain within the scope of this study and to define interface areas with manufacturing and launch operations, the following guidelines and assumptions were used.

Overall Vehicle —

- Retrorockets and ullage rockets will be installed at the launch pad.
- The clustering cross beam, cluster links, and heat shields will be manufactured in existing East Coast or Gulf Coast facilities, and shipped to Cape Canaveral by commercial water transportation, where the two pieces of the cross beam will be assembled.
- A removable launch platform and flame deflector will be used. These items will be refurbished at Cape Canaveral.

- Arming devices for all stages of the vehicle will be installed during the two-days allotted to prelaunch countdown operations.
- Barge transportation is conducted on a 24-hour-per-day, 7-day-per-week basis, as required.

Solid Motors —

- Cases for solid motors will be manufactured on the East or Gulf Coasts and shipped by commercial water transportation to the propellant manufacturer.
- The strongback and top lift fixture are installed on the rocket motor case before pouring propellant into the case. These items will remain with the solid rocket motor until the motor is positioned vertically at the launch pad.
- No storage requirement exists for cool-down of solid motors after curing.
- Solid motors are shipped, one to a barge, in the horizontal position.
- One-way barge travel time between either the solid propellant manufacturer or Cape Canaveral and the Solid Motor Substage Facility is 24 hours or less.
- A separate Solid Motor Substage Facility will be required for receiving inspection, installation of command destruct equipment (less arming devices), electrical wiring, telemetering equipment, thrust-vector-control equipment, malfunction detection equipment, and lower skirt. Some additional subsystem components will be installed during assembly of the first stage on the launch pad. This buildup facility is expected to be located on existing waterways between the solid propellant manufacturer and Cape Canaveral.
- Motors will be stored within land transportation distance of the Solid Motor Substage Facility for periods of up to 9 months. This capability is needed to meet the requirements of the Mars mission.

Second Stage —

- M-1 engines are static fired by the manufacturer and shipped to the second stage manufacturer.
- The pallet used as base support for the stage will be used as a mounting base during assembly of stage components, and will be used until the stage is installed at the launch building.
- The second-stage manufacturer is responsible for the first stage-second stage interstage, which will be installed on the first stage at the launch building.
- The second stage will be transported in the vertical position by barge from the manufacturer to the Mississippi Test Facility and to Cape Canaveral. Both locations are within 10 days (one-way) barge travel time from the manufacturer.
- Second-stage captive test firing will be required on each vehicle. This will be accomplished only at the Mississippi Test Facility.

- The barge delivers a stage to the Mississippi Test Facility and, for the return trip, picks up a stage that has received captive test firing.
- The M-1 engine can be replaced at either the Mississippi Test Facility or the Stage Checkout Building at Cape Canaveral. There will be no requirement to change M-1 engines at the launch pad.
- Two bays of the Stage Checkout Building can be used for 2 month's storage during the buildup for the Mars mission.
- The second stage will be refurbished at the second-stage manufacturing facility after static firing.
- The second stage will be stored for periods of up to 9 months. This capability is needed to meet the requirements of the Mars mission.

Transtage —

- A separate manufacturer will be responsible for the transtage.
- The two propulsion units of the transtage will be static fired separately at the manufacturer's facility and will be installed on the second-stage forward skirt extension at Cape Canaveral.
- Commercial transportation will be used and will not exceed 20 days, one way, from manufacturer to Cape Canaveral, with the transportation equipment being returned to the manufacturer within 10 days.

Payload —

- Payload includes payload-to-second-stage interstage upon arrival at Cape Canaveral.
- Payload will be shipped by barge in the vertical position.
- Additional definition of payload is beyond the scope of this study.

### 3.3.4.2 Functional Flow — First Stage

A functional flow diagram for the solid first stage from manufacturing to Cape Canaveral operations is shown in Figure 3.3.4-1. The major steps are shown divided into three major facility areas.

Solid Propellant Facility — The solid motor case, upper skirt, and nozzle are manufactured and shipped to the solid-propellant manufacturer. The rocket case is prepared for pouring of the solid propellant. This includes degreasing and installation of the internal liner. The rocket case is installed on the strongback and the top lift fixture is installed. This assembly is then moved to the casting area where the propellant is poured and allowed to cure. The nozzle blocking and stabilizing equipment and upper and lower environmental closures are installed. Upon completion, the strongback with solid motor is loaded on a barge for transportation to the Solid Motor Substage Facility. The strongback includes an events recorder which records the environment of the solid motor

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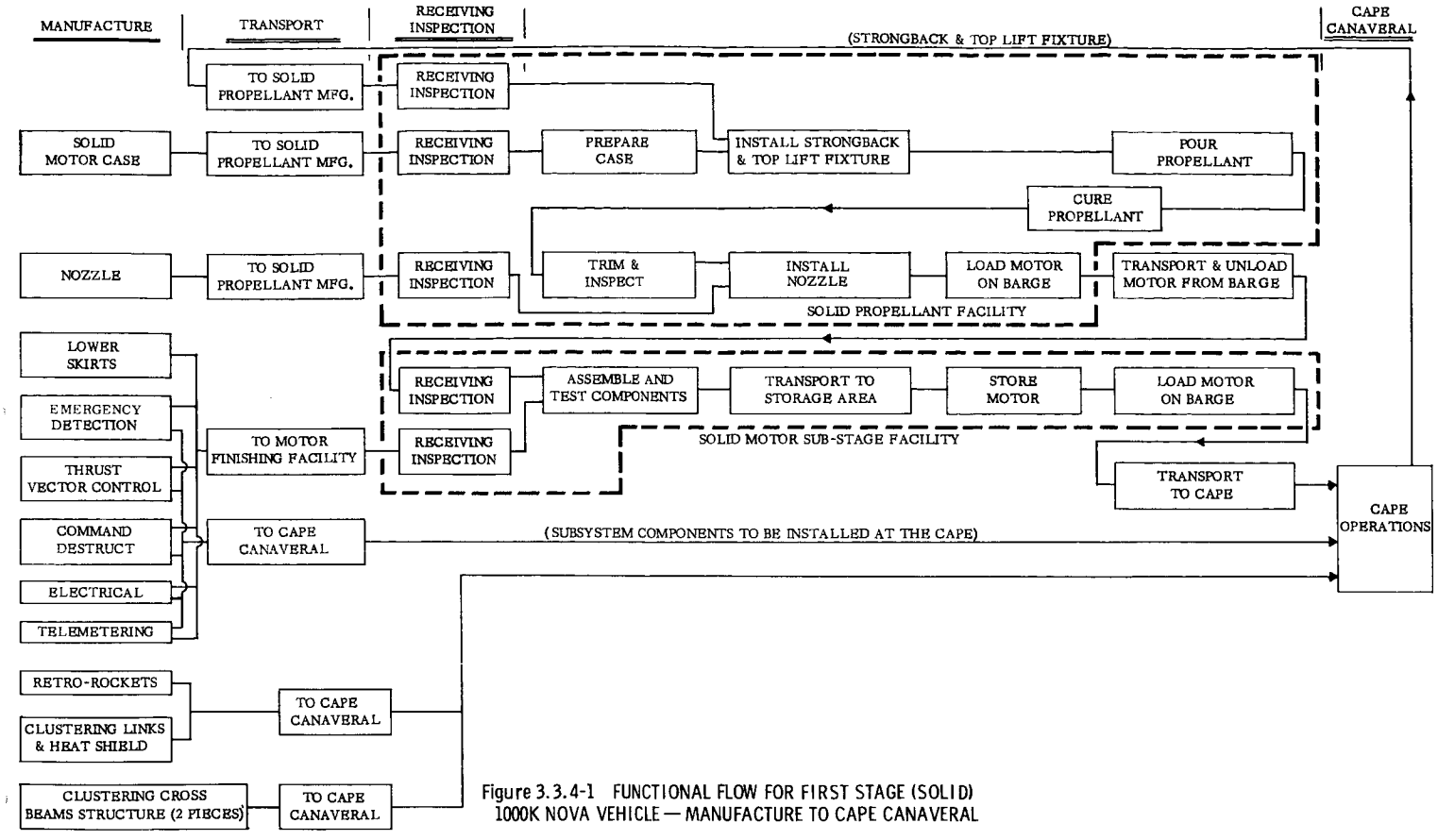


Figure 3.3.4-1 FUNCTIONAL FLOW FOR FIRST STAGE (SOLID) 1000K NOVA VEHICLE — MANUFACTURE TO CAPE CANAVERAL

from casting until the strongback is removed after the motor is erected to the vertical position at Cape Canaveral.

Solid Motor Substage Facility — The lower skirts, malfunction detection, thrust vector control, command destruct, retrorockets, electrical, and telemetering subsystems are transported from the manufacturer to the Solid Motor Substage Facility where they undergo a receiving inspection. The solid motor is transported by barge to this facility, where the motor is unloaded and given a receiving inspection. The subsystems are installed on the motor and tested. After testing, the solid motor is transported to a storage area. The motors will be in storage for periods varying from part of 1 month to 9 months. As the motors are required at Cape Canaveral, they are loaded onto a barge and transported to the Cape.

Cape Area Facility — Several items are sent directly from the manufacturer to the Cape. These include the auxiliary power unit for TVC, retrorockets, clustering links, heat shields, and clustering cross beam and skirt structure. These items are installed during the assembly of the first stage in the launch building.

### 3.3.4.3 Functional Flow — Second Stage, Transtage, and Payload

A functional flow diagram for the second stage, transtage, and payload is shown in Figure 3.3.4-2. The major steps are divided into five areas.

M-1 Engine Manufacturing — The M-1 engine manufacturer is responsible for manufacturing the engine, transporting it to the static test area, performing the static test, and transporting it back to the manufacturing area, where the engine will be refurbished and prepared for transportation to the second-stage manufacturing facility.

Second-Stage Manufacturing — The second-stage $LH_2$ and $LO_2$ tanks are manufactured, moved to a hydrostatic test area, and tested. The tanks are transported to the stage-assembly area, where the second-stage tankage and structure is assembled and then mounted on the transportation pallet. Finally, subsystem components and M-1 engines are installed, and a stage checkout is completed.

The complete stage is transported to the Mississippi Test Facility for captive test firing. Upon completion of the captive test firing, the second stage is returned to the manufacturer for refurbishment and storage until it is required at the Cape to support the launch program. The first stage-second stage interstage would be installed on the pallet before shipment of the second stage to the Cape. Second-stage storage time is expected to vary from 1 to 9 months, with the mean at 4.5 months.

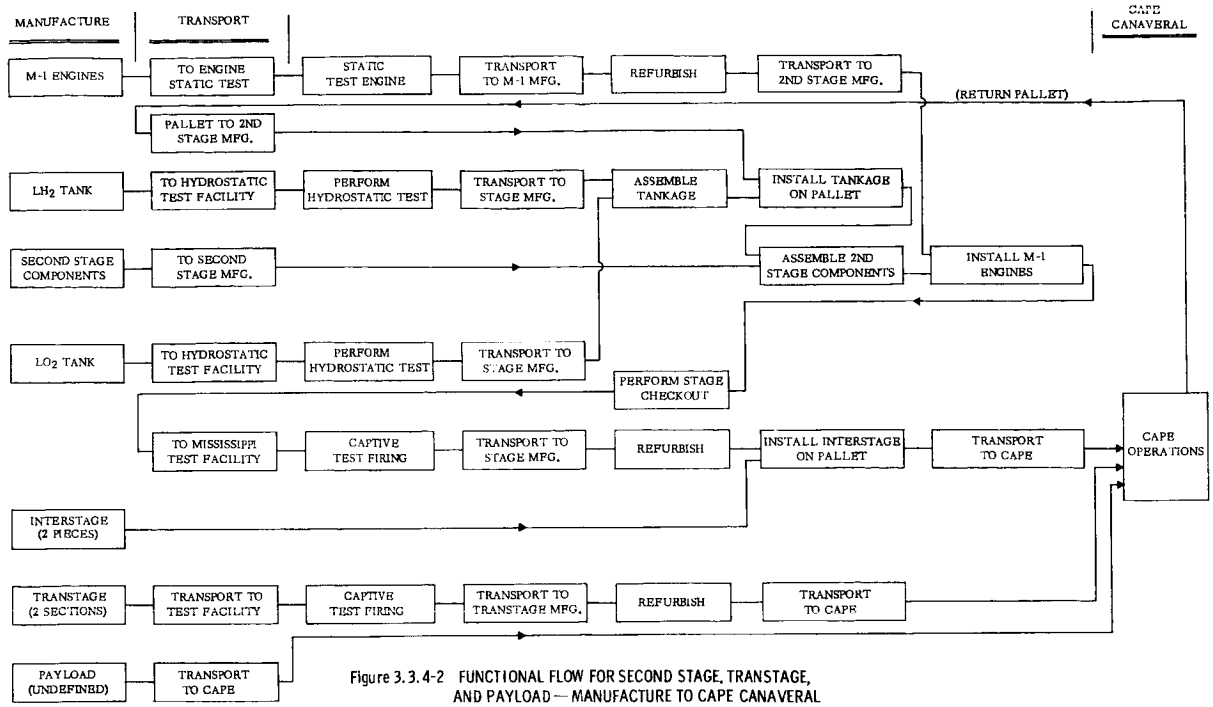


Figure 3.3.4-2 FUNCTIONAL FLOW FOR SECOND STAGE, TRANSTAGE, AND PAYLOAD — MANUFACTURE TO CAPE CANAVERAL

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Transtage Manufacturing — The transtage is manufactured in two propulsion units that include tankage. These are transported to a captive test area, where test firings are performed, and then are returned to the transtage manufacturer for refurbishment. These units will be transported to the Cape as required to support the launch program.

Payload Manufacturing — The payload was undefined for this study. It is assumed that all the units will be transported directly to the Cape as the program requires.

Cape Area — The second stage, transtage, and payload are transported to the Cape, where receiving, inspection, modification, assembly, and launch operations are conducted, as discussed in Section 3.3.7.

### 3.3.4.4 Operational Schedule

A preliminary analysis of the mission model for the 4-ship Mars mission and the 50-man lunar base revealed that the required launch rate varies from zero to six launches in any specific 3-month period. Additional study will be required to determine the optimum operational schedule at the Cape. However, to determine the requirements for facilities and equipment, a typical schedule was made for solid motors and second stage. This schedule is divided into three sections, as shown in Figure 3.3.4-3.

Vehicle Launches — This section provides the following information:

- Number of launches to be made in each month.
- Cumulative launches made in each year.
- Program cumulative total of vehicle launches at any given month.

Solid Motor Requirements — This section provides the following information:

- Motors required at the Cape in each month. The maximum number required in any one month is 13.
- Cumulative requirements at the Cape by any given month.
- Production rate per month. Maximum required rate is 5 per month.
- Cumulative total produced by any given date. A total of 474 is required to support the mission model.
- Peak requirements for solid motors in storage are 39, 29, and 36 during April 1974, July 1976, and January 1981, respectively.
- The motor requirement line shows that the motors must be through the Solid Motor Substage Facility and available for shipment to the Cape 4 months before the launch date.

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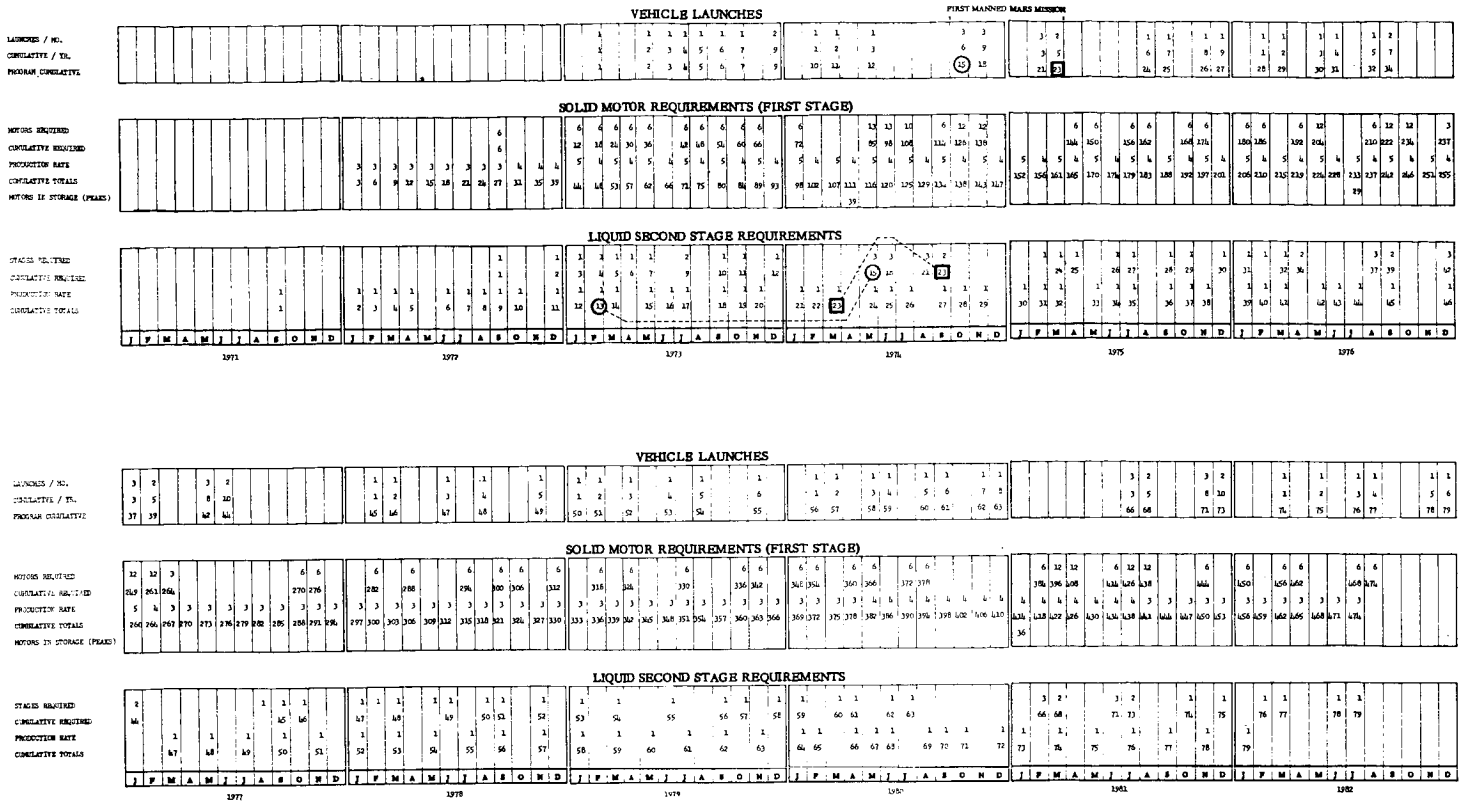


Figure 3.3.4-3 TYPICAL SCHEDULE — 4-SHIP MARS MISSION AND 50-MAN LUNAR BASE

Liquid Second-Stage Requirements — This section provides the following information:

- Stages required at the Cape in each month. The maximum required in any one month is 3.
- Cumulative requirements for second stages at the Cape by any given month.
- Production requirements by months. The maximum required rate is 10 per year.
- Cumulative total produced by any given date. It should be noted that the number produced to date does not include captive test and refurbishment, which require approximately 5 months of additional time.

Schedule Analysis — The information presented in Figure 3.3.4-3 was analyzed to explore the relationship between manufacturing schedules, launch availability dates, and length of storage required. It was found that the manned Mars mission schedules are not compatible with a uniform production rate unless a backlog of solid motors and liquid stages can be built up and stored to meet the peak requirements of the Mars mission. Accordingly, solid motors and liquid second stages must have the capability of being stored for varying periods of up to 9 months. Storage facilities will be required for this purpose.

The following examples illustrate this problem:

- Vehicles 13, 14, and 15 are scheduled for launch in October 1974. The second stages for Vehicles 13, 14, and 15 are required at AMR in May 1974. However, to meet a uniform production schedule, the second stage for Vehicle 13 must be fabricated by February 1973. Allowing 5 months for acceptance firing tests and refurbishment, approximately 9 months of storage are indicated before it is needed at AMR. Vehicle 23, which is required for the same series of Mars mission launches, is launched in March 1975. Its second stage is required at AMR in September 1974. It is fabricated in March 1974. Allowing 5 months for acceptance firing tests, little or no time is required in storage.
- Storage times for other units will vary between these extremes.
- In a similar manner, it can be shown that storage periods for solid motors will vary between 0 and 9 months.

Other Mission Models — The other three mission models were not studied in detail. The model with a 3-ship Mars mission and a 50-man lunar base is similar to the mission model previously discussed, and manufacturing and Cape operations scheduling problems appear to be similar.

The mission model for the 4-ship Mars mission and 20-man lunar base, and that for the 3-ship Mars mission and 20-man lunar base both present problems in the 1978-80 time period. During these years, the launch requirements are from 50- to 33-percent lower than the average for the expected 10-year period.

This is a potential scheduling and production problem and will require additional study if these mission models appear desirable.

In all mission models, the Mars missions are generating the critical requirements for launch pads, production capacity, and storage.

### 3.3.5 Stage-Acceptance Static Test

#### 3.3.5.1 Introduction

All liquid stages (second stage and transtage) will be processed through an acceptance static firing test prior to release for flight. In the case of the second stage, all acceptance firings will be conducted at the Mississippi Test Facility (MTF). The transtage propulsion units will be static fired at the manufacturer's test facility. The primary purpose of conducting hot-firing tests on every liquid-stage is to ensure that all systems are, or will be, in the best state of readiness for launch missions. These tests also provide increased confidence in propulsion and system operations. It is assumed that the M-1 engines can be operated under sea-level conditions without altitude-compensating devices.

#### 3.3.5.2 Test Objectives

The overall objective of the acceptance-test program is to detect and correct any deficiencies related to performance of the stage while operating in the acoustic, thermal, and dynamic environment imposed by the engines.

#### 3.3.5.3 Test Operations

The second stage will arrive at MTF by barge and will be unloaded and transferred to the test stand. As soon as proper connections are made, checkout of power, switching circuits, and electronic and hydromechanical systems will be initiated. Completion of these activities will be followed by leak checks of the pneumatic and fuel systems and a check of all pressure switch settings.

Before static firing, a complete checkout of the electrical network, including RFI testing, will be completed. Although RFI and electrointerference tests will have been conducted during stage-assembly checkout at the assembly plant, it is recognized that the GSE-static test configuration may impose a different RF and electrical environment. Tests will therefore have to be conducted to ensure reliable equipment operation in the static test configuration. Leak tests of the $LO_2$ and $LH_2$ systems will be accomplished using $GN_2$ first, and then the $LO_2$ and $LH_2$. Gimbal cornering tests of the nozzles will be performed and the engine systems will be checked out.

After completion of stand, stage, and GSE checkout, a dry run of the static test will be accomplished. A short-duration (30 seconds) live firing will be conducted (short-duration tests will be eliminated as soon as practical). Following the

short-duration firing, all test data will be evaluated and the stage and stand will be inspected. After all corrective actions have been taken, the full-duration firing run will be made. The engine gimbals will be actuated to determine proper operation of the control systems and to evaluate thrust alignment. In addition, all electronic systems will be in operation to determine performance in the engine operating environment.

After the static firing, the stage will be secured, inspected, and functionally tested to determine stage integrity. The refurbishment requirements will be noted and if another static firing is deemed unnecessary by analysis of the data, the stage will be purged, decontaminated, and prepared for shipment.

### 3.3.5.4 Facilities

NOVA liquid-stage development and acceptance static testing will be performed at the Mississippi Test Facility (MTF). This facility is located 40 miles northeast of New Orleans on the Pearl River in Mississippi. The test facilities will be located in a test area approximately five miles square, which is surrounded by an uninhabited buffer zone of approximately 128,400 acres. First site-development and construction work will be for the Saturn static-test stands and supporting facilities. In addition, various administrative, supporting, and service buildings will be constructed that will eventually serve the entire MTF, including NOVA test operations.

Support buildings will include engineering, acoustical, electronics and instrument laboratories, site maintenance buildings, automotive shop, inflammable materials storage, warehouses, telephone and emergency services, central control, and data handling facilities. Central propellant receiving and storage facilities and high-pressure gas-compressor buildings will also be constructed to supply the requirements of all test programs.

A canal system will be constructed on the site, and several miles of river channel will be improved to permit delivery of all vehicle stages by barge from the manufacturing facility to their respective test stands. The canal system will also provide access for propellant transfer barges between the central storage areas and the test stands. A navigation lock, which provides access between the Pearl River and the canal system, will closely control the water level in the canals. A bascule bridge will be constructed on the canal side of the lock to provide access into the test site for vehicular and rail traffic from the south.

All canal lock and bridge traffic will be controlled from a central control building. Both the lock and the bridge must be initially constructed with sufficient clearance to permit passage of the NOVA second-stage barge. Preliminary investigation of barge requirements indicates that it will have a beam of approximately 100 feet and a length of 230 feet.

3.3.5.4.1 NOVA Static-Test Site

The tentative MTS test area site plan is shown in Figure 3.3.5-1. As indicated on this plan, the NOVA test complex is located generally in the northeast area of the site and north of the Saturn and Advanced Saturn test complexes. However, for the T65 vehicle, test positions will not be required for the first stage, since it utilizes solid-propellant motors, nor for the transtage, since it will be static tested at the manufacturer's test facility.

The T65 test complex will consist of three identical test stands for second-stage development and acceptance testing, and one stand for testing of single M-1 engines. The test positions will generally be arranged as shown in Figure 3.3.5-2. Actual siting of the positions is not within the scopy of this study.

In addition to the test stands, the following facilities will be required at the test complex. In general, they will be similar to the corresponding facilities in the test complex for the S-IC stage of Saturn V.

Test Control Centers — The test control centers will be reinforced-concrete, one-story structures with a basement. These buildings will house equipment and personnel required to control, observe, supervise, and monitor the operations at each test stand.

Each center will contain a control room, a terminal room, a computer room, a crew ready room, and an annotation room. Support shops for electrical, communications, instrumentation, video, and camera maintenance will be included. Office and storage space will be provided as well as the usual service space required for electrical and mechanical equipment and janitorial supplies.

Data Acquisition Facility — This facility will be required as a centralized collection point for the NOVA test-facility data system. Data collected here will be sent to the MTF data handling center for processing and storage.

Instrumentation Towers — Two instrumentation towers will be required adjacent to each test position. Each tower will include:

- Platforms for remotely controlled TV and motion picture cameras and other test and recording equipment
- Flood lights to provide light on the test stage
- Ladders, catwalks, and vertical man-lifts.

Observation Bunkers — An observation bunker will be required adjacent to each test position. The bunker will be a protective enclosure from which test personnel can see test firings at close range.

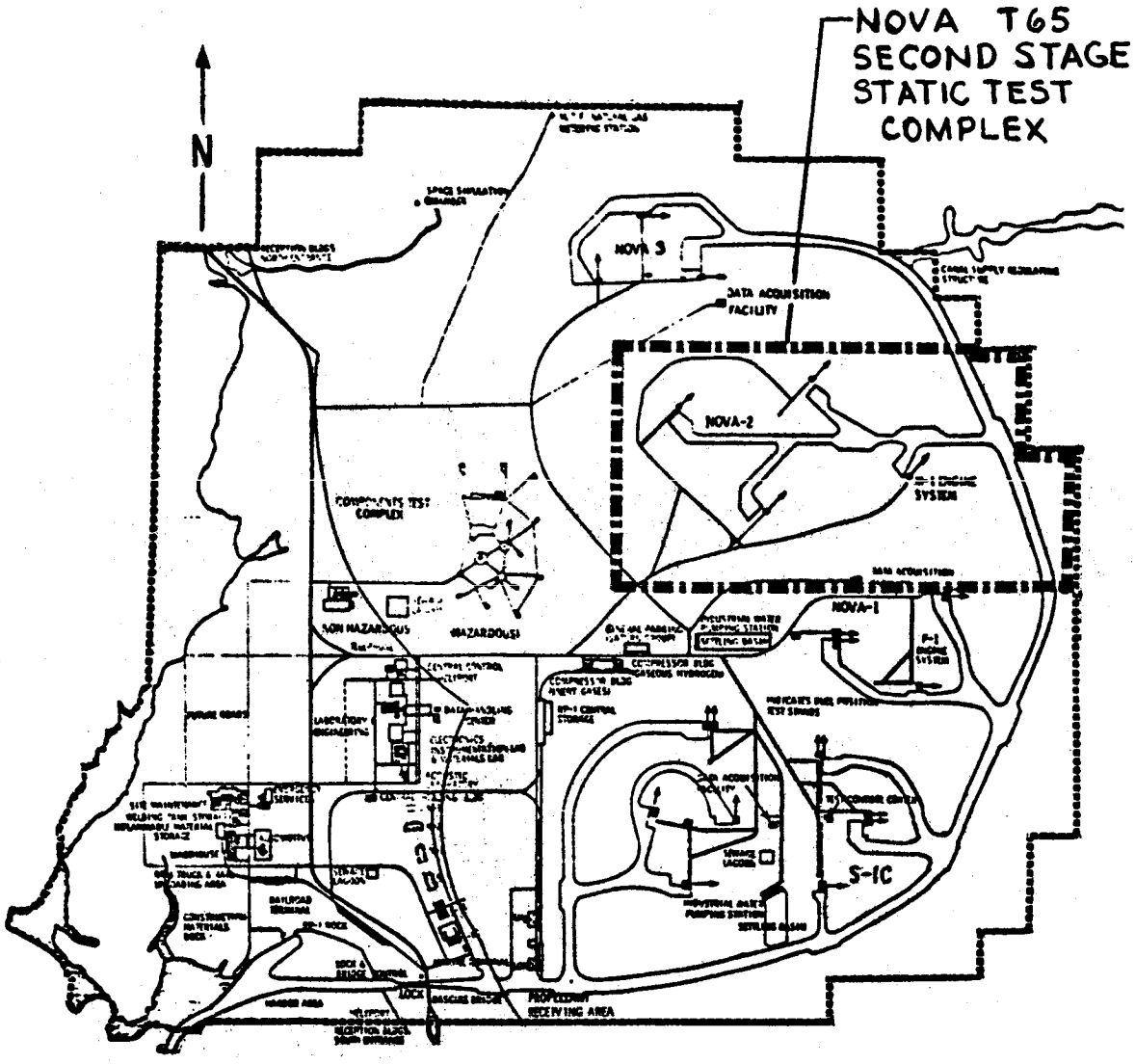


Figure 3.3.5-1 MISSISSIPPI TEST FACILITY SITE PLAN
Saturn and NOVA Grouping

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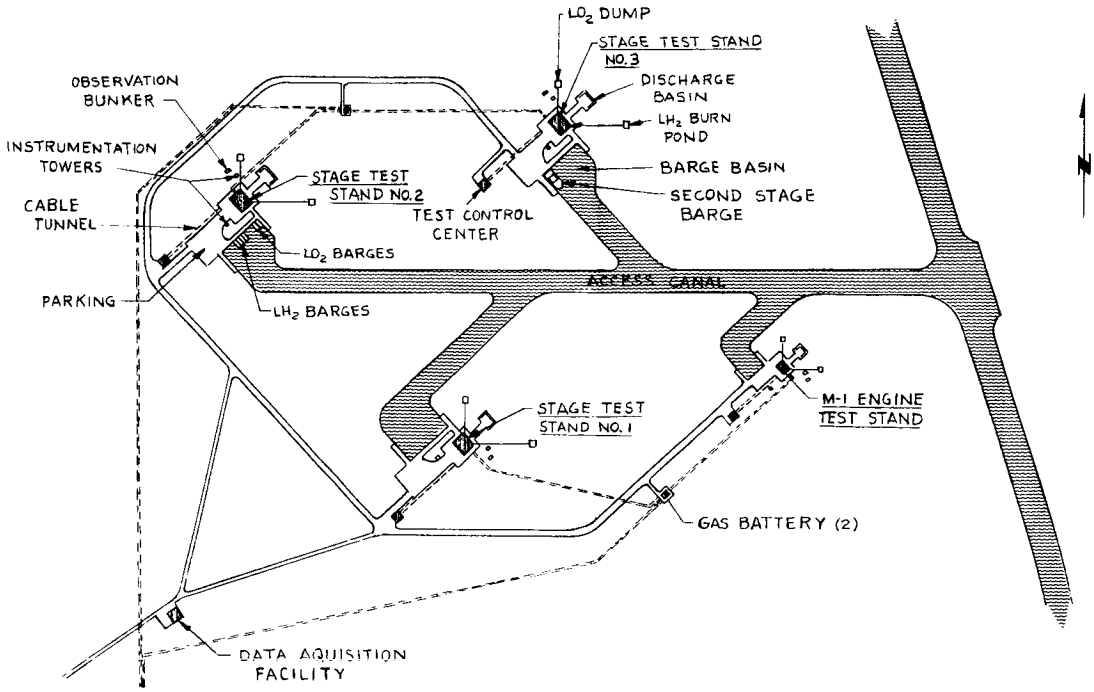


Figure 3.3.5-2 MISSISSIPPI TEST FACILITY
T65 Second Stage Test Complex

Test Communications — An operational system of communications facilities will be required within the test complex. This system will include intercoms and public address and warning systems.

Instrumentation and Test Control — A centralized instrumentation system will be provided. This facility will gather, condition, transmit, and present in usable form all data necessary for the checkout, calibration, and control of the second stage and associated functions and equipment during test operations.

Tunnels — Instrumentation tunnels will be provided to connect the test control centers and test stands. In addition to usage for instrumentation, data acquisition, control, and communications, the tunnel will be used as an emergency passageway.

Cryogenic Systems — Cryogenics required for the complex are liquid hydrogen ($LH_2$) and liquid oxygen ($LO_2$). These will be pumped directly into the second-stage tankage from supply barges moored near the test stand. For the M-1 engine test stand, $LH_2$ and $LO_2$ storage tanks will be constructed on the test-stand structure. Piping and equipment will be provided on the ground for coupling to the barge system, and for transfer of cryogenics from the barges to the stand. A gaseous hydrogen vent and burn system, emergency drains, $LO_2$ hold ponds, and $LH_2$ burn ponds will also be required at each test position, as well as exhaust-product discharge basins.

High-Pressure Industrial Water System — High-pressure industrial water will be required in the test complex for flame deflector cooling, test stand deluge systems, and propellant barge terminal deluge. This water will be supplied from a water pumping station and storage basin located near the test complex.

High-Pressure Gas Storage and Transfer System — High pressure air, nitrogen, and helium gases will be supplied to the test-stand complex from the MTF central-compressor buildings. Each gas system at the test complex will have the capacity for storing and supplying all second-stage and M-1 engine requirements. Piping, valving, filters, and controls will be required.

Electrical System — Primary electrical power must be supplied to the test complex. Electrical substations will be located in the test stands and test control center. Distribution from the substations will be 3-phase power at 120/208 volts, 277/480 volts, or 2300 volts as required to supply the load.

Special power equipment will be necessary. This will include regulated 60-cycle power, 400-cycle power, and a 28-volt d.c. system. Emergency power will be supplied by an engine-driven generator located near the test control center. This generator will provide standby power to the test stands and test control center for emergency air conditioning and lighting and critical control and instrumentation circuits.

Grounding System — Special grounding systems will be installed to eliminate or reduce the possibility of generation or retransmission of radio frequency interference in critical areas.

Transportation Facilities — Transportation facilities, including roads, canals and docks, will be provided within the complex. These will be used for land- or water-vehicle access to the test stands. Vehicle access to the M-1 engine stand, the test control center, and the gas storage areas will also be provided. Parking areas and paved hard stands will be provided as required. A complete docking facility, to include canal basin, dolphins, and mooring slips, will be provided at all test stands for mooring engine-delivery, stage delivery, and cryogenic barges.

Miscellaneous Facilities — Facilities for non-test-oriented systems will be provided within the test complex. These will include potable water, electrical and lighting systems, environmental control, sanitation, waste disposal drainage systems, fire protection, compressed air, communications, natural gas, and mechanical systems.

### 3.3.5.4.2 Second-Stage Static-Test Stand

A second-stage test stand is illustrated in Figure 3.3.5-3. It will be a single-position stand consisting of a reinforced-concrete substructure with two integral main-support piers, a steel-framed stage-support and thrust frame, a water-cooled single-direction flame deflector, and steel superstructure to support stage-handling crane and access platforms. Access will be provided to the engine turbopump area by a fixed platform. Access from below the engines will be provided by a rolling platform positioned on a cantilever support structure outboard of one main pier during hot-firing tests. A 20-ton derrick crane mounted on a corner of the same pier at the level of the rolling platform will raise or lower individual M-1 engines mounted in a handling-installer dolly.

Equipment for servicing, test and checkout, test control, thrust measurement, etc., will be contained on the stand and within rooms in the piers and substructure. The substructure will also contain water piping and control valves for flame deflector cooling and fire fighting. Personnel access to all working levels will be provided by elevators and stairways within the piers and by emergency stairs on their exterior.

The test stand will be rated nominally at 7,500,000 pounds thrust. However, the actual total thrust of the five-engine second stage on the stand will not exceed 5,175,000 pounds, since the maximum thrust developed by the M-1 engine at sea level will be only 1,035,000 pounds. A growth factor has been added to the actual values to arrive at the maximum design rating for the stand.

The second stage will be erected to a vertical position on the thrust frame supported at its four corners by the main piers. It will be mated at its lower interstage to an adapter ring on the thrust frame. The interstage will not be assembled

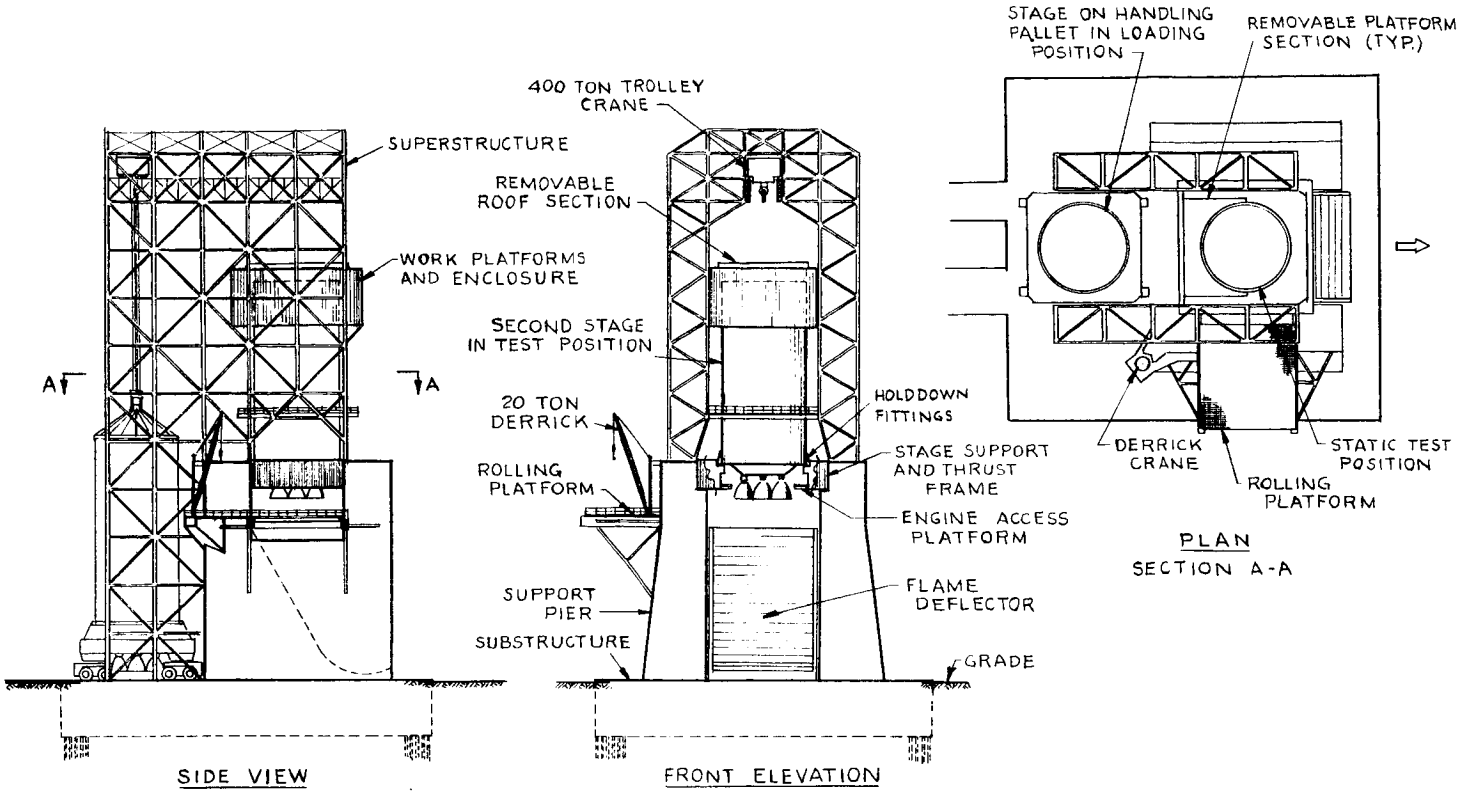


Figure 3.3.5-3 MISSISSIPPI TEST FACILITY
T65 Second Stage Acceptance Test Stand

to the stage for static firing tests, since it physically restricts the normal engine gimbal angular range and may be subject to damage during static testing.

The stage will be held down on the adapter ring by tension bolts passing through the outer flanges of a series of hold-down fittings. These fittings will be attached to the stage at the outside of its lower circumference and interstage mating channel during the initial assembly operation (see Figure 3.3.5-3). The fittings will be removed after static firing tests when the stage has been returned for refurbishment.

The adapter ring, hold-down provisions, test-stand thrust frame, and pier hold-downs must be designed for the following conditions:

| | |
|---|---|
| Second-stage net weight (static firing condition) | 595,440 pounds |
| Stage hold-down fittings | 3,600 pounds |
| Second stage weight empty (on test stand) | 599,040 pounds |
| Unusable propellants and gas residuals | 121,800 pounds |
| Stage weight at burnout (on test stand) | 720,840 pounds |
| Usable propellants | 8,064,000 pounds |
| Stage weight at ignition (on test stand) | 8,784,840 pounds |
| Maximum thrust at sea level | 5,175,000 pounds |
| Stage weight at burnout | -720,840 pounds |
| Maximum upward load on stage hold-downs | 4,454,160 pounds |

The maximum dynamic rebound condition on the stand would occur if all engines were simultaneously shut down immediately after achieving full thrust, assuming a full propellant load at start. Assuming further that 10 percent of usable propellant has been consumed at thrust termination, the downward load on the stand will change suddenly from 2,803,440 to 7,978,440 pounds — the increase corresponding to the full sea-level stage thrust of 5,175,000 pounds. The maximum load reversal on the stage hold-down mechanism will occur at stage burnout. At that time, the load will change from the net upward thrust force of 4,454,160 pounds to a downward load of 720,840 pounds — the difference again being equal to the stage thrust. Adequate dynamic load, growth, and safety factors must be incorporated in the test-stand design for these conditions.

The second stage, mounted on its pallet, will be brought to the test-stand area by barge, as described in 3.3.6.2.3. The barge will be moored and stabilized with its stern tied up to the dock to allow the stage and pallet to be rolled off by wheeled ground-transport units. One set of four such units is required at the test complex. These units will move individually to the different stands on the complex service roads to load and unload stages as required.

The stage will be rolled into position under the test-stand handling crane as shown in Figure 3.3.5-3. The protective covering will then be removed and

a lift ring will be installed on top of the stage by the handling crane. The lift ring will have been picked up from its handling dolly by the crane prior to moving the stage into position. The stage will be lifted vertically off its pallet high enough to clear the top of the thrust frame and then moved laterally into position, lowered onto the adapter ring, and secured in place with the hold-down fittings. The stage-handling pallet and protective material will then be moved to a nearby parking area. The lift ring will be returned to its handling dolly and this equipment will be parked alongside the pallet or moved to another stand, as required. The use of wheeled transporters rather than lifting the stage directly off the barge, permits use of the same barge to return the stage previously occupying the stand. The stage previously on the stand will be returned to its pallet and placed in the parking area. After the new stage has been installed and its pallet parked, the previous stage will be loaded on board the barge for the return trip to the manufacturing facility for refurbishment. Parking hard stands and fixed support piers must be provided for two pallets.

3.3.5.4.3 M-1 Engine Static-Test Stand

The engine test stand, nominally rated at 1,500,000 pounds thrust, will be used to trouble-shoot and evaluate engine performance for engines which perform unsatisfactorily during a stage static firing. The actual thrust developed by the M-1 engine at sea level will be 1,035,000 pounds. The stand will consist of a concrete substructure, support piers, and superstructure on which the engine will be mounted. A water-cooled flame deflector will be used, similar to the stage deflector, but much smaller in size. A rolling platform also similar to that used in the stage test stand will provide access under the base of the engine. A derrick crane with a capacity of approximately 20 tons will be required at the level of the rolling platform to lift the M-1 engine onto its vertical handling-installer dolly.

The stand superstructure will provide an overhead mounting attachment for supporting the engine on the stand. This attachment will have adapter fittings identical to the engine mountings on the stage thrust structure. The mounting attachments will accommodate both the center nongimbaling engine and the outer gimbaling engines. Fittings identical to those on the stage must also be provided for attaching TVC actuator cylinders. The gimbaling engine hydraulic power package is mounted integrally with the propellant-pump turbine-drive pad, and will remain with the engine during static testing on the engine stand. A ground hydraulic pumping unit with external cooler and filter, signal programmer, and power servos, and instrumentation similar to that which will be used during stage tests, will be required at the test stand.

A complete cryogenic supply and feed system must also be provided on the stand. This equipment will include insulated $LH_2$ and $LO_2$ storage tanks with vents, filling controls, filters, valves, and piping between the tanks and supply connections at the cryogenic-barge mooring docks. Supply lines from the cryogenic tanks to the engines should include prevalves and pressure-volume

compensating ducts identical to stage flight hardware. A cryogenic feed pressurization system must also be furnished on the stand. Equipment in this system will include tank-vent valve controls, pressurizing gas supply pressure regulators, pressure transducers, diffusers, and supply and sensing lines.

Engines mounted on handling-installer dollies may be brought to the stand from any stage-checkout stand via connecting access roads. The engine will be positioned under the stand derrick crane. The engine and dolly will be picked up by the crane using a special handling beam and sling set. The engine will be placed on the rolling platform and wheeled into position on the dolly. The dolly will elevate the engine to allow connections to be made to the stand mounting attachment. Engines brought separately to the test site by barge may be off-loaded directly at the test-stand barge dock and wheeled into position under the crane.

### 3.3.6 Transportation

This section outlines the requirements for the transportation of major launch-vehicle components from the factory to the test or launch sites. Specific transportation equipment concepts that meet these requirements are described in sufficient detail to support cost estimates.

#### 3.3.6.1 Requirements

A maximum of five rocket cases per month must be delivered to the solid propellant manufacturer to satisfy program production requirements. Existing commercial tug and barge transportation appears to be the most feasible transportation mode to perform this function.

The transportation of the solid motors from the solid-propellant manufacturer to the solid-motor substage facility and from there to the Cape will be by special barge as described in the next section. These barges will be too large to use the existing intercoastal waterways. Commercial ocean-going tugs will be required to tow these barges. It appears likely that the Solid Propellant Facility will be located in either Dade County, Florida, or Camden County, Georgia. Port facilities and access waterways at AMR must be sized to allow the movement of these barges from the ocean to unloading facilities located near the Solid Motor Checkout Facility.

A preliminary analysis of transportation of the cross-beam structure indicates that when the structure is divided into two pieces (each section: 70 feet long, 32 feet wide, 15 feet deep) it can be transported from existing East or Gulf Coast facilities to AMR by existing commercial water transportation. However, special supporting and tie-down equipment will be required.

Other first-stage components and subsystems will be transported by conventional commercial carriers — road, water, rail, or air — as required.

The second stage is transported in the vertical position by barge. Clearance distances are:

- Vertical clearance = between 175 to 200 feet.
- Horizontal clearance = 105 feet at local obstructions.

Waterways into and around the Mississippi Test Facility must be planned and sized to meet these requirements. Since the manufacturing location is not specified, a limit of 10 days one-way barge travel time was assumed to determine numbers of barges required for system cost estimates. For optimum use of barges, schedules should be arranged so that return trips to the manufacturing plant always carry a tested second stage for refurbishment.

The transportation of the transtage propulsion units creates no new problem areas. These units can be transported by commercial water transportation. For the purpose of this study, the location is assumed to be within a 20-day one-way water transportation route.

Payload transportation problems are similar to those of the second stage with respect to width requirements. When the entire payload is transported vertically, its height is assumed to be lower than that of the second stage.

### 3.3.6.2 Transportation and Handling Equipment

The primary considerations that influenced the selection of transportation modes for the large-launch-vehicle components and the equipment for transporting and handling them are their size and weight. Water transport must be employed for movements of any appreciable distance. Land transport will be restricted to short distances on special roadways within primary operational areas.

The largest vehicle components requiring special handling equipment are the first-stage solid motor and the liquid second stage. The handling concept for both of these involves the use of special fixtures which remain with them from the early manufacturing phase until they are finally erected in the vertical launch building at AMR. In the case of the solid motor, this fixture is a full-length strongback that supports the motor horizontally during subassembly and transport, and is also used to rotate the motor to the vertical during final erection. The liquid second stage is assembled and remains in a vertical attitude at all times, supported under its lower interstage interface by a handling pallet.

Special ocean-going barges will be used to transport the solid motors and second stages on their handling fixtures between manufacturing, storage, test, and launch areas. Identical ground transporter units will be located at all of these operational areas to load and unload the barge and to transport motors and stages within these areas. The transporter for the solid motor is a special

unit equipped with four tracked crawlers. This vehicle is also used with a heavy lift crane to rotate the motor in its strongback to the vertical for erection on the launch pad. The second-stage transporter consists of a set of four 4-wheeled semi-independent tractors that engage the four corners of the handling pallet. After operations in the stage checkout building at AMR, the stage, mounted vertically on its handling pallet, will be rolled into the launch building. There the stage will be lifted off the pallet for final erection. The strongbacks and pallets will be returned by the special barges to the manufacturing areas for recycling.

Other large components, such as the first-stage clustering structure, solid-motor nozzles and skirt extensions, interstages and transtages, will be handled by special dollies and will be transported by commercial ocean shipping or barges.

### 3.3.6.2.1 First-Stage Solid Motors

The handling concept developed for the first-stage solid motors is based on the strength limitations of the motor itself, as discussed in 3.2.8.6.4.8. Analysis of the motor strength showed that it could not support its own weight in bending when simply supported at its ends. Also, it was shown that when supported on two intermediate supports it could not sustain the concentrated lateral bearing loads at the supports even though it would be adequate in bending. It was found that to support the motor on individual supports, a minimum of seven supports would be required. These supports would have to be unyielding; that is, they could not be allowed to deflect under load. Clearly, this condition could not be met and still allow transportation and handling of the motor.

Several alternate solutions to this problem were considered before a final concept was selected. The first alternate was to increase the motor-case thickness to provide the necessary stiffness. To provide an adequate margin of safety would require a case thickness approximately three times the thickness required for flight conditions. Such a thickness would almost triple the first-stage inert weight, with consequent decrease of payload capability of the overall vehicle. The payload decrease would be approximately 40 percent after all feasible compensations, such as increased chamber pressure, were included. Such a large payload degradation is clearly unacceptable.

The second alternate was to pressurize the motor internally to stabilize the motor case. Preliminary calculations indicated an internal pressure of approximately 600 psia would be required to provide an adequate margin of safety. Such a pressure would necessitate treating the motor as a pressure vessel with all of the time-consuming and costly safeguards required. Also, the material used in the motor case must be treated as a brittle material under these conditions, thereby complicating the handling problem even more. Furthermore, the effects of such pressurizing on the propellant grain are not well understood. It is possible that grain damage would result from these conditions. Therefore, this alternate is not considered acceptable.

The third alternate was to fabricate the motor in two segments, with the segments being mated during assembly on the launch platform. Providing a joint in the motor would increase the inert weight of the first stage by a small amount with consequent minor payload-capability degradation. The extra assembly steps required, together with joint-testing requirements, would significantly increase pad-occupancy time. Segmenting of the motor would also slightly decrease the reliability of the vehicle. This solution, while feasible, was not considered for this study because unitized motors had already been selected for the preliminary design vehicle. However, further investigation in this area is desirable.

The fourth alternate was the use of a strongback to provide sufficient stiffness and support-load distribution to overcome the strength limitations of the motor case. This solution will overcome the defects of payload degradation, reliability degradation, and damage to the propellant grain noted in the first three alternates. The strongback will be a large heavy structure that will increase the required load-carrying capacity of motor transporters and handling equipment. However, it does not penalize the performance of the vehicle in any way and was chosen as the best solution. The motor handling and transporting plan was, therefore, developed on the basis of the use of a strongback.

Motor-case stiffness limitations are such that all handling and transportation operations from casting of the propellant to erecting to the vertical position immediately prior to installation on the launch platform will require the use of the strongback.

After casting and curing the propellant, the motor and strongback will be rotated to a horizontal position and located on semipermanent support structures. A crawler-type transporter will then be moved endways over the motor and, by means of lifting links attached to the strongback, used to pick up the motor and transport it through assembly, inspection, and checkout operations at the manufacturing area. When all manufacturing operations are completed, the motor will be positioned in its strongback on a barge and secured for shipment to the substage assembly facility. The crawler transporter will remain at the manufacturing area. It is planned that the transporters used at the manufacturing area, substage assembly facility, and launch site will be identical and that handling methods in these areas will be similar.

Strongback and Lift Ring — The strongback will consist of two stiff longitudinal beams, one on either side of the motor, with cross frames, shaped to the motor contour, between them. The cross frames will be spanned by closely spaced stringers. These will be covered by a cylindrical plate. The plate will be lined with a pliable bearing pad which provides the actual contact surface between the motor and strongback. The pad will facilitate distribution of the bearing load and prevent shear transfer between the strongback and the motor case. The conceptual strongback configuration is shown in Figure 3.3.6-1.

The strongback was sized and designed to restrict maximum centerline deflection of the motor within allowable limits when supported by trunnions at the nozzle

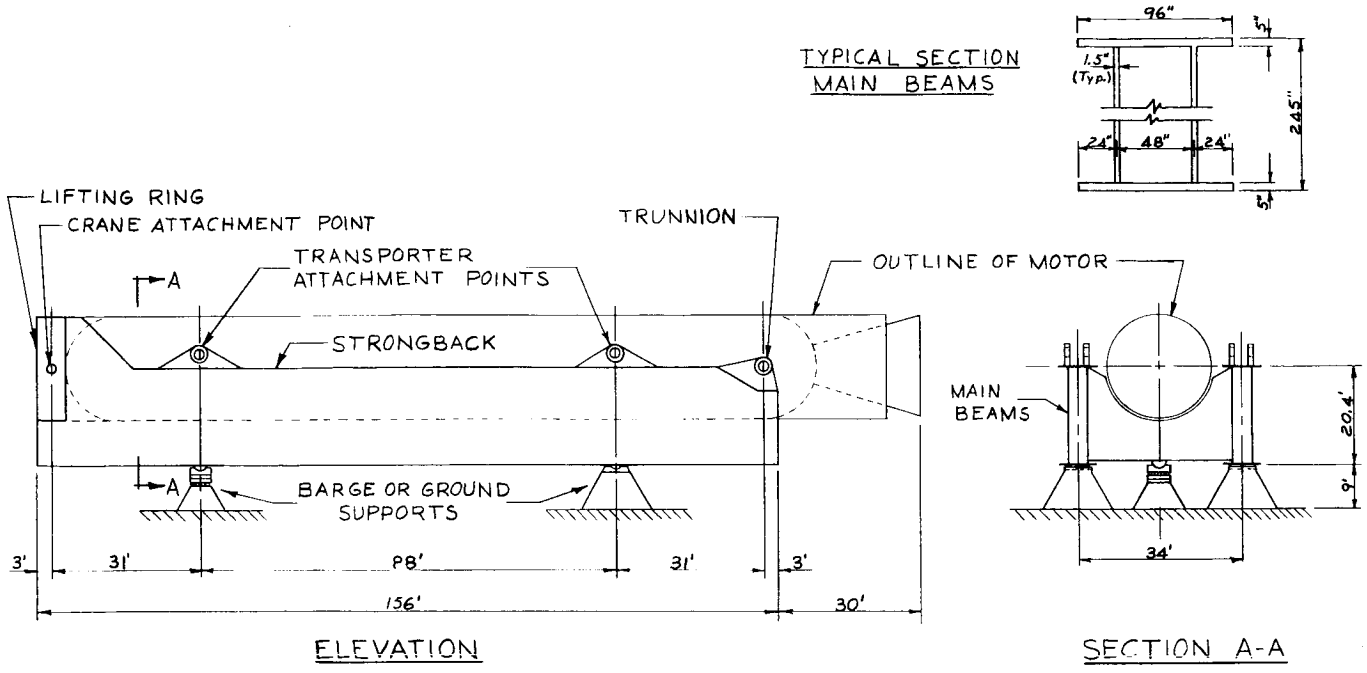


Figure 3.3.6-1 SOLID MOTOR HANDLING AND TRANSPORTATION STRONGBACK

end of the strongback and at the crane attachment points at the forward end. Design analysis included consideration of adequate margin of safety, deflections caused by the weight of the strongback, and contribution of the motor case to the stiffness of the motor-strongback combination.

For the beams shown in Figure 3.3.6-1, the margin of safety is 2.74, which is adequate for this support condition. This support condition will be realized only when the motor is being lowered from the vertical to the horizontal position after motor cure, and during final erection at the launch building. Under all other handling and transportation conditions, the strongback will be supported at intermediate points located as shown in Figure 3.3.6-1. The intermediate support points will provide a margin of safety greater than 3.0. The weight of this strongback is estimated to be 2.7 million pounds, with stress requirements such that low-carbon structural steel may be used for its construction. This weight represents only a preliminary estimate and may be decreased by refined detail design. These results do, however, show that the use of a strongback is a feasible solution. The term "margin of safety" is to be understood as meaning the ratio of the moment that will cause failure of the motor case to the moment existing in the motor case when resting in a static condition and includes dynamic loading effects and a factor of safety.

The support points on the strongback include those for crane attachment, pickup and transporting by crawler transporter, and stationary storage and barge transportation. The crawler transporter support points will be brackets attached to the top of the strongback beams, located as shown in Figure 3.3.6-1, and engaged by the lifting links of the crawler transporter. The stationary-storage and barge-support points, two at the nozzle end and one at the forward end, will be attached to the bottom of the strongback as shown in Figure 3.3.6-1. The three-point support arrangement was chosen as the simplest way of overcoming support-height irregularities without causing higher stresses in the motor case.

The motor lifting ring will be attached to the forward stub skirt of the motor case prior to casting the propellant and will remain attached throughout assembly and transportation until after the motor has been installed on the launch platform. The lifting ring will support the weight of the motor through direct bearing in all cases where the motor is in a vertical nozzle-end-up position. When the motor is installed in the strongback, the lifting ring will become a part of the strongback. During rotation to a vertical nozzle-end-down position and until the crane picks up the full weight of the motor, the lifting ring will carry the axial component of the motor weight to the strongback. When the motor and strongback are in a vertical nozzle-end-down position, the motor will hang suspended from the lifting ring supported by the crane and strongback. To remove the motor from the strongback, the crane will pick up the full weight of the motor, and the lifting ring will be detached from the strongback. The motor will then be moved laterally to clear the strongback and will be raised to its position on the launch platform by the crane. Some type of

auxiliary structure will be required to stabilize and support the strongback during removal of the motor and until it is returned to the horizontal position.

After the lifting ring is detached from the motor, it is returned to the strongback, and the strongback is rotated to the horizontal, and transported to a barge for return to the manufacturing area.

Permanent or semipermanent support pedestals will be provided at each place where a motor and strongback will be stored in the manufacturing, assembly, and transportation line. The pedestals will be movable at locations, such as the launch building, where movement is desirable for handling convenience. At other locations, such as storage areas, the pedestals will be permanently fixed. In all cases, the pedestals will require special high-capacity foundation structures.

Land-Transport Crawler — The motor and strongback will be handled on the ground by a crawler-type transporter. This transporter will also be used to support and maneuver one end of the strongback while rotating the motor from the horizontal to the vertical position. The transporter will include four crawler units provided with hydraulic cylinders to provide load leveling and vertical-lift capability. The crawler units will be self-propelled and steerable. The transporter used at the manufacturing, assembly, and storage areas will be identical to the transporter to be used at the launch site. The transporter is illustrated in Figure 3.3.6-2.

The "trunnion pickup arms" shown in Figure 3.3.6-2 will engage the nozzle-end trunnions of the strongback to lift it clear of the support pedestals and walk it in as an overhead crane in the vertical launch building lifts the forward end to rotate the motor in the strongback to the vertical position. This procedure, which is illustrated in Figure 3.3.6-3, will be reversed to return the empty strongback to the horizontal position, and the transporter will then return the empty strongback to an empty barge for return to the manufacturing area.

To install the motor and strongback on the barge, the crawler transporter will lift them from the support pedestals and move them to the proper position on the barge and lower the strongback on the barge support points. The crawler transporter's lifting links will then be disengaged and the transporter will be driven off the barge. The procedure will be reversed to remove the motor and strongback from the barge.

Water Transport Barge — The solid motor and strongback will be transported from the manufacturing storage area to the launch site by means of a special barge. The water transportation route will include access canals and open-sea environments; therefore, the barge must be designed as an ocean-going barge with provisions for withstanding possible ocean storms. The draft of the barge will be maintained as required for inland canal operations. The barge will not be self-powered, but will contain an auxiliary powerplant to provide

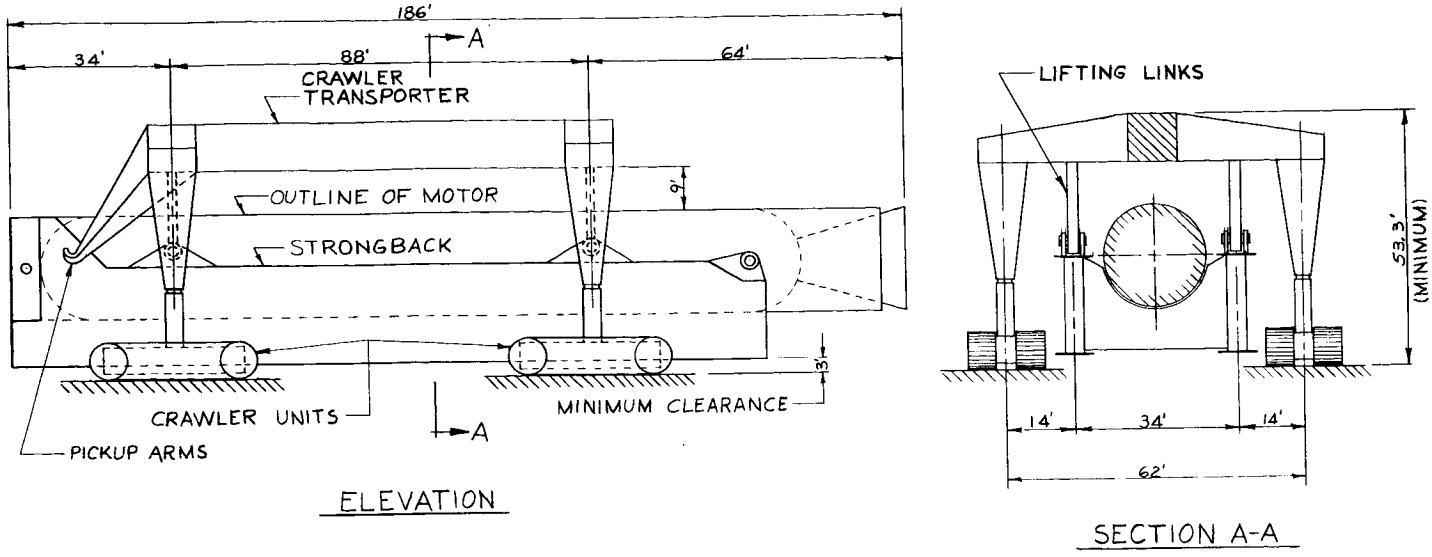


Figure 3.3.6-2 SOLID MOTOR CRAWLER TRANSPORTER

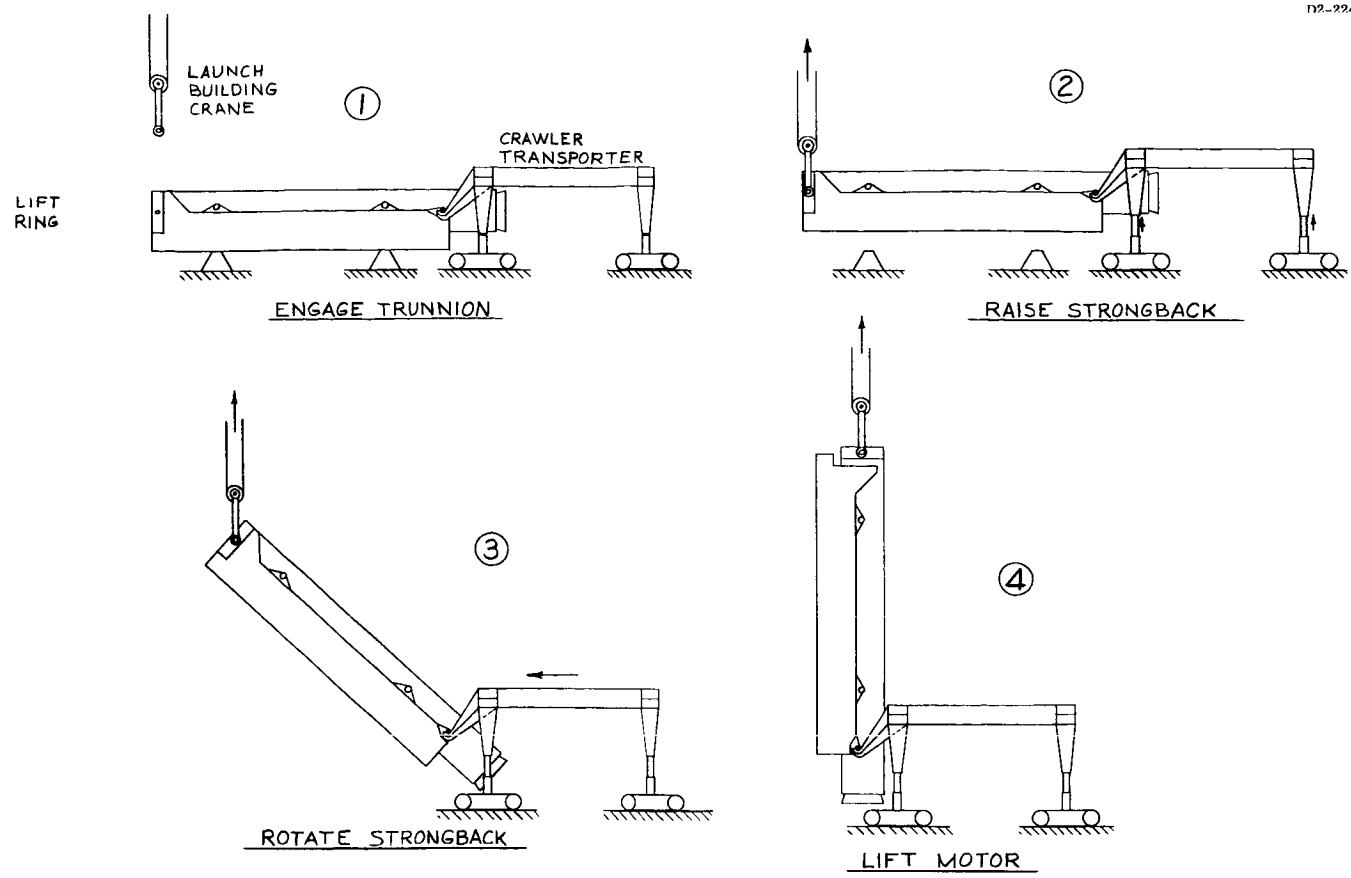


Figure 3.3.6-3 SOLID MOTOR ROTATION SEQUENCE

for utilities, ballast-pumping equipment, and solid-motor environmental protection. The barge will be manned to provide for equipment maintenance and control while under way and will have living facilities for the number of men required.

The barge will be essentially a hollow hull as shown in Figure 3.3.6-4. The main longitudinal strength members will be rigid beams on either side of the cargo well that will provide longitudinal strength for the barge and support for the crawler transporter as it moves onto the barge to load or unload the motor and strongback. The support points, two at the nozzle end and one at the forward end, will have limited rotational and translational capabilities so that the bending and twisting of the barge in a seaway will not cause significant stress in the motor case. Provisions will be made to secure the strongback to the barge so that it is stable on its support.

The barge will be provided with water-ballast compartments and pumping equipment to allow the barge to be sunk onto continuous submerged piers at the loading and unloading slips. This system will stabilize the barge during the loading and unloading operations. The ballast system will be available for use underway, as required by load and sea conditions.

Environmental Protection and Control — Environmental protection and control for the solid first-stage motor during transportation will be provided by enclosing the motor with an insulated structure attached to the strongback. This structure will be of lightweight, rigid, sandwich-type construction with the proper heat-transfer properties. The strongback will be insulated and fitted with clossures as required so that it will function as the environmental enclosure for that part of the motor that it surrounds. Environmental control will be provided by circulating conditioned air within the enclosure. The conditioned air will be introduced through plug-in connections to units provided on the barge or at selected storage locations.

### 3.3.6.2.2 First-Stage Cluster Structure

The first-stage cluster structure will be fabricated in two halves, which will be shipped to the launch area before assembly. The halves will be approximately 32 feet by 70 feet by 15 feet. Such dimensions will require special handling and transportation dollies. However, the weight of the cluster structure is relatively small. Therefore, the load capacity of the dolly will not be a problem. The size of the structure, however, will require shipment by commercial water transportation from the manufacturing areas to the launch area. A general-purpose barge will be used for this shipment. Special supporting and tie-down equipment will be required.

### 3.3.6.2.3 Second Stage and Interstage

The transportation concept for the second stage involves the use of a handling pallet. The pallet will support the stage through the final assembly and

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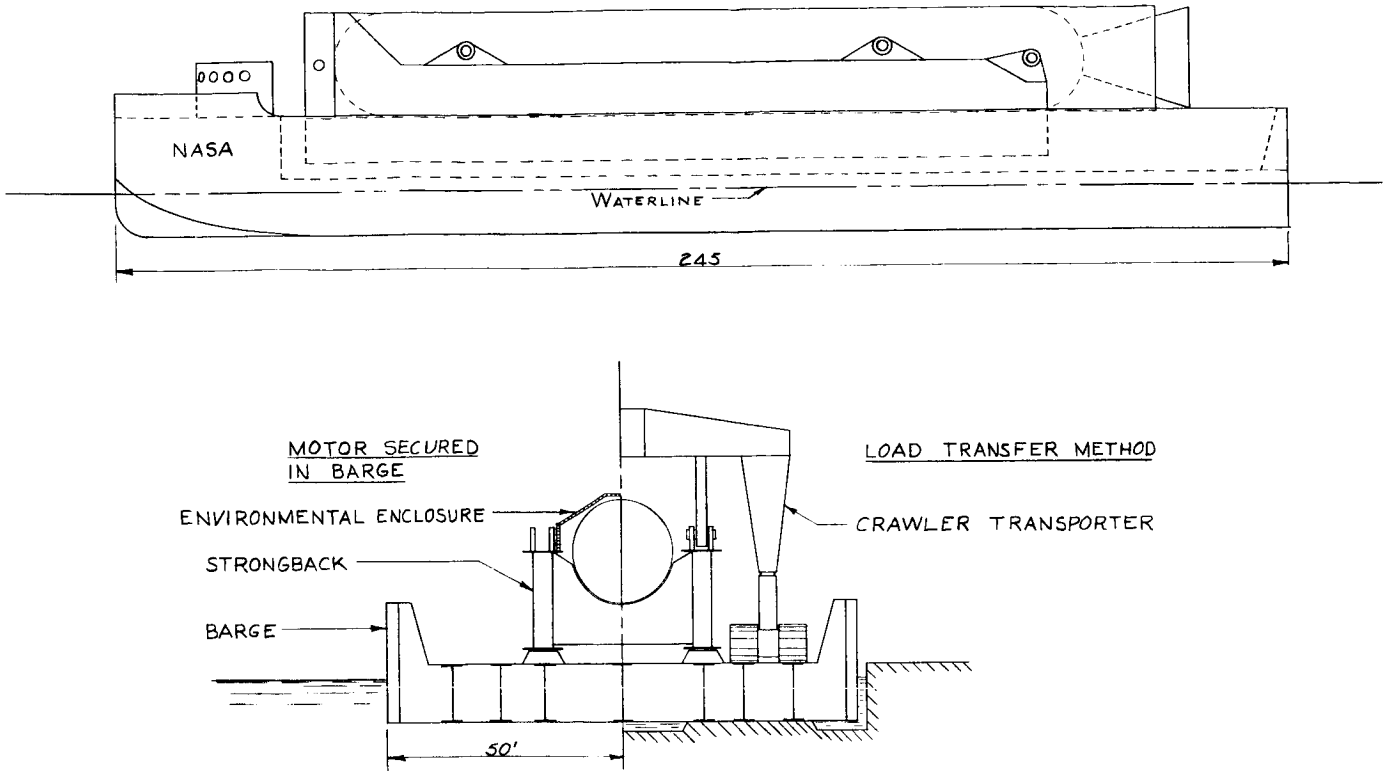


Figure 3.3.6-4 SOLID MOTOR WATER TRANSPORTATION BARGE

checkout process, transportation to and from the static test site, and transportation to and within the launch site. During all these steps, the stage will remain on the pallet except during static-test operations. All and transportation of the stage and pallet will be accomplished by pneumatic-tired, self-powered, ground-transporter units conceived by the Food Machinery Corporation. The pallet and transporter units are illustrated in Figure 3.3.6-5. All water transportation will be by special ocean-going barge, with the stage carried in the vertical position.

After fabrication, cleaning, and assembly, the stage structure will be mounted on its handling pallet in the vertical position. It will be supported at its lower interstage interface by an adapter ring, which will be an integral part of the pallet structure. The pallet will be supported under strong points by floor piers. After installation on the pallet, transporter units will be moved under and locked to the pallet at the corners. The pallet will then be raised off the piers and moved with the stage structure to an assembly area where engines and all stage subsystems will be installed. For this process, the pallet must be positioned high enough so that the engines can be installed from below, as shown in Figure 3.3.6-6. The engines, when installed, will project into a cut-out in the center of the pallet approximately equal to the stage diameter. The pallet and assembled stage will then be wheeled into a stage-integration area for checkout.

From the integration area, the stage will be moved to a dock facility for loading aboard a special barge, as shown in Figure 3.3.6-7. The barge will be moored at a loading dock with its stern butting against the dock pier. The stage and pallet will be rolled onto the barge from the stern, and positioned with the engines over a well. Four load-transfer cylinders or large screw jacks on the barge will lift the pallet off the transporter units, which will then be rolled off the barge. The pallet will be lowered to the barge deck and secured for transport. By using this procedure, both center-of-gravity height and overall height above water level will be held to a minimum.

The barge will be propelled by tug to the Mississippi Test Facility (MTF). Upon arrival at the test stand, the stage and pallet will be rolled off the barge by another set of wheeled transporter units and positioned adjacent to the test stand. From this position, the stage alone will be lifted by an overhead crane to its position on the stand. The pallet and wheel units will be moved to a parking area until required. After testing, the stage will be replaced on the pallet and returned to the manufacturing area where it will be refurbished and prepared for shipment to AMR.

The same equipment and procedures will be used to transport the stage to AMR. Identical transporter units will be used to move the stage, on the pallet, to a stage checkout building. From there, the stage and pallet will be rolled into position within a vertical launch building. An overhead crane within the building will lift the stage from the pallet and position it on top of the first stage. The pallet will then be placed aboard an empty barge for return to the manufacturing area.

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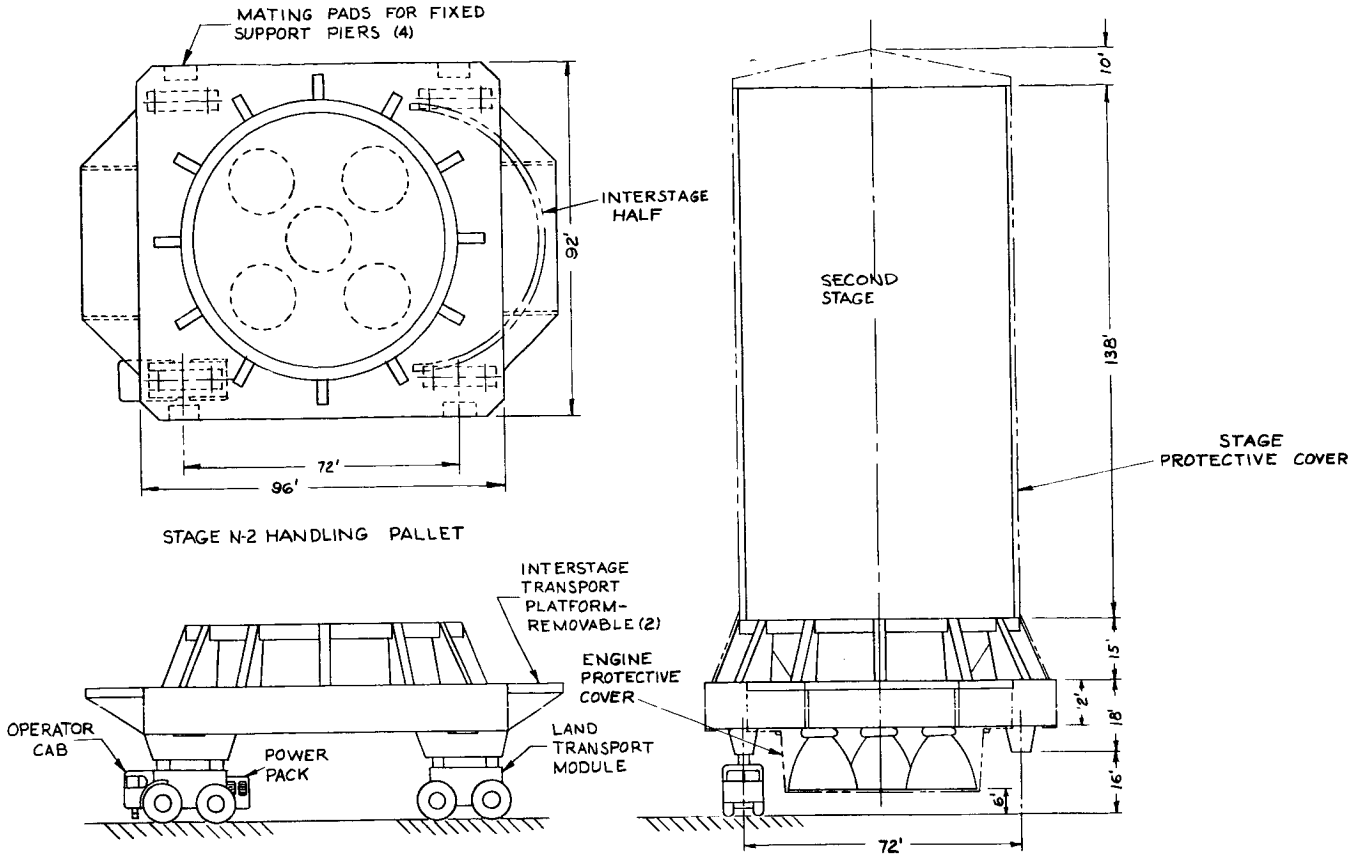


Figure 3.3.6-5 SECOND STAGE LAND TRANSPORT

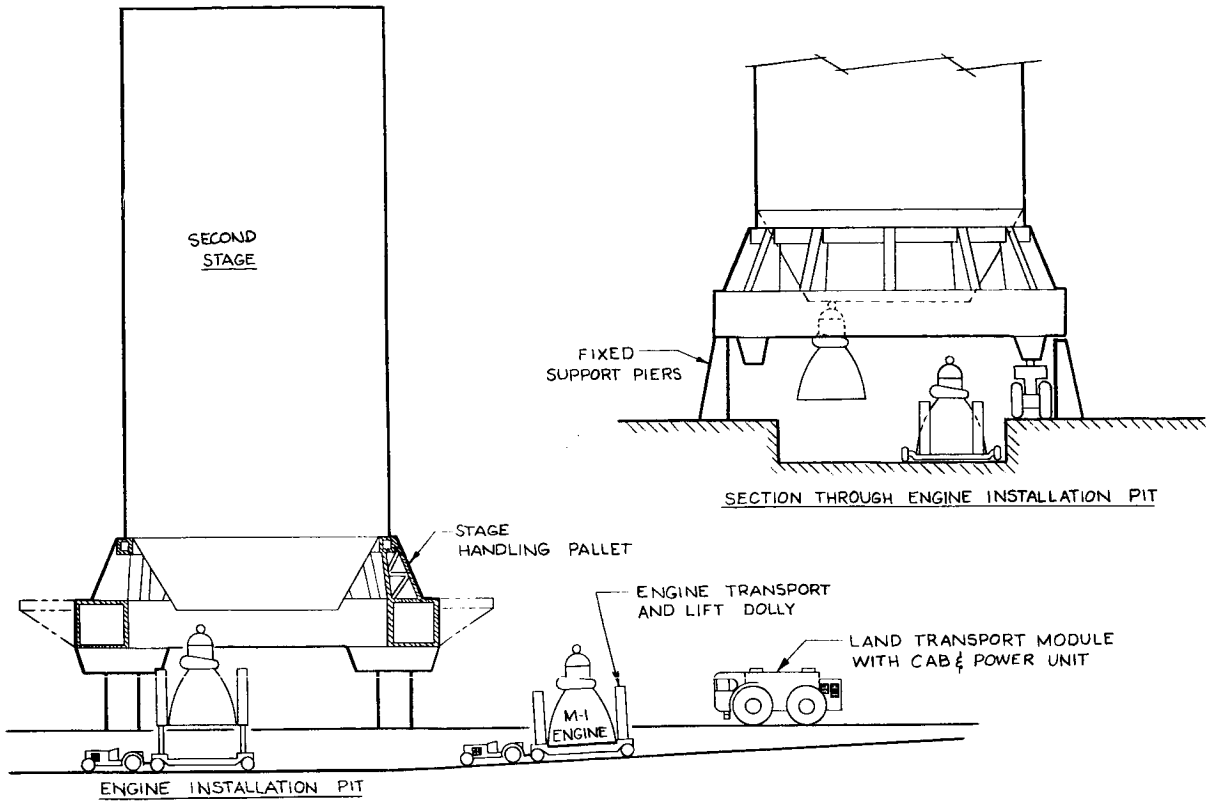


Figure 3.3.6-6 FACTORY HANDLING AND ENGINE INSTALLATION
Second Stage

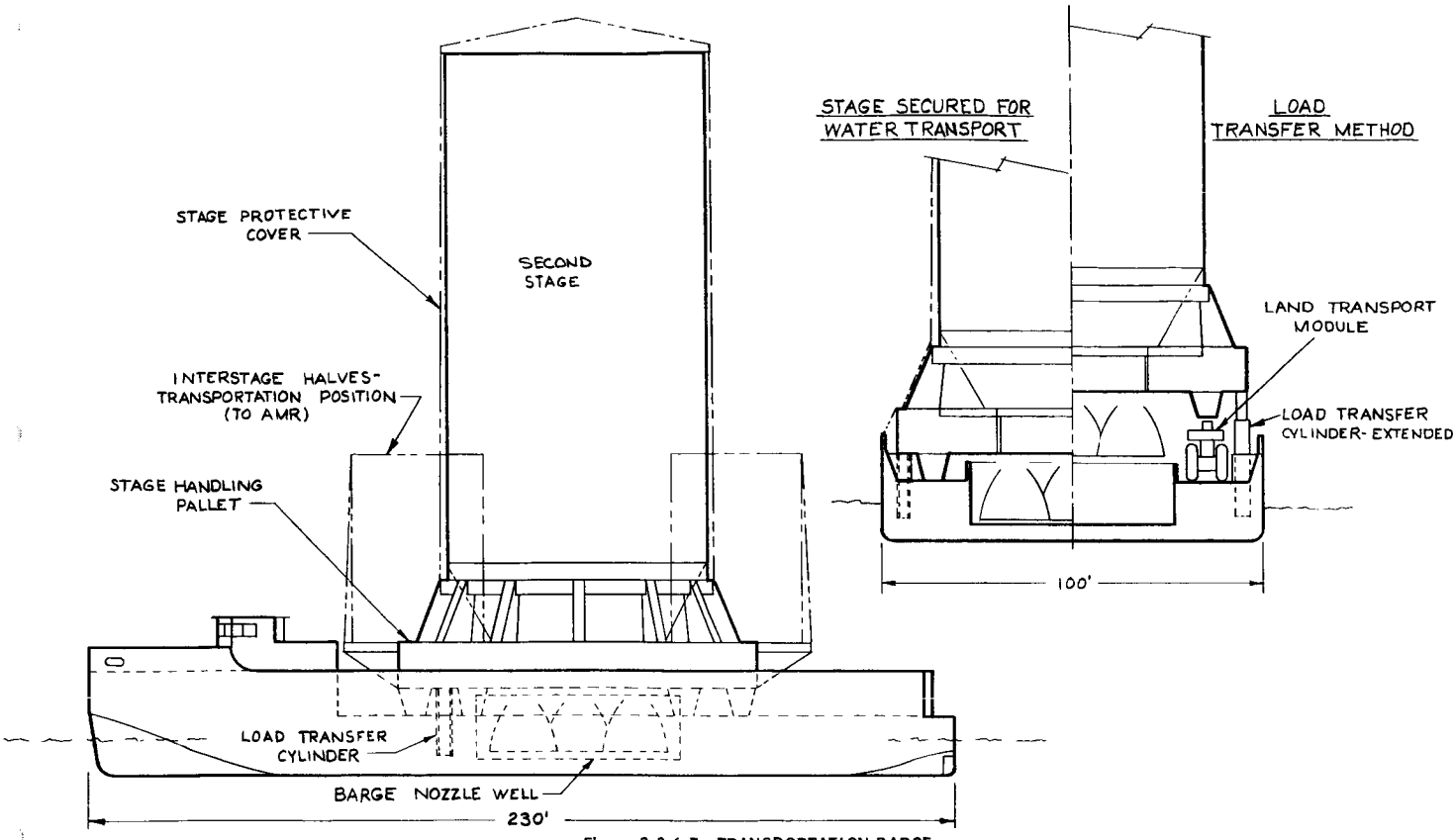


Figure 3.3.6-7 TRANSPORTATION BARGE
Second Stage

Stage Handling Pallet — The second-stage handling pallet will consist of a steel box-beam-type structure. A circular adapter ring will be attached to the top of the box-beam to provide continuous support for the stage along its lower interface. The structure will have an opening in the center large enough to permit clearance for the M-1 engines. Sufficient clearance will be provided to allow full gimbaling of the nozzles while on the pallet.

The box-beam will be provided with support points to mate with the wheeled transporter units and fixed floor-support piers. The support points will provide a structural connection between the pallet and the hydraulic cylinders of each transporter to form a stable rolling unit. The pier support points will not require such a connection.

Ground Transport Units — The ground-transporter units to be used for the second stage are pneumatic-tired units conceived by the Food Machinery Corporation. These units will provide load capacity and stability well within the requirements for transportation of the second stage. Rubber-tired units will provide flexibility of use and maneuverability exceeding that of any other system capable of meeting the load and stability requirements. The units were sized for the static weight of the stage and pallet plus overload due to a nominal 40-mph wind with a gust factor of 1.4. A dynamic load factor of 1.5 was used, giving a maximum design load per 4-wheel unit of 800,000 pounds. A total of four such units is adequate for this load at a maximum loaded speed of 1.5 mph.

The wheel units are powered by self-contained gasoline or diesel-electric systems. Power and steering control systems are designed to permit control of all system movements by one operator. Cross-control cabling with plug-in connectors will be installed on each pallet. This will allow a minimum turning radius of 200 feet with automotive-type steering and zero feet when all wheels are turned simultaneously.

Prepared high-capacity roadways with maximum vertical slopes of 5 percent will be required for all loaded operations.

Water Transport Barge — The second stage will be transported between the manufacturing area, the static test site, and the launch site on a special barge as shown in Figure 3.3.6-7. The routes require travel on inland canals, coastal waterways, and open sea. The barge will be designed with strength and stability to meet open-sea conditions but with a sufficiently shallow draft to move on inland canals. Overall barge dimensions are approximately 100 feet in beam by 230 feet in length.

The barge will not be self-propelled, but will have an auxiliary powerplant to provide for utilities, ballast-pumping equipment, load-transfer equipment, and stage environmental control. The barge will be manned while under way to provide maintenance and control for the equipment.

Sufficient ballast capacity will be provided to enable the empty barge to be sunk onto submerged support piers for loading and unloading operations. Underway ballasting capability will be included as required for stability of the empty barge.

The barge will be designed with two main longitudinal strength members, one on each side of the nozzle well. These members will provide longitudinal strength for the barge and support for the wheeled transporters when loading and unloading the stage.

Interstage Handling Equipment — The interstage structure, being a relatively light piece of hardware, will require no special handling or transportation equipment. It will be shipped from the manufacturing area to the launch site on the second-stage pallet along with the second stage. Removable platform extensions will be included on the stage-handling pallet when the second stage is moved to AMR, as shown in Figures 3.3.6-5 and 3.3.6-7. Provision for this additional use of the pallet can be made without interfering with its primary use. General-purpose dollies will be used to move the interstage structure around at the manufacturing and launch sites.

Environmental Protection and Control — Environmental protection and control for the second stage and the interstage halves will be accomplished by enclosing them in a flexible, membrane-type cover. A light, covered, metal frame will be secured to the top of the stage. The flexible membrane will be secured to the frame at the top, and to the pallet at the bottom. In addition, a membrance covering enclosing the five engines will be attached to the underside of the pallet. Additional protection will be provided during water transport by auxiliary coverings between the pallet and barge superstructure.

### 3.3.7 Launch Facilities and Equipment

#### 3.3.7.1 Introduction

The study of NOVA launch facilities required at AMR is being carried out under a separate NASA contract awarded to Martin-Denver. This study includes the derivation of cost information, which is presented in Section 5.3 of this report.

Martin-Denver was provided with detailed information on the T65 configuration and with cost estimates for stage-peculiar ground support equipment required at AMR.

A Martin-Denver report, "NOVA Launch Facility Study," NASA-CR-63-7, dated March 1963, covers NOVA facility requirements and costs in considerable detail. The information presented below is a partial statement of the launch facility features, described in the above report, for T65-type vehicles.

### 3.3.7.2 Summary

The hybrid launch facility concept has been selected for the T65 vehicle because analyses to date have indicated that this concept is the least expensive. For the T65-type vehicle, this concept is characterized by:

- Off-pad checkout of liquid second stage, transtage, and payload
- Off-pad assembly of second stage and transtage
- On-pad assembly and checkout of solid-motor first stage
- On-pad assembly of first stage, second stage-transtage combination, and payload.

The number of launch buildings required is a function of the maximum launch rate required for the Mars missions. Four buildings are required for the three-ship Mars mission and six buildings for the four-ship Mars mission.

Two types of launch control centers have been considered. One type is a soft installation using microwave data transmission links. The other is a hardened center connected to the launch building by hardlines. For the purposes of this study, Marin has selected a centralized soft launch control center for the four-launch-building complex. The six-building complex is provided with three hardened centers, each serving a pair of launch buildings.

### 3.3.7.3 Guidelines and Assumptions

#### 3.3.7.3.1 Site

- The launch facility will be located to the north of Complex 39 at the Cape. Off-shore launch facilities have not been considered.
- Launch pads should be spaced, if possible, such that uncontrolled (civilian) areas will not be exposed to more than 120 decibels of sound pressure or more than 0.2 psi overpressure (in case of an incident on the pad). However, these ground rules may be reconsidered if they are restrictive to vehicles that otherwise would be desirable.
- Launch pads must be placed so that they will not impose more than a 0.4 psi overpressure on the pads at Complex 39.
- The space vehicle must be protected by either separation distance or structural shell (building) so that it will not be exposed to more than 0.2 psi due to an incident on an adjacent pad.
- General-support areas shall be spaced so as not to be exposed to more than 0.28 psi or 125 decibels.

3.3.7.3.2 Mission

- The facility will be sized to meet the requirements of the manned Mars mission. A 6-month launch span has been used for the mission. Planned launch rates used to size and cost the facility are given in the mission models outlined in Section 3.3.3.
- Launch attempts are not required more frequently than once a week. No standby vehicle is required for simultaneous or next-day launch.
- The payload has been defined only to gross size limits. Consideration of special payload launch facility features has not been included.

3.3.7.3.3 Vehicle

- The space vehicle must be protected from the side pressures and flying debris associated with hurricane-force winds.
- The building is designed to provide for a 2.2-degree drift cone at launch under NASA 99-percent ground wind conditions (no gust).
- Liquid stages will use an autogenous pressurization system.
- The vehicle is capable of holding for 8 hours after propellant loading.

3.3.7.3.4 Operations

- Scheduled operations will be performed during normal 40-hour work weeks. Certain handling operations, launch operations, and behind-schedule operations are exceptions that will be worked during overtime.
- Unscheduled operations caused by malfunctions will be partially allowed for in the normal 40-hour week and partially on overtime. The estimated time will be split 50-50.

3.3.7.4 Launch Facility Concepts

Several launch facility concepts were considered for the T65 configuration. These concepts generally differ in the location of the checkout and assembly operations. The following three were the prime contenders:

- Hybrid — Off-pad checkout, on-pad assembly
- Mobile — Off-pad assembly and checkout
- Fixed — On-pad assembly and checkout

The size and weight of the T65-configuration solid motors plus safety considerations, dictate that they cannot be reasonably handled by the mobile concept. They are adaptable, however, to the fixed or hybrid concepts. Development of hoisting devices whose capabilities far exceed those of existing equipment is required. This extension of the state of the art is considered feasible.

The hybrid concept was selected over the fixed concept for development of cost data because analyses to date indicate the hybrid concept is the least expensive. Therefore, facilities and operations are described below only for the hybrid concept.

Figure 3.3.7-1 illustrates the functional flow of space-vehicle stages and cluster structure from receipt at AMR through launch. Facilities and operations involved in this sequence are described in more detail in 3.3.7.5.

The number of launch positions (buildings) required is a function of the maximum launch rate required by the manned Mars missions. Mission Models 1 and 2, as defined in Section 3.3.3 for the four-ship manned Mars mission, require six launch positions. Mission Models 3 and 4 for the three-ship manned Mars mission require four launch positions.

### 3.3.7.5 General Description

Figure 3.3.7-2 shows the general site plan for the NOVA launch facility. Four launch positions are shown as a typical example.

#### 3.3.7.5.1 Unloading Facility

Major components of the space vehicle are delivered to the unloading dock on ocean-going barges. Figure 3.3.7-3 shows a more detailed view of the unloading facility. The barges are positioned in slips and stabilized during the removal of stages and components.

Solid motors are received in the horizontal position cradled in strongbacks, Transporters are moved onto the barge to pick up and remove the motor-strongback combination. Because of the high weight of the motor and strongback, these transporters are crawler-mounted vehicles. Figure 3.3.7-4 illustrates unloading of the solid motor.

The second stage is received in the vertical position mounted on its handling pallet. Rubber-tired transporters lift the stage and pallet hydraulically, roll them off the barge, and move them to the stage checkout area.

#### 3.3.7.5.2 Solid-Motor Checkout Area

Solid motors are moved from the unloading dock to the solid-motor checkout area for receiving inspection, modification as required, and checkout of installed subsystems. Facilities are provided for temporary storage of the solid motors until they are required at the launch building.

#### 3.3.7.5.3 Stage Checkout Area

Second stages are positioned in one of the cells of the Stage Checkout Building (SCB). Figure 3.3.7-5 shows the SCB for the second stage (the large building

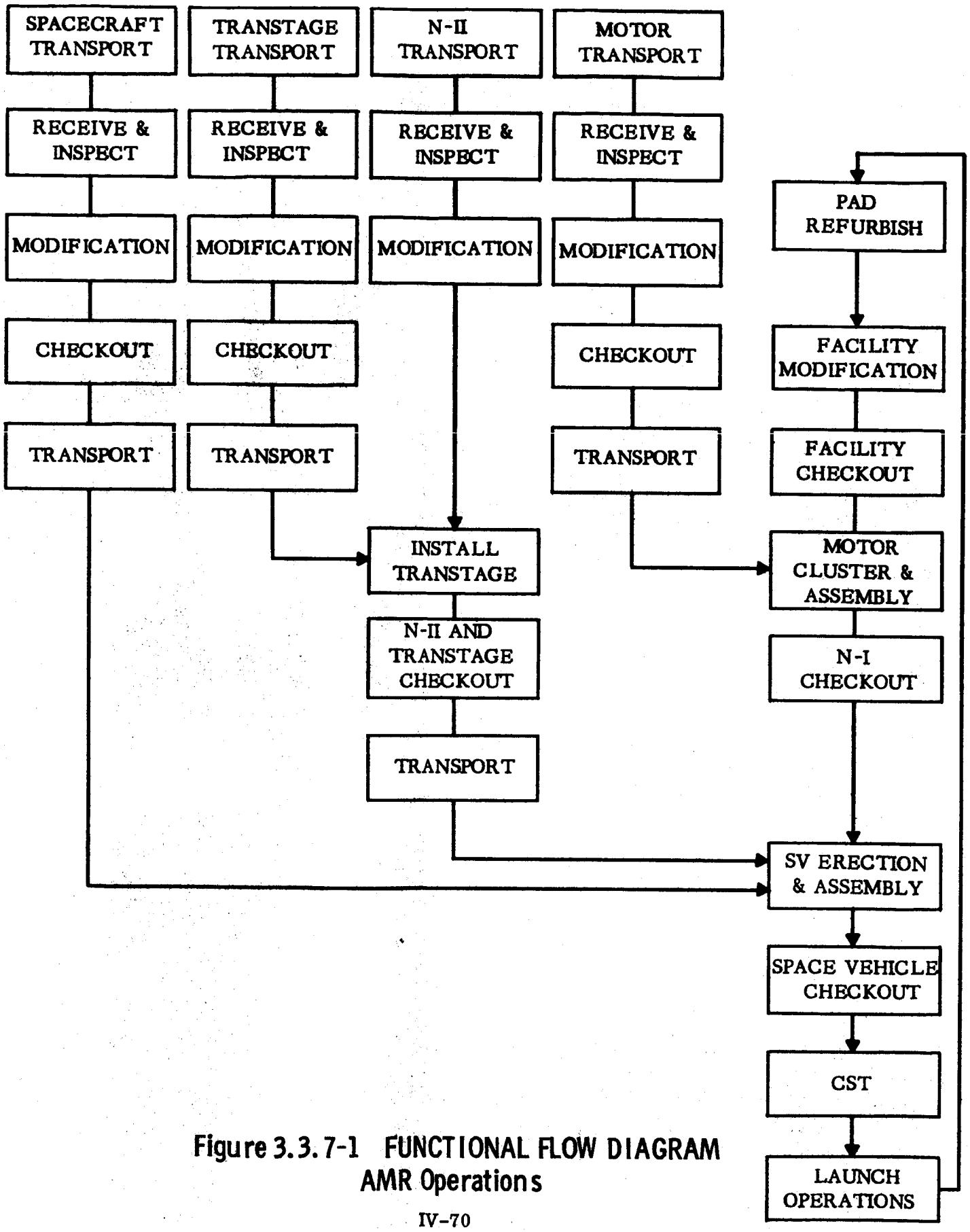


Figure 3.3.7-1 FUNCTIONAL FLOW DIAGRAM
AMR Operations

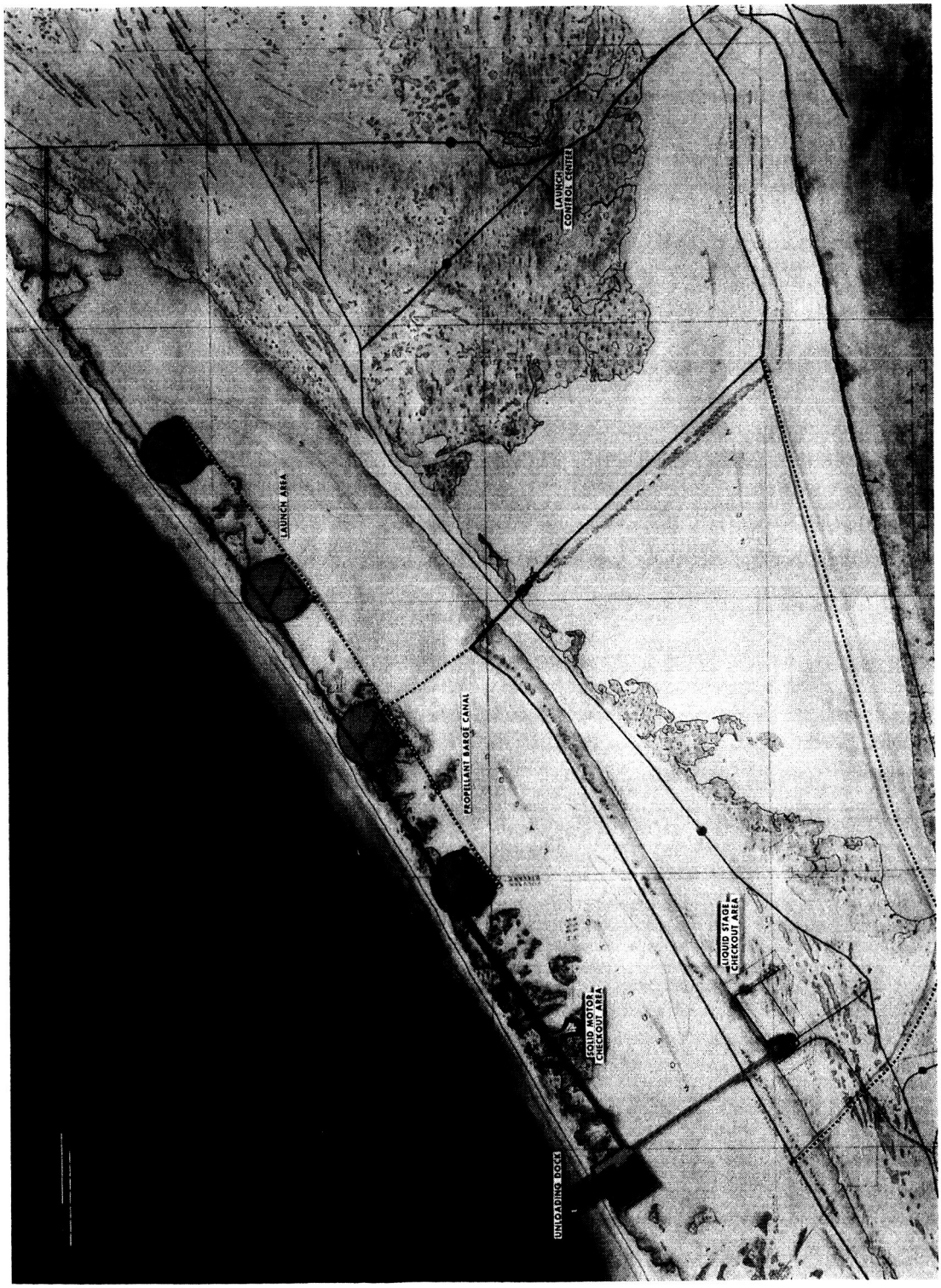


Figure 3.3.7-2 TYPICAL NOVA SITE PLAN

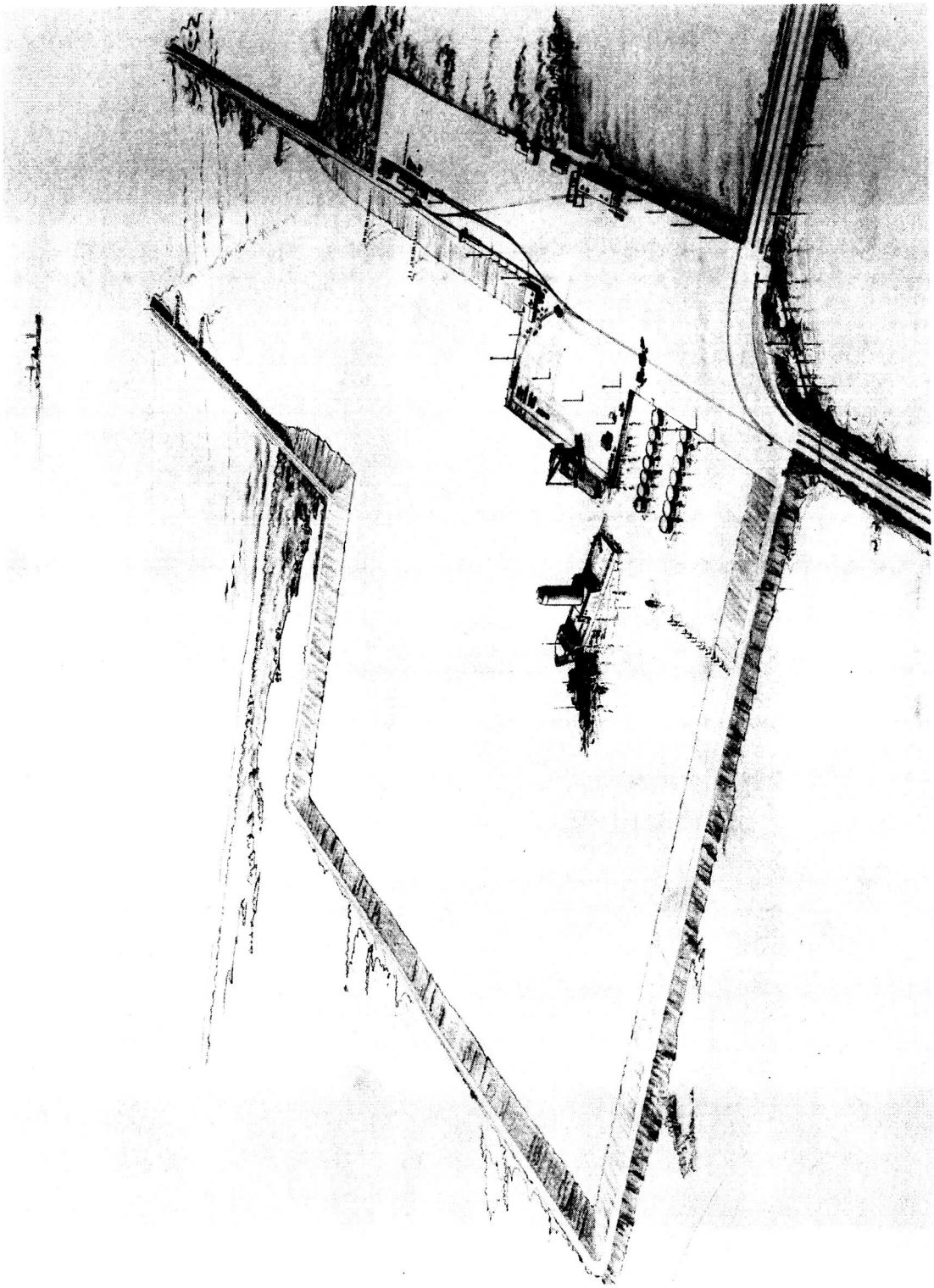

Figure 3.3.7-3 UNLOADING FACILITY

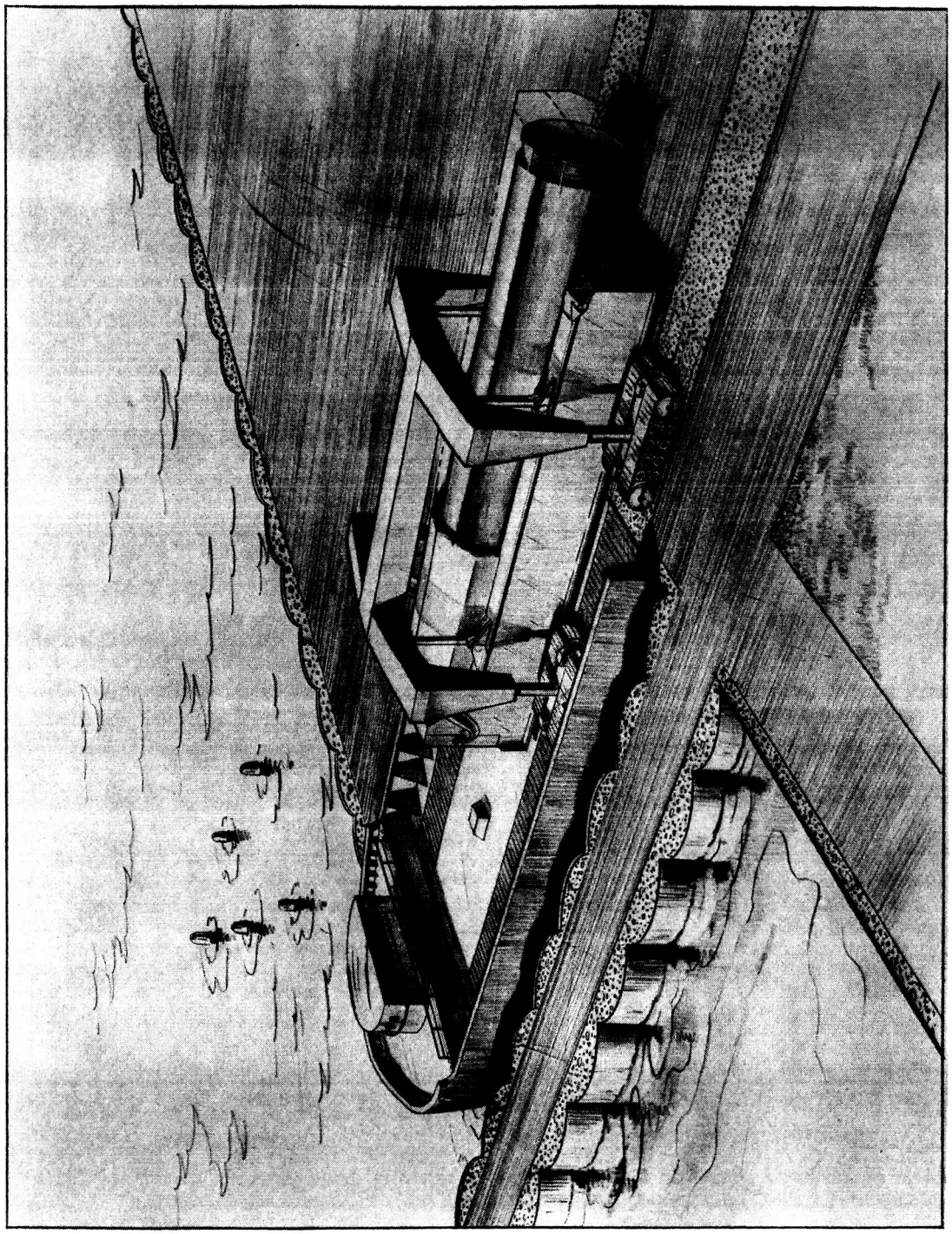

Figure 3.3.7-4 SOLID MOTOR UNLOADING

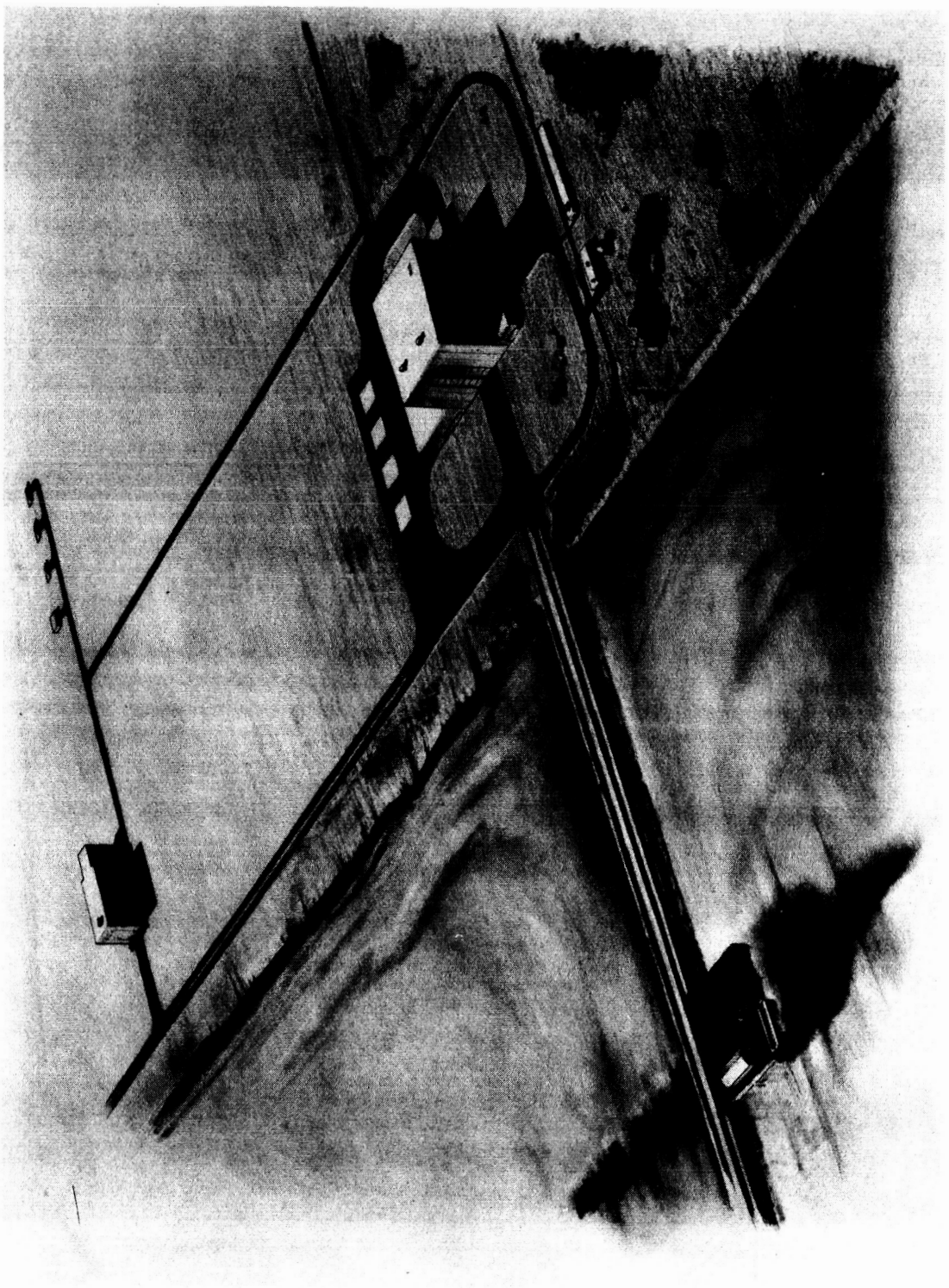

Figure 3.3.7-5 STAGE CHECKOUT FACILITY

in the foreground). The adjacent low-bay building is the SCB for the transtage. In the background of Figure 3.3.7-5 is a building for checkout of the spacecraft. The smaller structures are for storage of ordnance. General support buildings are also located in the area of the Stage Checkout Building.

The operations in the SCB area start with receiving. The stage is inspected and any modifications are incorporated. The stage is then checked out to ensure that it is ready for assembly with the other stages at the launch building. The checkout will include pressure tests, engine leak checks, gimbaling, and equipment functional tests as necessary to provide confidence that avoidable delays at the pad will be minimum.

SCB operations include one major assembly operation — the assembly of the transtage to the top of the second stage. Where appropriate, checkout operations are performed after this assembly has been made.

The stage checkout area also includes facilities for assembly of the first-stage cluster structure and the first stage-second stage interstage.

3.3.7.5.4 Launch Building

Figure 3.3.7-6 shows a close-up of the launch building. The design includes removable flame ducts and deflector and provides for internal erection and assembly of the vehicle. The umbilical arms swing into protected areas in the walls of the building at liftoff. The roof provides weather protection during erection, assembly, and checkout but is opened at the time of launch. The inside of the building is provided with an acoustic liner that is also designed to withstand (with a minimum of refurbishment) the temperatures expected during liftoff. The launch building will stand about 650 feet high and has an outside diameter of about 350 feet. The building is hardened to withstand peak overpressures that might result from an incident on an adjacent pad. For the four-building launch complex, the required hardness is 1.05 psi. For the six-building complex, the required hardness is 1.75 psi.

Space-vehicle assembly operations are started with the emplacement of the solid motors on the launch platform within the building as described in 3.3.6.2. After motor emplacement, the first-stage cluster structure is installed and assembly and checkout of the first stage is completed.

Space-vehicle assembly is completed with the installation of the second stage-transtage combination and the payload (spacecraft). The completed space vehicle is checked out as an integrated unit.

Finally, combined system tests are performed on the space vehicle-launch system combination and the space vehicle is ready for launch operations.

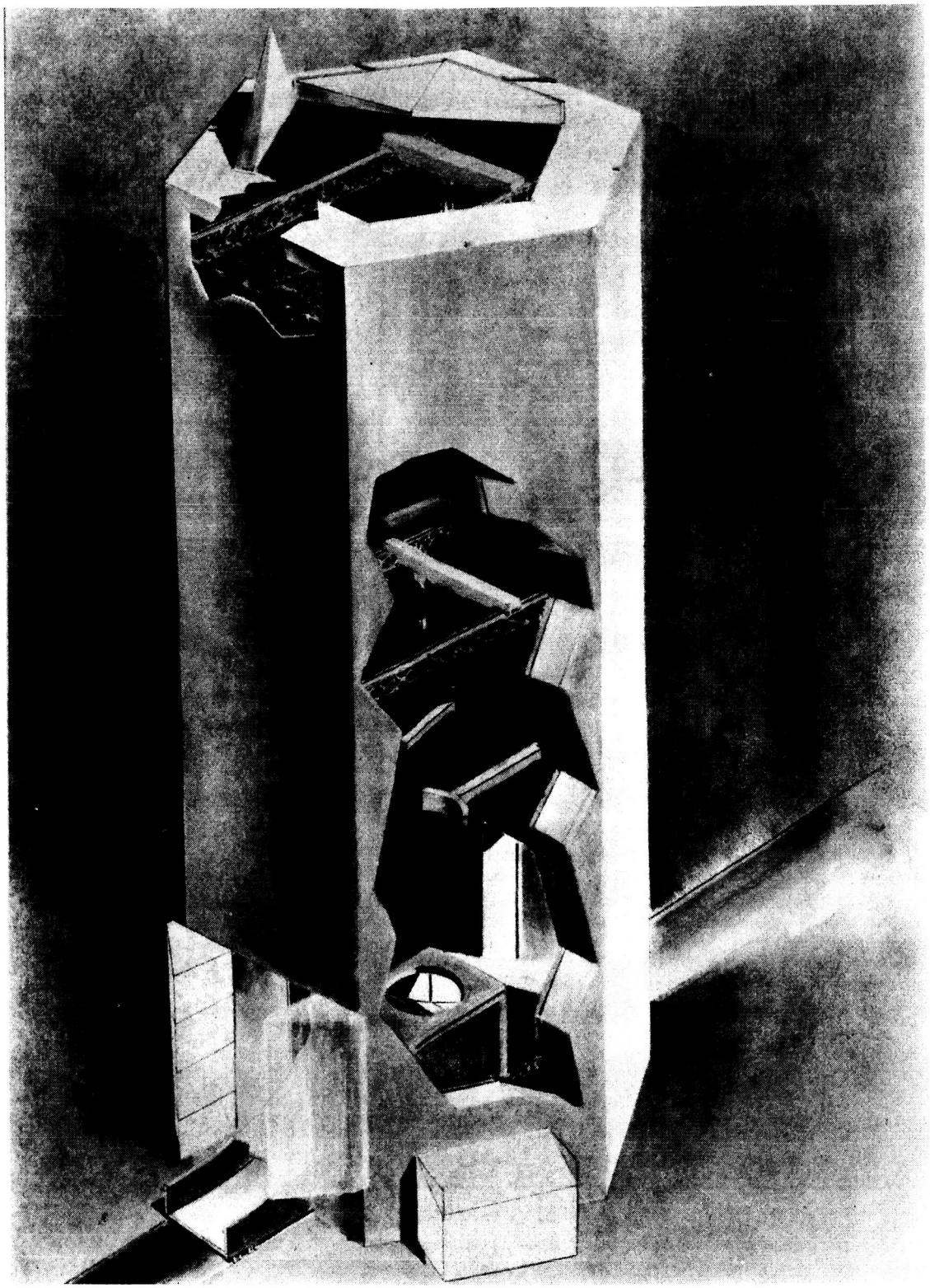

Figure 3.3.7-6 LAUNCH BUILDING

The launch area has a ring of instrumentation and service roads and a propellant storage system, as shown in Figure 3.3.7-7. Cryogenic propellants will be delivered to the area by an extension of the intracoastal waterway as shown in Figure 3.3.7-2. These propellants are then transferred from the barges to the pad-storage dewars, which are sized for the requirements of one launch. The dewars are refilled as subsequent launches are scheduled at the pad.

3.3.7.5.5 Launch Control Center and Range Facilities

Figure 3.3.7-2 also shows a centralized launch control center (LCC), which is located in such a position that it can conveniently use microwave transmission equipment with a minimum probability of interference. This centralized LCC is planned for the four-launch-building complex.

For the six-building complex one hardened LCC is planned for each pair of launch buildings. In this case, landlines will be used for data transmission between launch building and LCC.

The NOVA program will also require support from AMR range instrumentation stations. Since these facilities are already available, no extra facility costs have been included in the cost estimates. However, range operation costs are included.

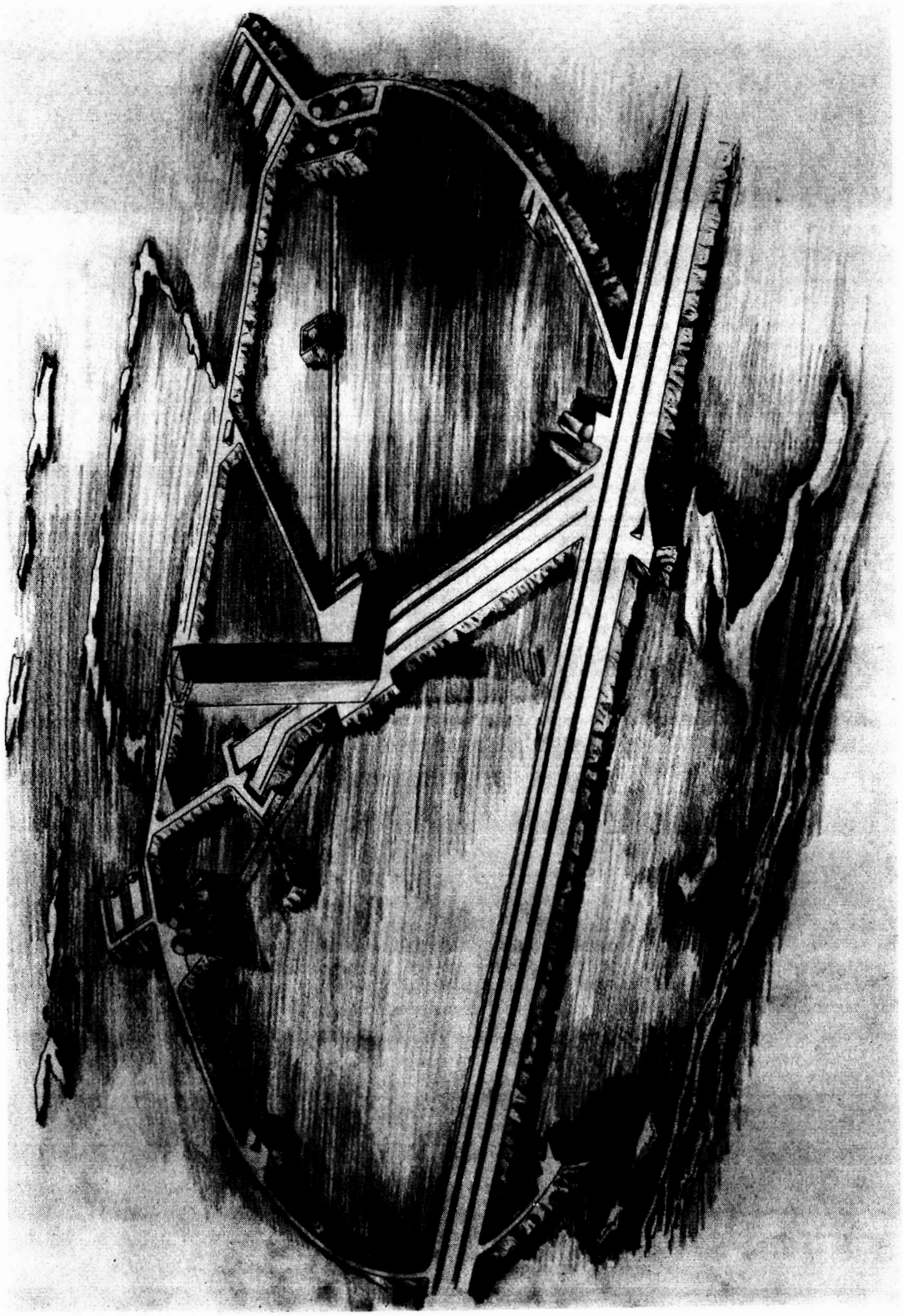

Figure 3.3.7-7 LAUNCH BUILDING AREA

## 3.4 MANUFACTURING AND FACILITIES

### 3.4.1 Manufacturing

Manufacturing studies were made of the T65D baseline vehicle to:

- Develop a feasible manufacturing plan
- Identify manufacturing technology problems
- Estimate production flow time
- Evaluate design producibility
- Estimate the magnitude of the manufacturing task

Items in the analysis are: engineering design, schedule and quantity of items to be produced, tooling, fabrication processes, assembly sequence, manpower skills, space, and equipment. Each item will be considered for the first and second stages only. The first stage is discussed in 3.4.1.3. The second stage is discussed in 3.4.1.4.

#### 3.4.1.1 Manufacturing Program Concepts for Baseline Vehicle

The manufacturing program for the baseline vehicle includes production of the structural components, motor cases, and nozzles of the solid first stage; the structural components of the liquid second stage; the interstage structure; the transtage structure; final assembly; installation of subsystems; manufacturing test of each stage; and refurbishment after static test of the liquid stage.

The individual stages will be produced at separate facilities. The interstage and transtage structures will be fabricated as part of the liquid-stage manufacturing task. Vehicle system components will be integrated on the launch pad at the Atlantic Missile Range.

During this study, manufacturing processes were selected that provide for minimum manufacturing development requirements, are practical, and will provide quality products.

It was assumed that the baseline vehicle would be manufactured as an integrated effort under a full-scale development program, followed by a continuing production program. Except for initial development, planning, and tooling, the manufacturing activities would take place at special facilities provided for the respective stages.

#### 3.4.1.2 Summary

This report presents a practical method of manufacturing the baseline vehicle. It indicates some of the major problems that must be overcome and presents an estimate of the magnitude of the task.

The manufacturing processes required to fabricate a majority of the detail parts for both stages of the vehicle are available now. Current lack of technology will be resolved in the recommended development programs. Essentially, parts fabrication will require an increase in the size and framework of manufacturing operations used currently.

The major problem in vehicle assembly and subassembly is the result of the size of the structures and the tooling requirements for producing them. The problem revolves around the need for tooling that is capable of handling extremely large components and assemblies and can reproduce the close tolerances required for flight vehicles. To ensure maximum uniformity and reliability, tooling for welding must be automated as much as possible. The size of the components also require that the assembly sequences be developed so that the transfer of parts from one tool to another is held to a minimum.

No manufacturing scheduling difficulties are foreseen for either vehicle stage. Manufacturing capability exists to begin the first-stage development programs, and, by the end of 1963, solid motor capability should exist for the flight test program. The greatest problem with the solid-propellant motors will be in tooling and fabrication of the nozzle. Motor cases, solid propellant, and structure are all producible at this time.

Development work on the second stage of the vehicle could also be started immediately, and the scheduled time period is practical for fabrication of a stage of this size. A new factory or assembly facility is required for subassembly and final assembly of the liquid stage. These new facilities should be located to allow water transportation of the completed units to the test facility and to the launch site. One important observation is that the stage design will be able to use much of the development work being done on the Saturn program.

### 3.4.1.3 Solid-Propellant First-Stage Ground Rules and Assumptions

The following ground rules and assumptions were made in analyzing the manufacturing process for the first stage of the baseline vehicle. The first stage consists basically of the clustering structure, motor cases, nozzles, and aft skirts. Production breakdown sketches would be made of the major stage parts before the manufacturing discussions.

The motor cases would be manufactured at a shipyard or steel fabrication plant that has access to water transportation for shipment of the cases to a propellant manufacturing site. The case motor would then be shipped to a motor finishing site where the aft skirt assemblies and nozzle would be attached and subsystems installed. Because this work would be performed on a loaded motor case, machining and drilling operations would not be allowed. The clustering structure would be shipped in halves to the vehicle assembly site. Some TVC components and some electrical/electronic system components would be shipped to the motor

finishing area for installation. The remainder would be sent to the vehicle assembly site.

The primary requirement in the tooling program is for interchangeable interfaces in the major vehicle components. These interfaces are: motor case to nozzle, motor case to aft skirt extension, motor case to forward skirt extension, support skirt to launch pad, and clustering structure to interstage.

The manufacturing processes considered are current production techniques and, in themselves, do not create facilities problems. Proper use of manpower and facilities requires a gradual program buildup with a constant production rate. Storage of completed hardware and motors is required.

### 3.4.1.3.1 Manufacturing Schedules

The Mars launch schedule does not allow a constant production rate. By scheduling lunar missions between the Mars flights, the production rate can be adapted to reasonable use of manpower and facilities. The most efficient solid-motor production rate to support a four-ship Mars mission and a 50-man lunar base was shown in Figure 3.3.4-3. This rate requires storage of the finished solid motors for as long as 9 months. Some completed structural units will be stored for 6 months. The maximum production rate of solid motor assemblies would be five per month. The clustering structure would be produced at the rate of one every 5 weeks.

Manufacturing of motors for PFRT and for the first flight vehicle appears on the "least slack" path of the PERT network. The number-one motor production flow time is 30 weeks (see Figure 3.4.1-1).

### 3.4.1.3.2 Tooling Requirements

Detail parts are made to suit the natural tolerance of the individual manufacturing processes and are then joined in a final assembly jig to match critical dimensions established by master tools. The master tooling concept is a means to control the accuracy of production tools and to provide a tangible means of coordinating related production tools. Master tooling will be required for interfaces with vendor and associate contractors.

Major production tools for motor-case components (Figure 3.4.1-2) are listed and briefly described in Table 3.4.1-1, and their use is described in 3.4.1.3.3. The number of units of each tool was not determined in this study since the number of tool units must be based on the actual delivery schedule and number of facilities in production. It has been assumed that more than one manufacturer would build the motor cases.

Major production tools for structural hardware are listed in Table 3.4.1-2.

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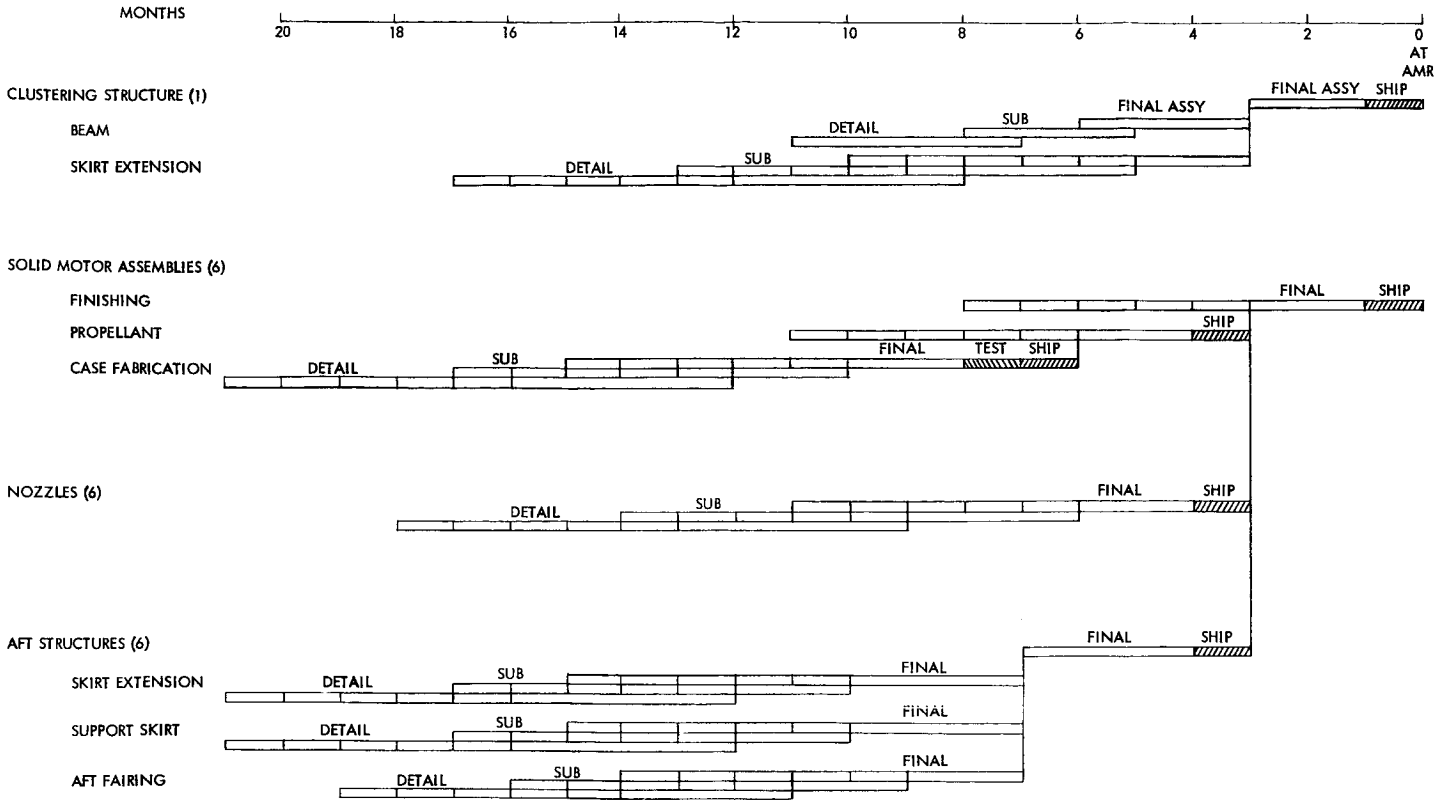
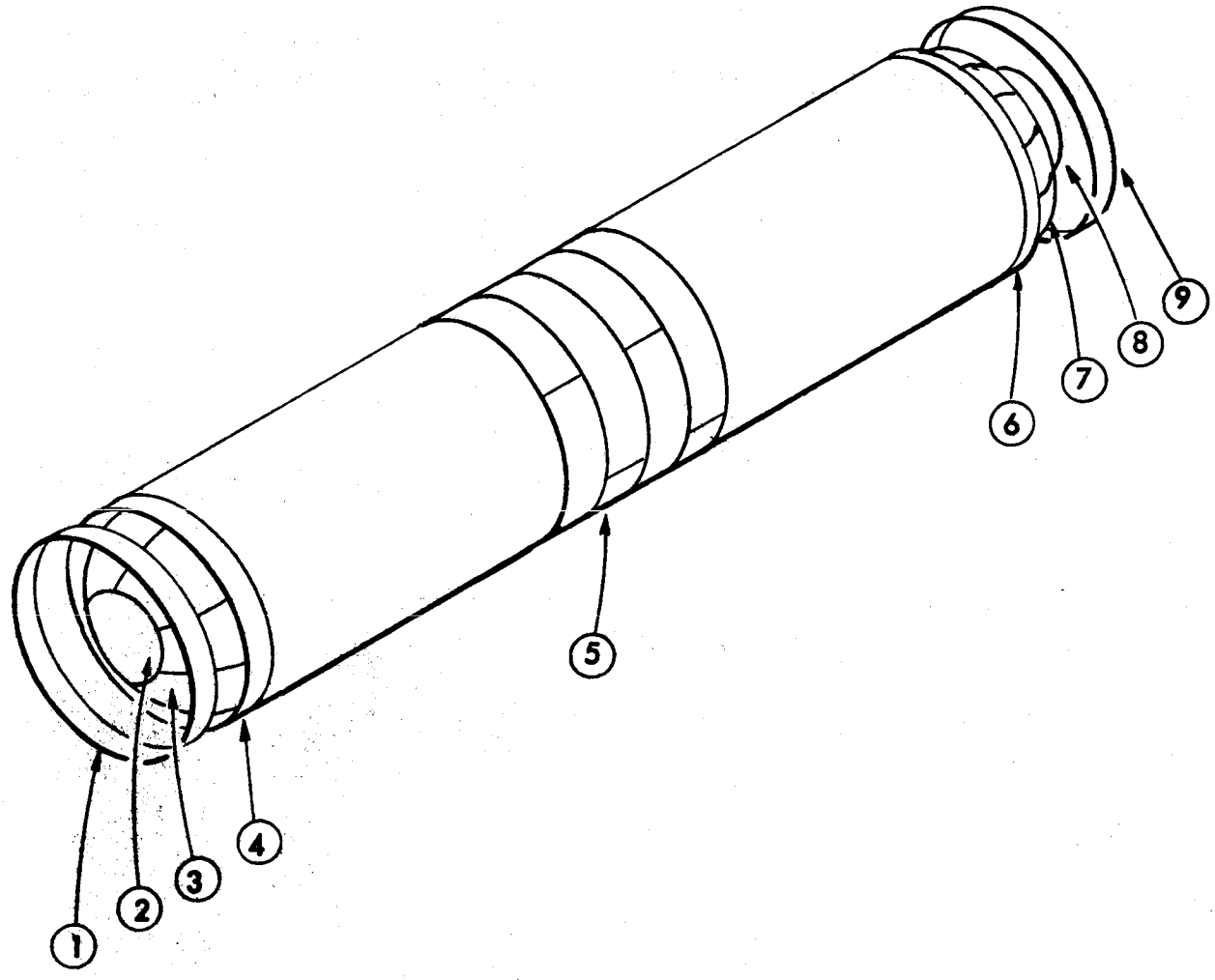



Figure 3.4.1-1 MANUFACTURING FLOW FOR NO. 1 FLIGHT TEST VEHICLE FIRST STAGE




| FWD DOME ASSY | CYLINDER ASSY | AFT DOME ASSY |
|---|---|---|
| 1. SKIRT | 5. CYLINDER HOOP (TYPICAL) | 6. Y RING |
| 2. POLAR CAP | | 7. GORE ASSY |
| 3. GORE ASSY | | 8. NOZZLE BOSS |
| 4. Y RING | | 9. SKIRT |

Figure 3.4.1-2 MANUFACTURING SKETCH
18% Nickel Steel Motor Case

MOTOR CASE TOOLS

Drill Jig 1 is used to drill interchangeable holes in the nozzle boss and motor case skirt. This tool is composed of three parts: a base, which contains a radial arm drill press, and two drill plates. One drill plate indexes to the inside diameter and outside face of the nozzle boss. The other drill plate indexes to the same features of the motor case aft skirt. The hole pattern is coordinated to a master gage.

Drill Jig 2 is used to drill interchangeable holes in the motor case forward skirts. This tool has a radial arm drill press in its base and one drill plate. The drill is positioned by bushed holes in the drill plate and indexes as does Drill Jig 1. The hole pattern is coordinated to a master gage.

Drill Jig 3 is used to drill production holes in the skirts and skirt rings using a tool-mounted drill motor. The drill is located by bushed holes in a drill plate. The tool indexes to the outside diameter.

Boring Fixtures 1, 2, and 3 are used to turn a forged ring to nozzle boss net dimensions. The tools are used on a vertical boring mill.

Boring Fixtures 4, 5, and 6 are used to turn a forged ring to Y-ring net dimensions on a vertical boring mill.

Boring Fixture 7 holds gore assemblies for turning net openings for nozzle boss, spun cap, and net O.D. to match Y-ring; turning is to be done on a vertical boring mill.

Trim Jig 1 locates and holds formed gores. A traveling mill head and traveling cutting torch (both capital equipment) are required to trim the part edges to net size with weld joint edge. Travel carriages, track, power, and controls are required.

Trim Fixture 1 is used to cut blank sizes from mill run plate. The largest part to be cut is 12 feet wide and 34 feet long. This tool requires the following equipment: cutting torch mounted on a traveling carriage, milling head mounted on a traveling carriage, track, controls, and power supply.

Weld Fixture 1 holds cylindrical parts for proper root opening and alignment for welding the longitudinal joint of the 260-inch-diameter motor case half cylinders. Welds are made from both sides. The longest joint is 12 feet long. Mechanized MIG weld heads, wire feed units, torch oscillators, track travel carriage, controls, and power supply are associated equipment. The weld heads are universally mounted on the travel carriage to allow adjustment of the torch head up to 45 degrees leading, trailing, and normal to direction of travel.

Table 3.4.1-1

MOTOR CASE TOOLS

Weld Fixture 2 locates and holds the formed gore pieces of both the forward and aft dome assemblies. Welding is done from the outside only. The types of equipment listed for Weld Fixture 1 are also required for this tool.

Weld Fixture 3 locates and holds the Y ring and skirt for welding, the gore assembly for welding to the Y ring, and the polar cap or nozzle boss for welding to the gore assembly. The weld fixture turns the parts past a weld head; therefore, there is no torch and travel carriage as in Weld Fixtures 1 and 2.

Weld Fixture 4 locates and holds the dome assemblies and cylinder for welding on both sides. This fixture will be used with the following equipment: weld heads, manipulators, wire feed units, torch oscillators, controls, and power supply. This tool requires powered wheel rollers (capital equipment) to rotate the motor case parts.

Weld Fixture 5 locates and holds the major case sections for joining by welding from both sides. It is supported by equipment used with Weld Fixture 4.

Form Die 1 used for forming gore segments, is a large spherical die to be used in a press.

Table 3.4.1-1 (Cont.)

## PRODUCTION ASSEMBLY TOOLS
## SKIRT, SUPPORT, EXTENSIONS, FAIRINGS, AND CLUSTER STRUCTURE

Half Clustering Structure
- Final half assembly jig
- Final assembly check fixture

Forward Skirt Extension
- Curved inner panel jig
- Straight inner panel jig
- Curved outer panel jig
- Straight outer panel jig
- Final assembly jig

Beam Structure
- Primary beam jig
- Curved inner tie jig
- Curved outer tie jig
- Straight outer tie jig
- Diagonal beam jig
- Center spider jig
- Half beam structure assembly jig

Aft Skirt Extension
- Panel assembly jig
- Final assembly jig

Support Skirt
- Core machining fixture
- Bonded panel jig
- Support pad weld jig
- Support leg jig
- Major assembly jig

Aft Fairing
- Panel assembly jig
- Final assembly jig

Base Heat Assembly
- Primary beam jig
- Secondary beam jig
- Four bonded panel jigs
- Four core-machining fixtures
- Final assembly jig

Total Aft Structure
- Check fixture

Table 3.4.1-2

### 3.4.1.3.3 Motor Case Fabrication

The most reasonable approach to the fabrication of 260-inch-diameter motor cases is the roll and weld method. This method is widely used throughout industry for similar products. Facilities, materials, and processes exist that, after minor development work, can support this manufacturing program.

Fabrication of the 260-inch diameter motor cases is based on the use of 18-percent nickel steel. Flame cutting is satisfactory for rough trim only. This material can be readily machined in the annealed condition with conventional high speed steel cutting tools. Carbide cutters must be used on the aged material. The material should be cold-formed before age hardening. Automated MIG is the most reliable and feasible welding process. Age hardening of major case sections will be done at 900°F to 950°F for 2 to 3 hours. Final case weld joints in the motor case design are as welded. Hydrostatic testing of the final case should be done horizontally. General manufacturing processes and basic tooling are listed below for each part of a motor case. Descriptions of some processes follow the listing and tools were described in Tables 3.4.1-1 and 3.4.1-2.

| Part Name | Manufacturing Process | Production Tool |
|---|---|---|
| Nozzle Boss (forged ring) | Clean up O.D., top and bottom surface | Standard Setup |
| | Rough cut boss section | Boring Fixture 1 |
| | Rough cut flange | Boring Fixture 2 |
| | Finish cut I.D. and face of boss | Boring Fixture 1 |
| | Finish cut outside surface of curved flange | Boring Fixture 2 |
| | Finish cut inside surface of curved flange and weld joint edge | Boring Fixture 3 |
| Y Ring (forged ring) | Clean up I.D., top and bottom surfaces | Standard Setup |
| | Rough cut O.D. and skirt flange | Boring Fixture 4 |
| | Rough cut I.D. and dome flange | Boring Fixture 5 |
| | Finish cut O.D. and top of skirt flange | Boring Fixture 4 |
| | Finish cut dome flange and skirt flange | Boring Fixture 5 |
| | Finish cut sidewall flange | Boring Fixture 6 |
| Gores (plate) | Flame cut blank | Trim Fixture 1 |
| | Press form net shape | Form Die 1 |
| | Flame cut excess | Trim Jig 1 |
| | Machine edges and weld joints | Trim Jig 1 |
| Skirt (plate) | Flame cut blank | Trim Fixture 1 |
| | Mill net length and width with weld edges | |
| | Preform ends for rolling (brake press) | |
| | Roll 260-inch diameter | |
| | Position parts and weld on each side | Weld Fixture 1 |

| Part Name | Manufacturing Process | Production Tool |
|---|---|---|
| Cylinder Hoop (plate) | Flame cut blank | Trim Fixture 1 |
| | Machine net length, width; weld joint edges | |
| | Preform ends for rolling (brake press) | |
| | Roll 260-inch diameter | |
| | Clean weld edges | |
| | Position parts and weld on each side | Weld Fixture 1 |
| Joint Ring (plate) | Flame cut blank | Trim Fixture 1 |
| | Mill net length and width | |
| | Mill net cross section | |
| | Preform ends for rolling | |
| | Roll 260-inch diameter | |
| | Clean weld edges | |
| | Position parts and weld from each side | Weld Fixture 1 |
| Cylinder Assembly | Clean weld edges | |
| | Position cylinder hoops and joint rings; align centerline optically | Weld Fixture 4 |
| | Weld from each side | |
| | Age harden in furnace | |
| Gore Assembly | Clean weld edges | |
| | Position and weld gores from outside | Weld Fixture 2 |
| | Position last gore and mark for trimming to fit | Weld Fixture 2 |
| | Machine edges of last gore | |
| | Position last gore and weld from one side | Weld Fixture 2 |
| | Turn net edges for Y-ring and polar cap or nozzle boss | Boring Fixture 7 |
| Dome Assembly | Position Y ring and gore assembly | Weld Fixture 3 |
| | Clean weld edges | |
| | Weld from outside | Weld Fixture 3 |
| | Position nozzle boss or spun cap | Weld Fixture 3 |
| | Clean weld edges | |
| | Weld from outside | Weld Fixture 3 |
| | Position skirt | Weld Fixture 3 |
| | Clean and weld from outside | |
| | Position cylinder hoop | |
| | Clean and weld from both sides | |

| Part Name | Manufacturing Process | Production Tool |
|---|---|---|
| Motor Case Assembly | Position forward dome assembly and cylinder assembly 1 | Weld Fixture 5 |
| | Clean weld edges and align optically | |
| | Weld from both sides | Weld Fixture 5 |
| | Position cylinder assembly 2 | Weld Fixture 5 |
| | Clean, align optically, and weld | |
| | Position aft assembly, clean, align, and weld | Weld Fixture 5 |
| | Position skirt ring, drill, and bolt in place | Drill Jig 1 |
| | Drill holes in nozzle boss | Drill Jig 2 |
| | Drill holes in aft skirt ring | Drill Jig 2 |
| | Drill holes in forward skirt ring | Drill Jig 3 |
| | Pressure test | |
| | Dry blast exterior and interior | |
| | Spray paint exterior and interior | |

The cylindrical hoops are made from two flat plates rolled to form half cylinders and then welded longitudinally. Plate material 120 to 144 inches wide by 35 feet long rolled into half cylinders and requiring 30 to 26 pieces for one motor case was assumed. The forward head uses a 144-inch-diameter spun cap. Motor sections up to 50 feet long can be age-hardened in case bottom furnaces. Thickened weld lands have been shown on the motor-case design drawing. However, it is anticipated that the joint thicknesses will be reduced by development of a local age-hardening process.

After hydrostatic testing, the case is cleaned thoroughly. Trichloroethylene solvent and alkaline solution are used as required, followed by sandblasting. Parts are then rinsed to remove abrasives and are warm-air dried. Threaded holes and machined surfaces are masked, and painting is completed as soon as possible after cleaning. Spray painting is done with an epoxy paint specified by the propellant manufacturer. In-process temperature must be maintained between 50 and 80°F. Lighting and ventilating facilities are required inside the motor cases.

Accelerated drying of the paint can be done with electric heat panels and infrared modules. Drying can be done while painting is in progress. Approximate drying time for 0.5-mil-thick epoxy paint is 15 to 20 minutes at 200°F surface temperature. Threaded holes and machined surfaces are hand cleaned to remove paint overspray and coated with a protective coating material.

At the motor finishing site, loaded motors would have the nozzles, aft skirt extension, support skirt, and aft fairing installed. All possible subsystem parts, such as electrical, thrust vector control, telemetry, etc., are also installed at this time. After the motor assembly is completed, it is subjected to checkout

test prior to delivery to the launch pad. The tests are nondestructive functional tests for electrical and mechanical systems and will help keep replacement and repair operations away from the launch site. To reduce launch pad occupancy time, all of these checkout tests need not be duplicated at the launch site.

3.4.1.3.4 Major Component Fabrication

The clustering assembly of beams and motor case extensions is fabricated in halves. These halves are shipped to the vehicle assembly site where they are joined. The clustering beams are riveted assemblies of machined plates. The motor case extensions are of relatively simple construction and use common aircraft-type assembly processes. (See Figure 3.4.1-3 for sketch showing major subassemblies and Figure 3.2.11-3 for detail structure.)

The forward and aft skirt assemblies are also aircraft-type assemblies. Tapered longerons can be spar-milled from heavy sections or fabricated by welding skin-milled plates. Stiffeners can be made in draw-bench-type stretch machines. Contours of circumferentials are best obtained by stretch forming, while circular parts can be rolled. Support skirt skins will require press forming or hydraulic bulge forming due to their gage and contour. Other skins can be rolled conically or cylindrically. (See Figure 3.4.1-4 for typical size and production break points and Figure 3.2.11-2 for detail structure.)

Nozzle fabrication was not studied for this vehicle. It is believed that nozzles represent the greatest fabrication problems due to size, relatively new materials, and probable close-tolerance parts. A detailed analysis for production is recommended for future study work.

3.4.1.3.5 Manufacturing Development

The manufacturing development program does not require extensive advances in technology. Most development work is a refinement of existing capabilities or an extension of existing programs.

Development work should be expedited by direct coordination between design engineers, manufacturing engineers, and shop personnel. Table 3.4.1-3 is a summary of the significant foreseeable problems. A few development areas have been defined in detail and are described below.

Explosive forming of gore segments and compound curved skins can achieve production capability in 6 months. This requires maximum effort and availability of the required facilities. Prior to explosive forming, the blank material is rough trimmed and roll formed in the longitudinal direction.

Localized heat treatment of welds in 18-percent nickel steel was recently performed in order to determine the mechanical properties. Results show that

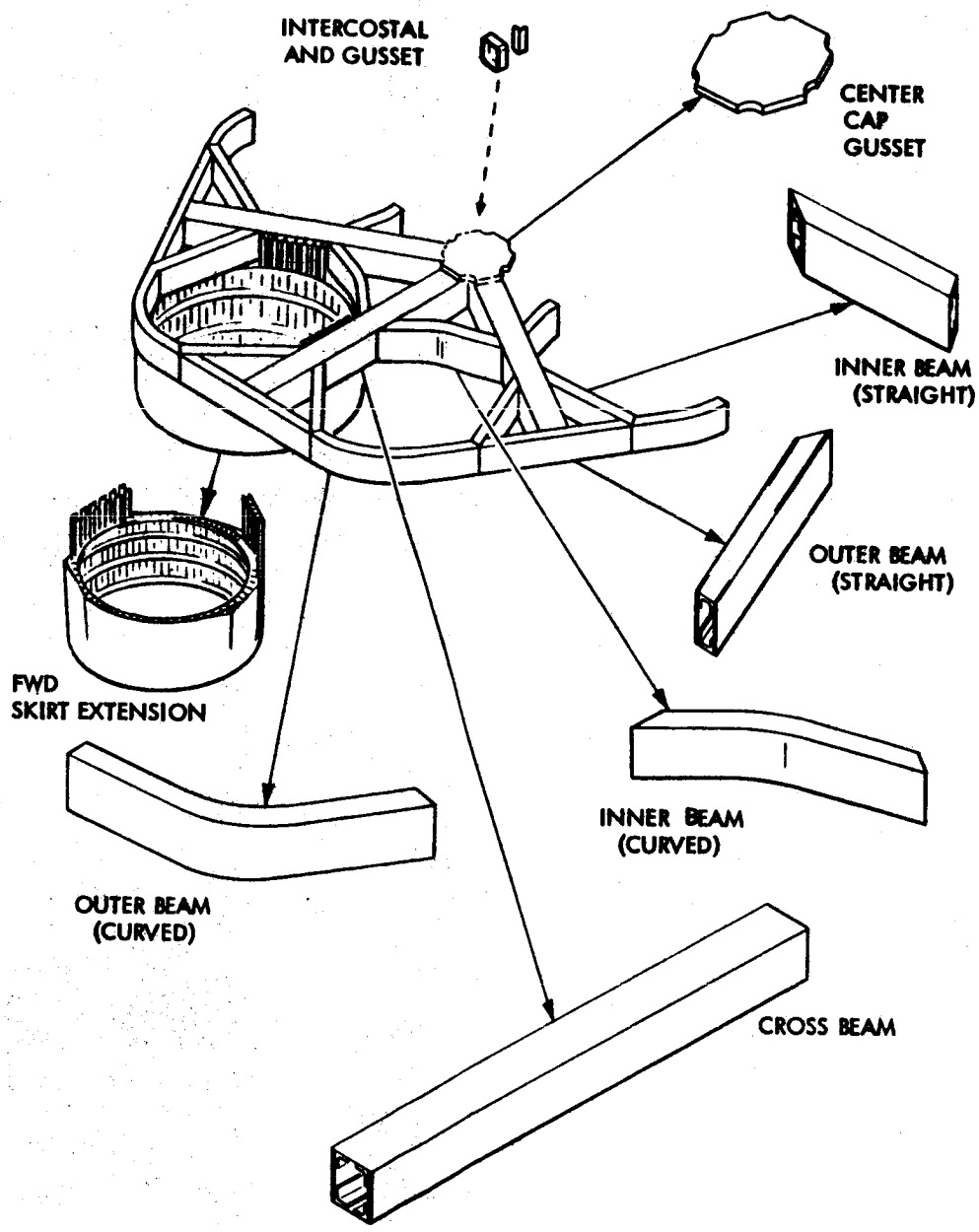



Figure 3.4.1-3 FIRST-STAGE CLUSTER STRUCTURE SUBASSEMBLIES

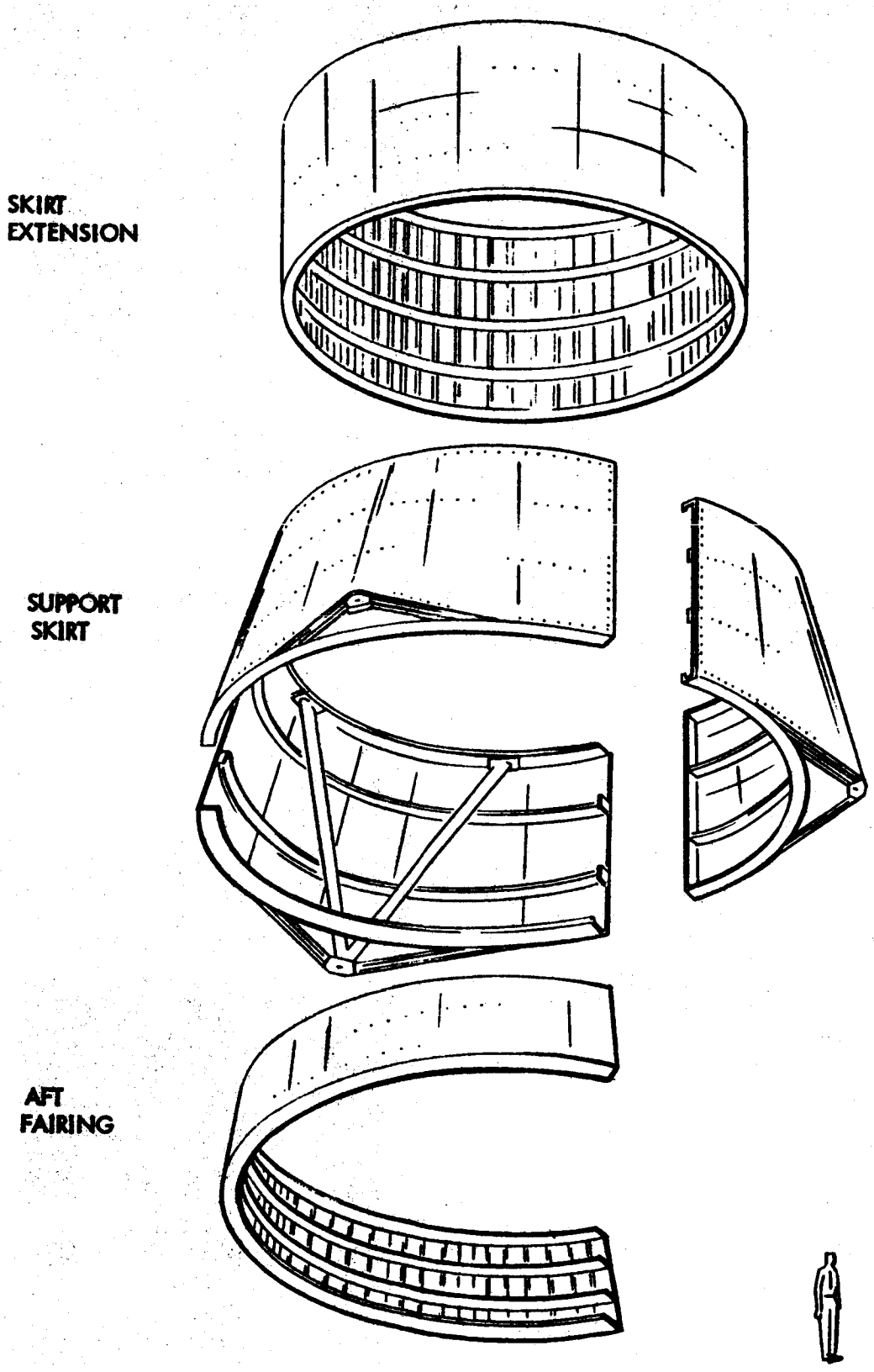



Figure 3.4.1-4 TYPICAL SIZE AND PRODUCTION BREAK POINTS

## MANUFACTURING DEVELOPMENT TASKS

| PROBLEM IDENTIFICATION | DEVELOPMENT PLAN |
|---|---|
| Establish basic welding characteristics of 18-percent nickel steel | Perform various welding operations on test specimens of the material. Investigate the usable gage envelope, joint configuration limitations, filler deposition rates, welding speeds, shrinkage factors, atmosphere and contamination control requirements, cooling rate, and filler rod material. |
| Develop process, tooling, and equipment design parameters for welding operations on the 260-inch diameter motor case | After completion of material evaluation, establish the following development programs: |
| Cylindrical section longitudinal fusion welds | Fabrication and evaluation of: (1) test specimens in the required gages and joint configurations; (2) subscale test hardware to simulate the dimensional and functional interrelationships of tool, equipment, and part; and (3) full-scale test hardware where the scale-up parameters cannot be otherwise simulated. Emphasis will be given to: |
| Selection of process | Cost and reliability comparisons of TIG, MIG, and subarc MIG processes for each application. For circumferential welds concentrate on TIG root welds with MIG on subarc filler passes. Test specimens and subscale tests will be required. |
| Selection of weld position and work piece | Concurrent with the process selection studies, identify the attitude and degree of travel for equipment and part that yield best results with each process. Establish design criteria for weld fixtures and jigs and speed and tracking tolerances for each work piece rotating equipment. Establish methods for counteracting uneven puddling action in other than the down-hand position. |
| Joining gore segments and attachment of cap and Y ring | Same as above |

Table 3.4.1-3

MANUFACTURING DEVELOPMENT TASKS

| PROBLEM IDENTIFICATION | DEVELOPMENT PLAN |
|---|---|
| Joining cylinder to cylinder | Same as above |
| Weld equipment survey and selection | Survey welding and positioning equipment manufacturers for equipment with the necessary capabilities and recommend appropriate procurement. |
| Weld repair procedures | Establish the repairability of 18-percent nickel steel in each joint configuration with test specimens. Recommend procedures where applicable. |
| Investigate the forming characteristics of 18-percent nickel steel | Various forming techniques will be applied to subscale test specimens to determine fabrication feasibility. |
| Determine the best method for forming case gores (18-percent nickel steel) | Although present technology indicates the use of pressed gores to form a welded assembly, other techniques will be investigated in an effort to find the most economical forming method. Effort will be given to spin, explosive, hydrostatic, and cryogenic forming. |
| Determine the best method for fabricating nozzle lining | Establish a program to develop the process and tooling required to mold parts net size. Establish a test program to develop the process and tooling required to mold parts oversize, cure and machine or grind to successfully fit the liner to the steel support structure within bonding requirements. Explore the repair capabilities and determine the feasibility of rework on out-of-tolerance items. |
| Develop the processes and tools for bonding segmented nozzle lining to steel support | Assuming bonding can be accomplished successfully, a bonded nozzle configuration contributes to assembly and detail simplicity; determine the bonding parameters and develop the process to bond lining to steel. Recommend a tool configuration and its capabilities. |
| Determine machining characteristics of 18-percent nickel steel | Run new alloy standard test program to gather data on machining parameters and, by analysis, determine the characteristics that affect process planning and tool design. |

Table 3.4.1-3 (Cont.)

MANUFACTURING DEVELOPMENT TASKS

| PROBLEM IDENTIFICATION | DEVELOPMENT PLAN |
|---|---|
| Investigate stress relief process for weld assemblies of 18-percent nickel steel | Perform a subscale program to establish the manufacturing process for locally stress relieving welds, using induction coils, thermite jacket, oven, etc. Recommend tool configuration and capability. |
| Establish a local age-hardening process for 18-percent nickel steel | Perform a subscale test program to gather data on tie time and temperature levels to obtain various yield strengths of cold-worked parts. Recommend processes. |
| Sealing the gimbal joint of the nozzle for minimum hot-gas leakage | Gather data on O rings, lubricant, and structural materials used in gimbaled nozzle joints to determine manufacturing assembly tolerances, alignment, and assembly process. |
| Investigate bulge forming of 7075 aluminum skins | Perform a subscale test program to establish feasibility of this process. Determine the technique and tooling for very large parts. |
| Develop processes and tools for fabricating bonded honeycomb structure | Process portions of full-size parts to establish machining, fitting, cleaning, adhesive application, and cure process. Recommend tooling and amount of core crushing. |

Table 4.3.1-3 (Cont.)

local aging of 18-percent nickel material welded in the aged condition increases the weld strength by about 50 percent to within 5 percent of the fully aged parent-material strength. The resulting percent elongation was slightly lower than the parent material.

### 3.4.1.3.6 Direct Manufacturing Manpower

The estimated manufacturing manhours to produce the number one unit booster components are shown in Table 3.4.1-4. Job distribution manhours for the number one unit booster are also shown.

The manpower estimates are based on the general manufacturing processes, number of work positions, flow time, weight, and size of the major stage components. The motor case and nozzle estimates were factored from data provided by other companies.

The estimate includes:

- A 5-day, two-shift factory operation
- The design and fabrication of one basic set of tooling
- The planning, tooling, and production of hardware for the first stage
- Manufacturing development work in material and process evaluation.

The estimate excludes:

- Propellant processing, motor assembly work, and vehicle assembly
- Systems, such as hydraulic and electrical, located within the structural components
- Blanket time and overhead manpower required to support factory functions
- Application of insulation.

### 3.4.1.4 Liquid Second-Stage Ground Rules and Assumptions

The following ground rules and assumptions were made in analyzing the manufacturing processes for the second stage of the T65 baseline vehicle. This stage will extend from the forward side of the Stage I cluster structure joint to the interface with the payload. The production breakdown for major structure is shown in Figure 3.4.1-5.

The aft skirt assembly is essentially the first stage-second stage interstage. Since the clearance between the second-stage engine nozzles and the aft skin interstage will not allow gimbaling of the engines, this section cannot be installed prior to static test firing. Also, the height limits of the standard shipping and handling pallet will not allow skirt installation prior to shipping to AMR. It will

DIRECT MANUFACTURING MANHOURS FOR THE NUMBER ONE UNIT OF VEHICLE T65

| | |
|---|---|
| 6 Motor Cases | 1,130,000 |
| 6 Aft Skirts and Fairings | 315,000 |
| 6 Nozzles | 510,000 |
| 6 Forward Skirts | 215,000 |
| 1 Base Heat Protection | 20,000 |
| 1 Clustering Structure | 160,000 |
| | 2,350,000 |

| | |
|---|---|
| Production Planning | 65,000 |
| Tool Design | 45,000 |
| Tool Fabrication | 280,000 |
| Production | 1,900,000 |
| Development | 50,000 |
| | 2,350,000 |

Table 3.4.1-4

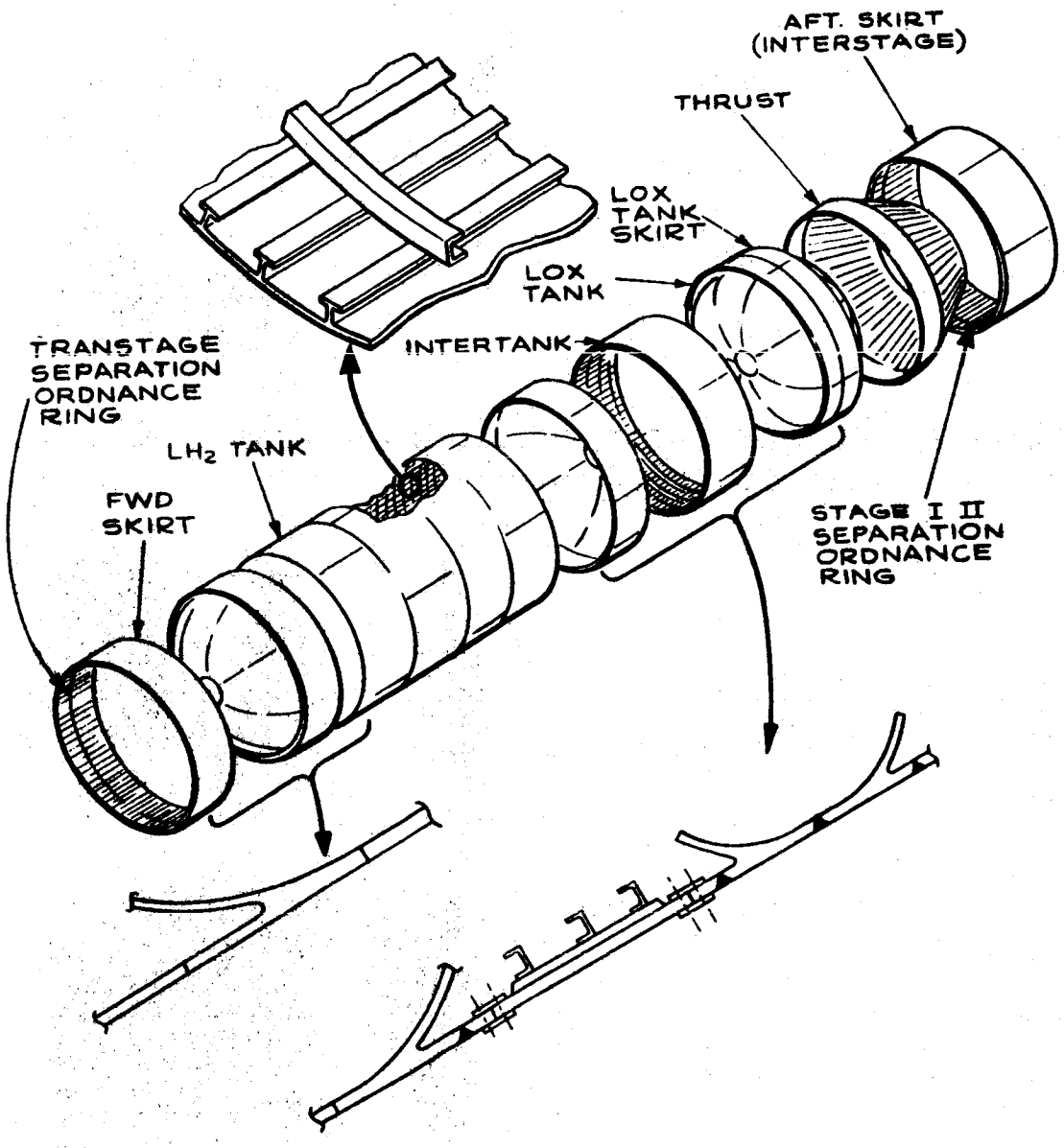



Figure 3.4.1-5 STRUCTURE BREAKDOWN

be manufactured by the second-stage contractor, fit checked, disassembled, and shipped to AMR with the second stage. The skirt will then be reassembled and installed at AMR.

The forward transtage portion of the forward skirt assembly is integral with the forward skirt assembly until separation by shaped charge. This portion houses the transtage propulsion units. It will be fabricated by the second-stage contractor and will interface with the payload and transtage propulsion unit, which are manufactured by separate contractors.

A new factory area will be required to handle the 70-foot-diameter vehicle. The factory location must have access for docking and for water transportation of completed stages. The new factory will not be ready for erection of assembly tooling at the start of the contract. Initial tool and production planning, tool design, and tool and detail part fabrication will be accomplished at other facilities to reduce total flow time.

The battleship unit will be fabricated at the new facilities. A mockup to master plumbing and wiring will be fabricated for the battleship engineering design group. The mockup will coordinate with a dummy engine and will be the control tool for plumbing and wiring manufacture. The R&D program will start in 1965-66 and require approximately 5 years.

The production program will follow the R&D program and last approximately 10 years. The production breakdown and tool design is based on a maximum rate of 12 vehicles per year.

#### 3.4.1.4.1 Manufacturing Schedules

Number one flow schedules were prepared for initial R&D vehicle units (see Figure 3.4.1-6). These schedules are considered realistic, but will require close program management. For program schedules see Section 3.7.

#### 3.4.1.4.2 Tooling Requirements

Tooling must be capable of maintaining tolerances during assembly of very large components and subassemblies. The tools must be sufficiently durable to provide service during the production of 12 vehicles per year over the assumed 10-year period.

An assembly sequence has been selected that will allow the greatest amount of work to be done in the subassembly positions. This will reduce the number of more expensive final assembly and joining positions and provide for a higher rate of fabrication with lowest total tooling cost.

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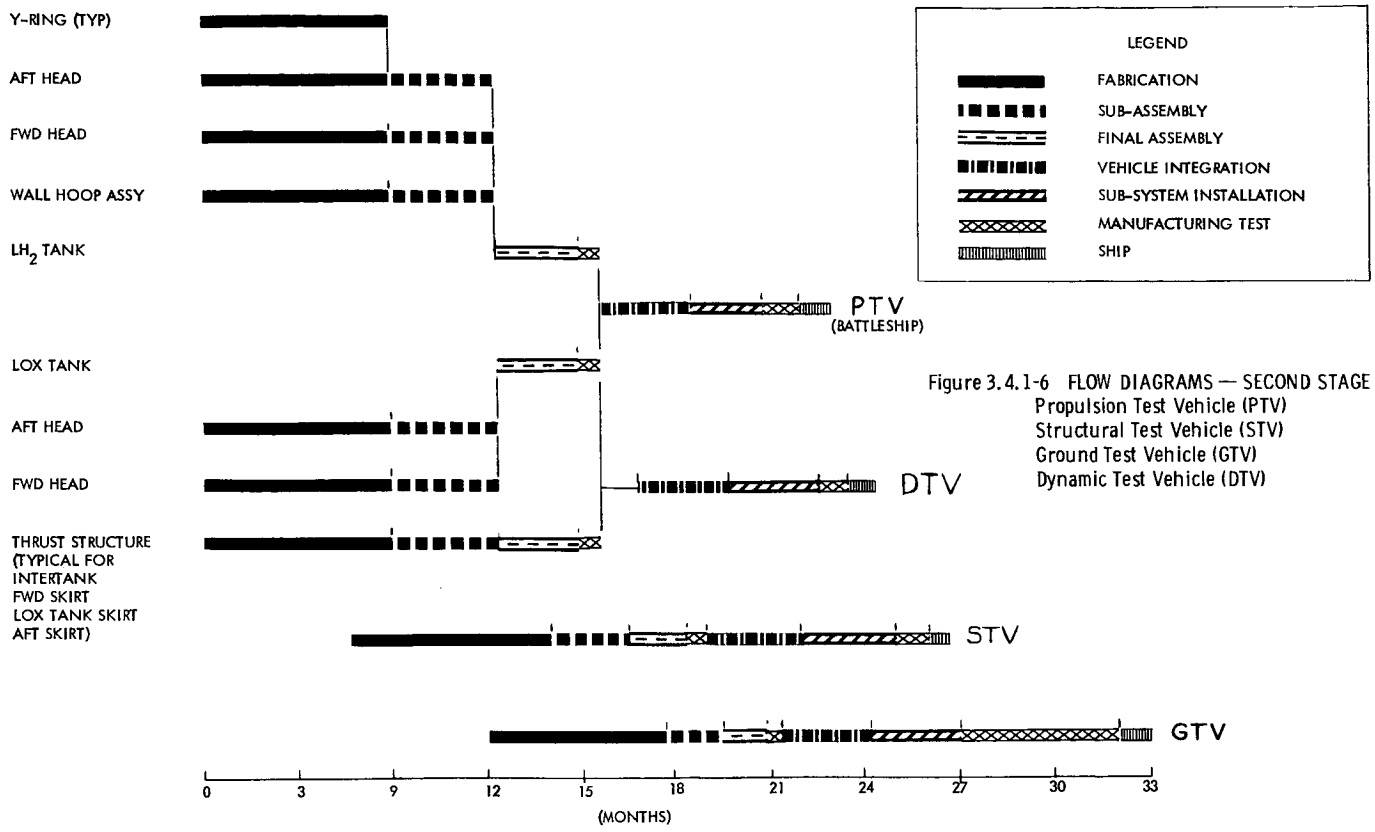


Figure 3.4.1-6 FLOW DIAGRAMS — SECOND STAGE
Propulsion Test Vehicle (PTV)
Structural Test Vehicle (STV)
Ground Test Vehicle (GTV)
Dynamic Test Vehicle (DTV)

The production flow for the second stage is shown in Figure 3.4.1-7. Typical tool lists are shown in Tables 3.4.1-5, 3.4.1-6, and 3.4.1-7.

The master tooling requirements for major items are listed as follows: joint I-II interstage, joint stage II-payload, joint stage II-transtage propulsion units, joint M-1 engines and thrust structure, fill and drain connections, plumbing line connections, and interfaces with vendor package items. A stage mockup will be fabricated of key areas for plumbing and wiring. This tool will act as master model for items not subject to a system of master dimensioning. The master dimensioning system will be used with optical tooling bars and docks to control large component items not convenient to master tool in the standard methods.

### 3.4.1.4.3 Fabrication Processes

The fabrication processes for the detail parts of the liquid second stage may all be selected from existing techniques. Where technology change is foreseen, or where a more detailed analysis might result in the selection of another process, it is mentioned in the discussion.

Y Rings — The Y rings will be produced in a manner similar to that used on the Saturn S-IC program except for final machining of the part. The operation is detailed in Figure 3.4.1-8. The spar-mill approach was selected because of the advantage over vertical bore milling of having a tool cutter moving over a fixed part. This method allows for machining variable cross sections at welded junctures and, thus, minimum-weight design. Flow time for fabrication and setup of this tooling is shortest because much of the required equipment is off the shelf and adaptations of standard tooling. A 20-year background of experience exists at some aerospace companies that can be used with this method. The selected method has minimum technical risk and shortest flow time per piece.

Use of anticipated advances in electron-beam welding with portable vacuum chambers could be used to join the ring. This might also permit a second method of fabrication in which the ring segments would be machined, rolled, and then joined. Selection of this method would depend on the weld shrinkage engendered by electron-beam welding and development of a suitable technique.

Tank Wall Skins — The tank wall skins will be fabricated as shown in Figure 3.4.1-9. The forming tolerances will be controlled with contour templates. Maximum-size pieces will be used to minimize welding.

The forming of skins in which deep integral stiffeners have been machined will require some development work. Research in this area is being pursued on the Saturn S-IC program, and the results will be available for the NOVA manufacturing effort.

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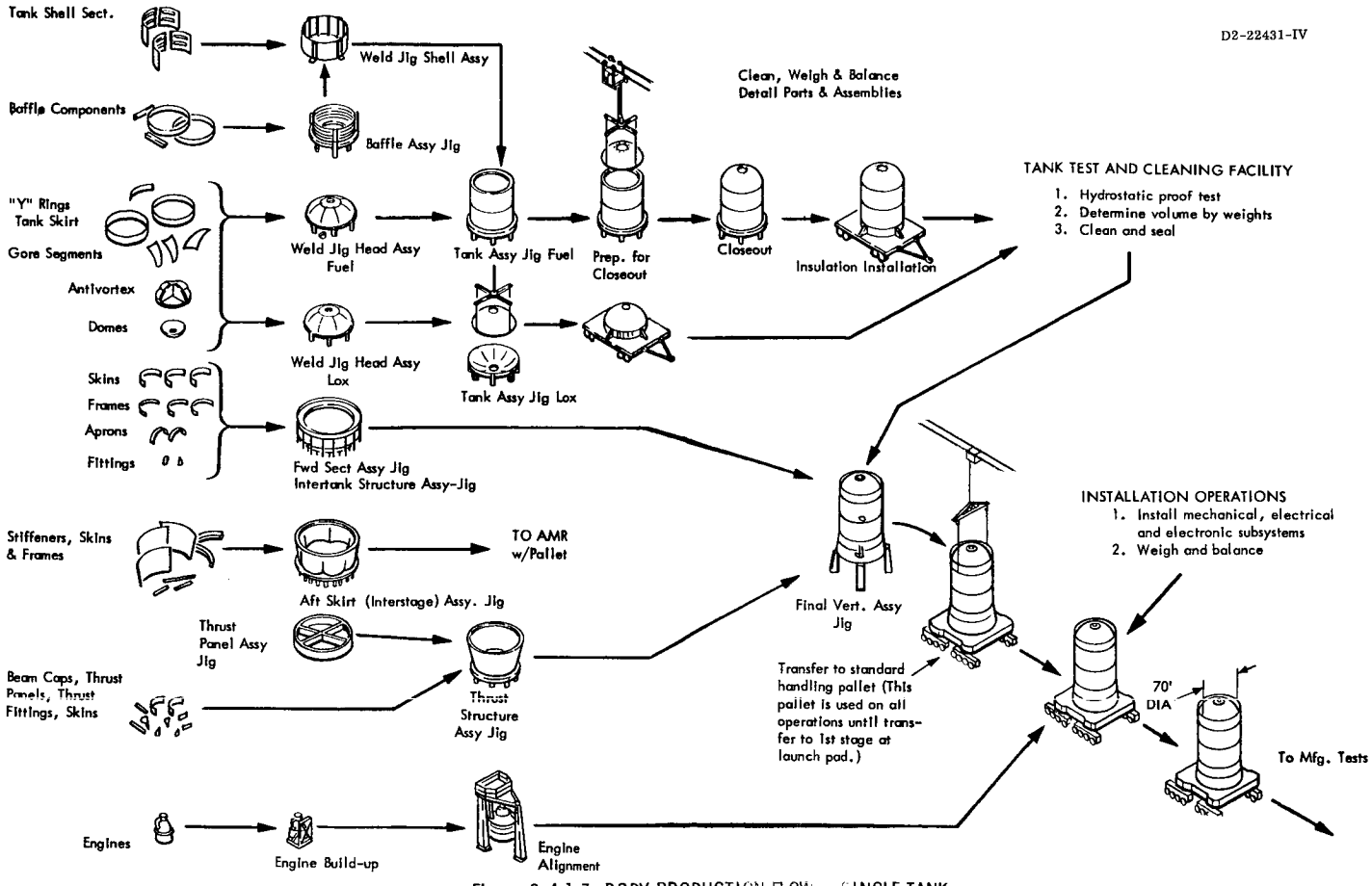



Figure 3.4.1-7 BODY PRODUCTION FLOW -- SINGLE TANK

TYPICAL DETAIL PART TOOLING

| Detail Parts | Process | Tool | Part Quantity | Tool Size (feet) |
|---|---|---|---|---|
| Gore Segment | Cut, form, trim | ( 1) Trim fixture<br>( 1) Forming die,<br>(10) Handling fixture<br>( 1) Trim fixture | 76 | 12 x 15 |
| Gore Segment | Cut, form, trim | ( 1) Forming die,<br>( 8) Handling fixture<br>( 1) Trim fixture | 64 | 10 x 15 |
| Gore Segment | Cut, form, trim | ( 1) Forming die,<br>( 5) Handling fixture<br>( 1) Trim Fixture | 36 | 10 x 10 |
| Head | Cut, spin, trim, machine | ( 1) Spin fixture<br>( 5) Handling fixture<br>( 1) Trim fixture | 4 | 10 ft. dia. |
| Y-Ring Segments | Cut, form, machine ends | ( 2) Handling fixture<br>( 1) Trim fixture | 24 | 2 x 60 |
| Hoop Section | Cut, machine, form | ( 5) Handling fixture | 36 | 12 x 25 |

Table 3.4.1-5

TYPICAL MINOR ASSEMBLY TOOLING

| Minor Assembly | Tool | Position | Part Quantity | Tool Size (feet) |
|---|---|---|---|---|
| Head Gore Subassembly | (2) FAJ | ( 1) Pickup | 2 | 16 H x 80 Dia. |
| Head Gore Subassembly | (2) FAJ | ( 1) Pickup | 2 | 10 H x 70 Dia. |
| Head Gore Subassembly | (2) FAJ | ( 1) Pickup | 2 | 5 H x 40 Dia. |
| Head Gore Subassembly | (2) FAJ | ( 1) Pickup | 2 | 15 H x 80 Dia. |
| Head Gore Subassembly | (2) FAJ | ( 1) Pickup | 2 | 10 H x 70 Dia. |
| Head Gore Subassembly | (2) FAJ | ( 1) Pickup | 2 | 5 H x 40 Dia. |
| Tank Sidewall Subassembly | (2) FAJ | ( 2) Pickup | 4 | 15 H x 70 Dia. |
| Baffle Panel Assembly | (2) FAJ | (10) Pickup | 18 | 5 W x 12 H x 25 L |
| Antivortex Assembly | (2) FAJ | ( 1) Pickup | 2 | 10 H x 40 Dia. |
| Insulation Panel | (5) FAJ | (20) Pickup | 90 | 5 W x 12 H x 15 L |
| Insulation Panel | (5) FAJ | (10) Pickup | 36 | 5 W x 12 H x 25 L |
| Forward Skirt Panel Assembly | (2) FAJ | (13) Pickup | 9 | 25 W x 5 H x 25 L |
| Aft Skirt Panel Assembly | (2) FAJ | ( 3) Pickup | 9 | 5 W x 10 H x 25 L |
| Thrust Structure Panel Assembly | (2) FAJ | ( 3) Pickup | 9 | 30 W x 5 H x 25 L |
| Thrust Kick Ring | (1) FAJ | ( 3) Pickup | 9 | 5 W x 5 H x 25 L |
| Intertank Structure Panel Assembly | (2) FAJ | ( 3) Pickup | 9 | 25 W x 5 H x 50 L |
| Interstage | (2) FAJ | ( 4) Pickup | 11 | 25 W x 5 H x 60 L |

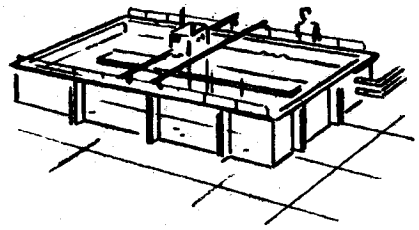
Table 3.4.1-6

TYPICAL MAJOR ASSEMBLY TOOLING

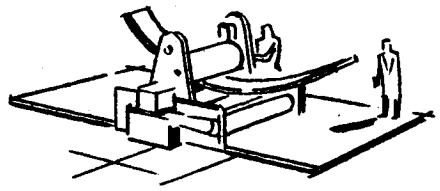
| Major Assembly | Tool | Position | Part Quantity | Tool Size (feet) |
|---|---|---|---|---|
| Tank Sidewall Assembly | (1) FAJ | (1) Pickup | 1 | 50 H x 90 Dia. |
| Head Assembly | (2) FAJ | (1) Pickup | 2 | 30 H x 90 Dia. |
| Head Assembly | (2) FAJ | (1) Pickup | 2 | 30 H x 90 Dia. |
| Y-Ring Assembly | (1) FAJ | (1) Pickup | 4 | 5 H x 80 Dia. |
| Thrust Structure Assembly | (2) FAJ | (1) Pickup | 1 | 30 H x 80 Dia. |
| Intertank Structure | (2) FAJ | (1) Pickup | 1 | 50 H x 80 Dia. |
| Aft Skirt (Interstage) | (2) FAJ | (1) Pickup | 1 | 50 H x 80 Dia. |
| Forward Skirt | (2) FAJ | (1) Pickup | 1 | 30 H x 80 Dia. |
| Engine Alignment | (1) Alignment jig | (2) Pickup | 4 | 30 H x 30 Dia. |
| Y-Ring Machining | (1) Circular Tracking Spar Mill | (1) Pickup | 4 | 15 H x 80 Dia. |

| Final Assembly | Tool | Position | Quantity | Size (feet) |
|---|---|---|---|---|
| Stage Assembly | (2) FAJ | (1) Pickup | 1 | 200 H x 100 Dia. |
| Stage Installation | | (2) Pickup | 1 | 200 H x 100 Dia. |
| Stage Test | | (2) Pickup | 1 | 200 H x 100 Dia. |

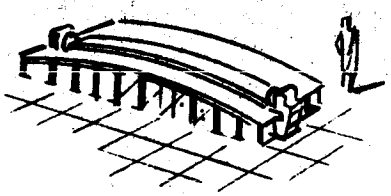
Table 3.4.1-7



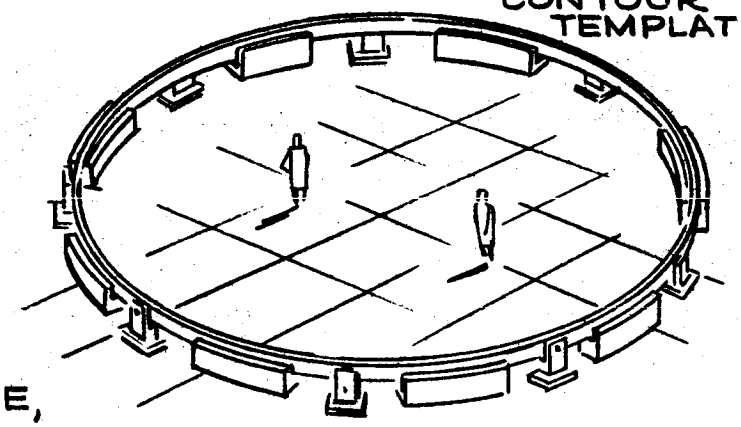
1. PROCESS: INSPECT
TOOL: ULTRASONIC TESTING TANK



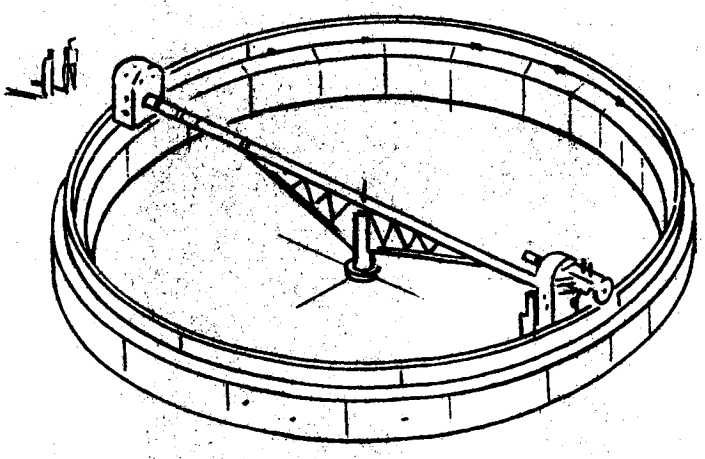
2. PROCESS: ROLL
TOOLS: CONTOUR PRESS, LIFT FIXTURE, CONTOUR TEMPLATE



3. PROCESS: TRIM ENDS
TOOLS: TRIM FIXTURE, HOLDING FIXTURE, LIFT FIXTURE.



4. PROCESS: FIT-UP, WELD.
TOOLS: WELD FIXTURE, HANDLING FIXTURE, LIFT FIXTURE, INSPECTION FIXTURES-(X-RAY SHIELDS)



5. PROCESS: MILL
TOOL: CIRCULAR TRACKING SPAR MILL

6 CLEAN & STORE

Figure 3.4.1-8 Y-RING FABRICATION

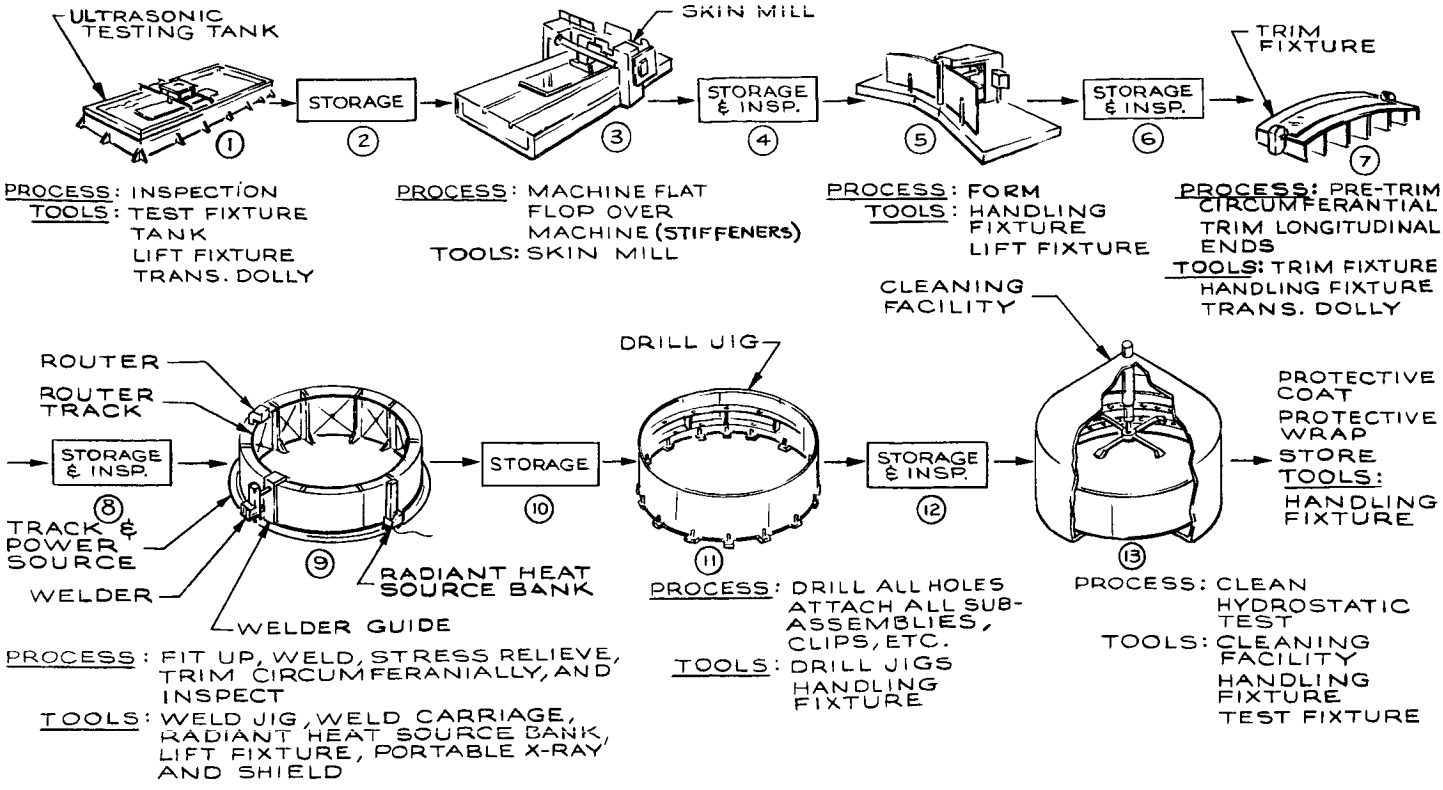



Figure 3.4.1-9 HYDROGEN TANK SIDEWALL ASSEMBLY

(1) CIRCLED NUMBERS REFER TO OPERATION POSITION

Tank Head Segments —The tank head gores will be bulge formed from sheets that have been machined to leave buildups for weld land area and fittings. The closeout cap will be spin-formed (see Figure 3.4.10). The use of explosive forming techniques may be desirable for gore forming and should be investigated more thoroughly than was done during the study. This may result in better quality parts and less expensive tooling.

Structure (Other Than Tanks) —Details of structure other than tanks will be similar to components that have been produced by the airframe industry for many years. The required processes have been defined generally in Figures 3.4.1-11, -12, and -13. A major problem — part size — complicates handling.

Plumbing, Fittings, Wiring — Miscellaneous material for the sensitive interconnections between major assemblies of the liquid stage will be readily producible using techniques well known to the industry.

### 3.4.1.4.4 Assembly Methods

The assembly methods proposed for the liquid second stage are discussed under the categories of subassembly, final assembly, test, and integration. To fully appreciate the significance of the task involved, it should be remembered that almost all subassemblies are at least 70 feet in diameter and that their weight is up to 15 tons, that the $LH_2$ tankage weighs 60 tons, the $LO_2$ tankage 45 tons, and that total stage structural weight is 145 tons. This presents the requirement that all jigs and all handling equipment be of rigid construction. The assembly methods must be selected to allow for minimum transfer of parts during the manufacturing process. The manufacturing flow is illustrated in Figure 3.4.1-7.

Subassembly — The structure has been sequenced into subassemblies of heads, sidewall hoops, slosh suppression panels, and external structure assemblies. These are discussed more fully below.

Head Subassembly — The head subassembly operation has been detailed in Figure 3.4.1-10. It is proposed that the slosh suppression details be installed prior to head assembly. While this will create some problems in joining the hoop assemblies, it will allow maximum completion in the subassembly position and will permit more thorough cleaning after the baffles are installed. It will also reduce the amount of scaffolding required during baffle installation.

The heads will be tested and cleaned after assembly. Testing at this point is desirable as detection of failure will result in less rework problems than would detection of failure after tank assembly. This operation may be discontinued after experience is gained in the production processes and more confidence is warranted in the welded joints.

BLANK

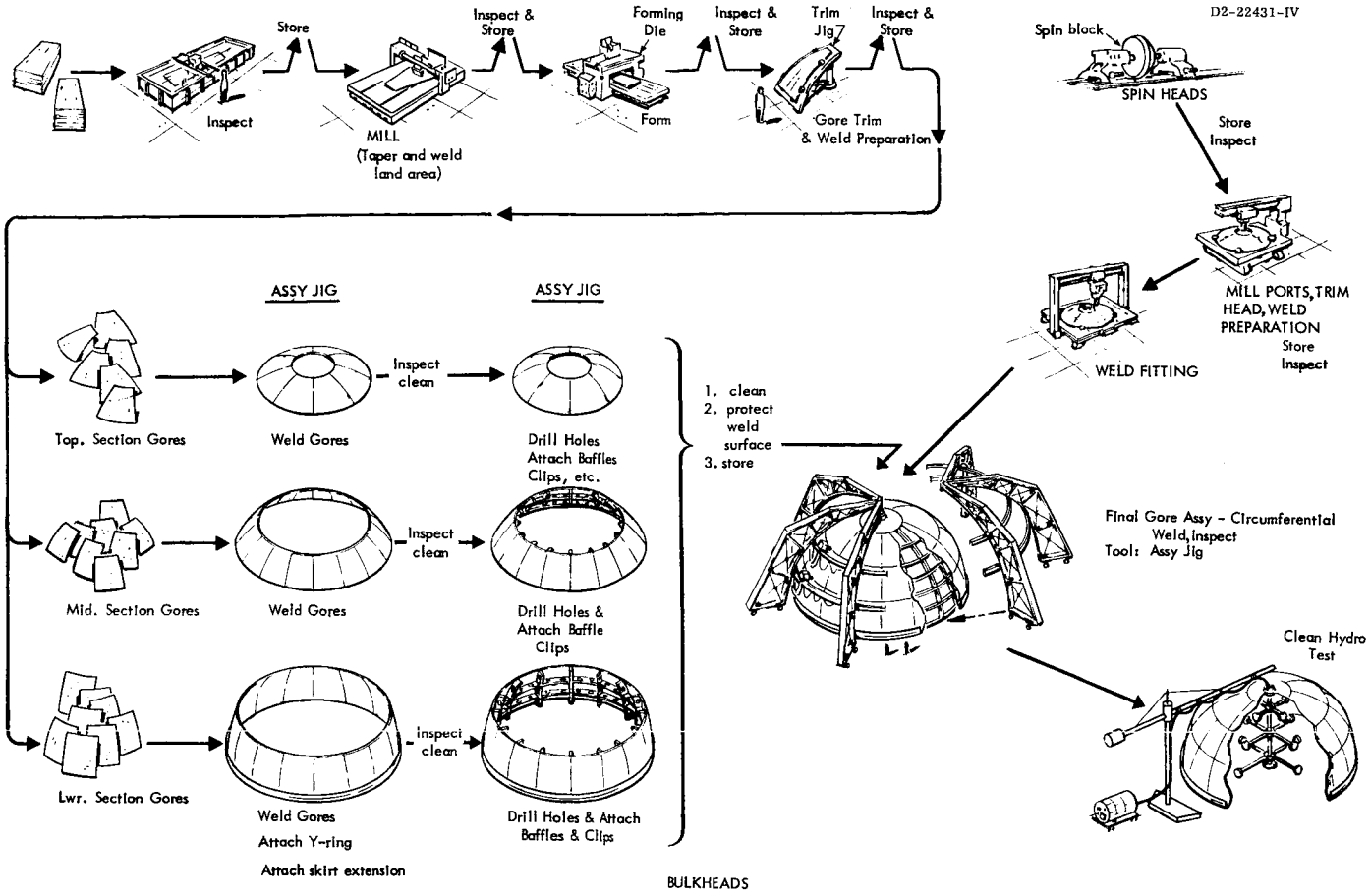



Figure 3.4.1-10 TYPICAL HEAD MANUFACTURE

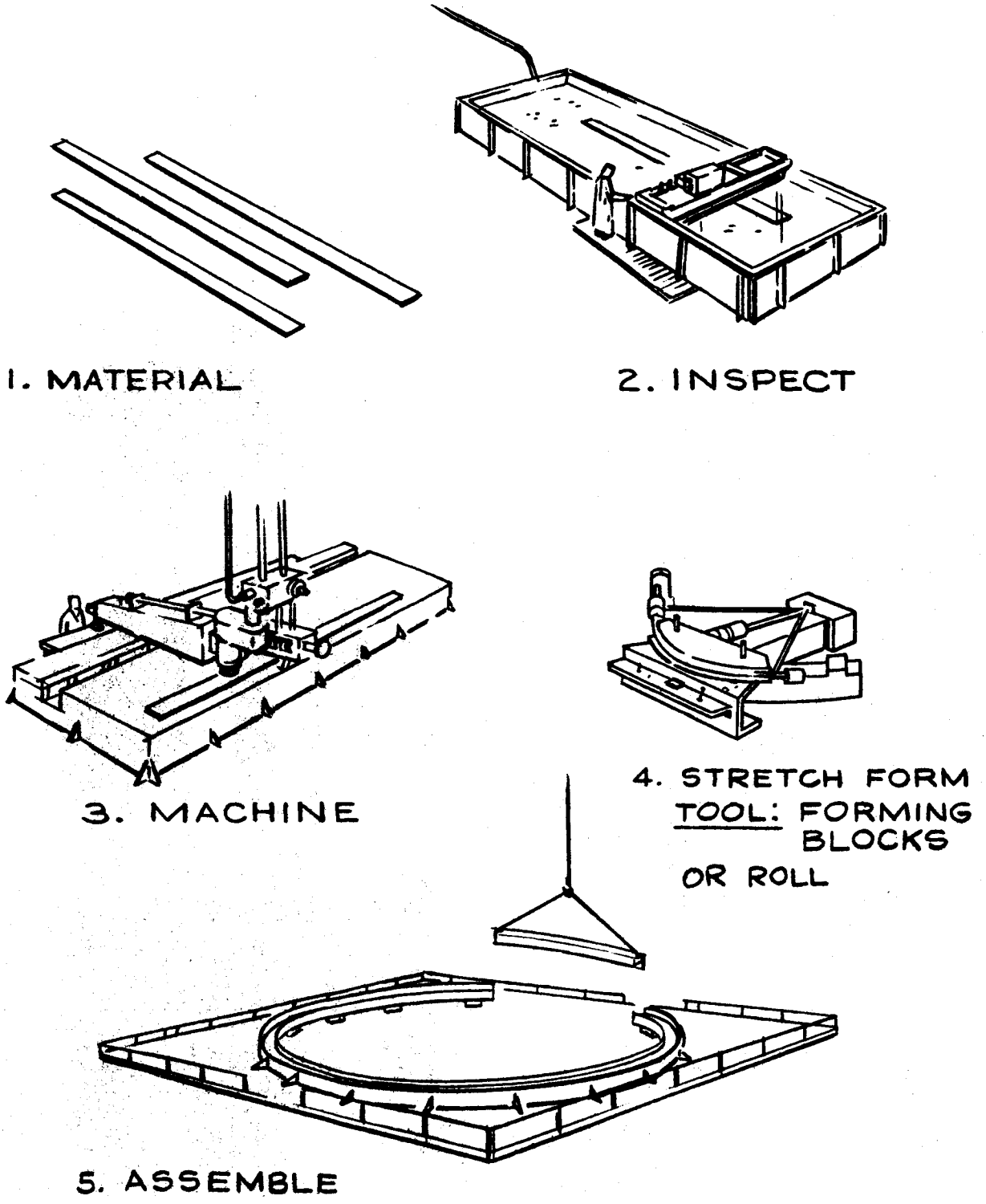



Figure 3.4.1-11 THRUST STRUCTURE KICK RINGS

Sidewall Hoops Subassembly — The tank wall hoops will be formed from relatively short rolled segments in a floor assembly jig (illustrated in Figure 3.4.1-9). Coordination of the hoops will be maintained through circumference control with pi tape check. The top and bottom interfaces will be kept plane with a level check. After completion of welding, the welds will be inspected and stress relieved. Slosh suppression structure will be installed and the assembly will then be cleaned.

A second assembly method that was considered consisted of joining the skin segments before forming, machining the waffle in that flat, and then forming the long sheet into the desired hoop. The advantages and disadvantages of each method are indicated in Table 3.4.1-8. It was decided that no significant savings could be anticipated through use of the latter method and the former was adopted.

Slosh Suppression Panels — The slosh suppression structure will be formed into subassemblies that can be installed into the head and tank sidewall subassemblies with minimum work. These parts are of ordinary airframe structure and will involve no unusual treatment except that a high degree of cleanliness must be maintained during assembly and that all parts must be thoroughly cleaned after assembly.

External Structure Assemblies — The structure assemblies that are not pressure vessels will consist of the thrust structure, the intertank structure, the aft skirt (or interstage), the forward skirt, and the $LO_2$ tank skirt. The assembly of these structures will involve no techniques that are new to the airframe industry. Adequate scaffolding must be provided in each case and in some instances (e.g., the intertank structure), rather large scaffolds will be required. Methods of assembly are indicated in a general way in Figures 3.4.1-12 and 3.4.1-13.

Final Assembly — Final assembly of the tank was defined as the closeout of the welded subassemblies for the $LO_2$ and the $LH_2$ tank. The two tanks are quite similar, and the $LO_2$ tank assembly will be discussed only as it differs from the $LH_2$ tank assembly.

The assembly sequence and production breaks that were selected for the final assembly of the tanks resulted from both reliability and producibility considerations. It was decided that, since the circumferential welds have less pressure-created stress than the longitudinal welds, they should be the closeout welds. (This reasoning assumes that longitudinal welds may be inspected more effectively in the subassembly position.) The assembly sequence further allows trim of head and sidewall hoop assemblies to correct for mismatch at final assembly. Consequently, the mismatch of detail parts will not be as critical; this will permit looser tolerances during fabrication. Critical coordination will also be reduced to circumferential control and maintaining planar conditions between subassembly interfaces.

## COMPARISON OF TANK WALL HOOP ASSEMBLY METHODS

### SHORT SHEETS
(Machined, Formed, Then Welded)

Advantages:

1. Smaller Pieces
2. Can check hoop accuracy prior to weld
3. Can machine final tolerances after rolling and welding
4. Less storage area required for details
5. Easier if brake forming method is used

Disadvantages:

1. More interfaces when fixturing welding hoop
2. Welded in position allowing stress in hoop due to weld shrinkage
3. Must trim and mill after rolling
4. Elaborate weld, trim, and stress relief fixture required
5. Welded in vertical

### LONG SHEETS
(Welded Together, Machined, Then Formed)

Advantages:

1. Fewer interfaces when welding hoop
2. Can weld most of hoop in flat in down-hand position
3. Can stress relieve most of hoop in flat
4. Inspection of welds easier
5. Can do all machining on skin mill (stiffeners, edge trim, weld preparation)
6. Welded in free position
7. Less tooling required for assembly

Disadvantages:

1. 10-ton piece to handle while machining and forming
2. Must roll weld areas (subject to cracking)
3. Need second weld fixture for last weld
4. Larger storage area required
5. More difficult to check hoop before final weld

Table 3.4.1-8

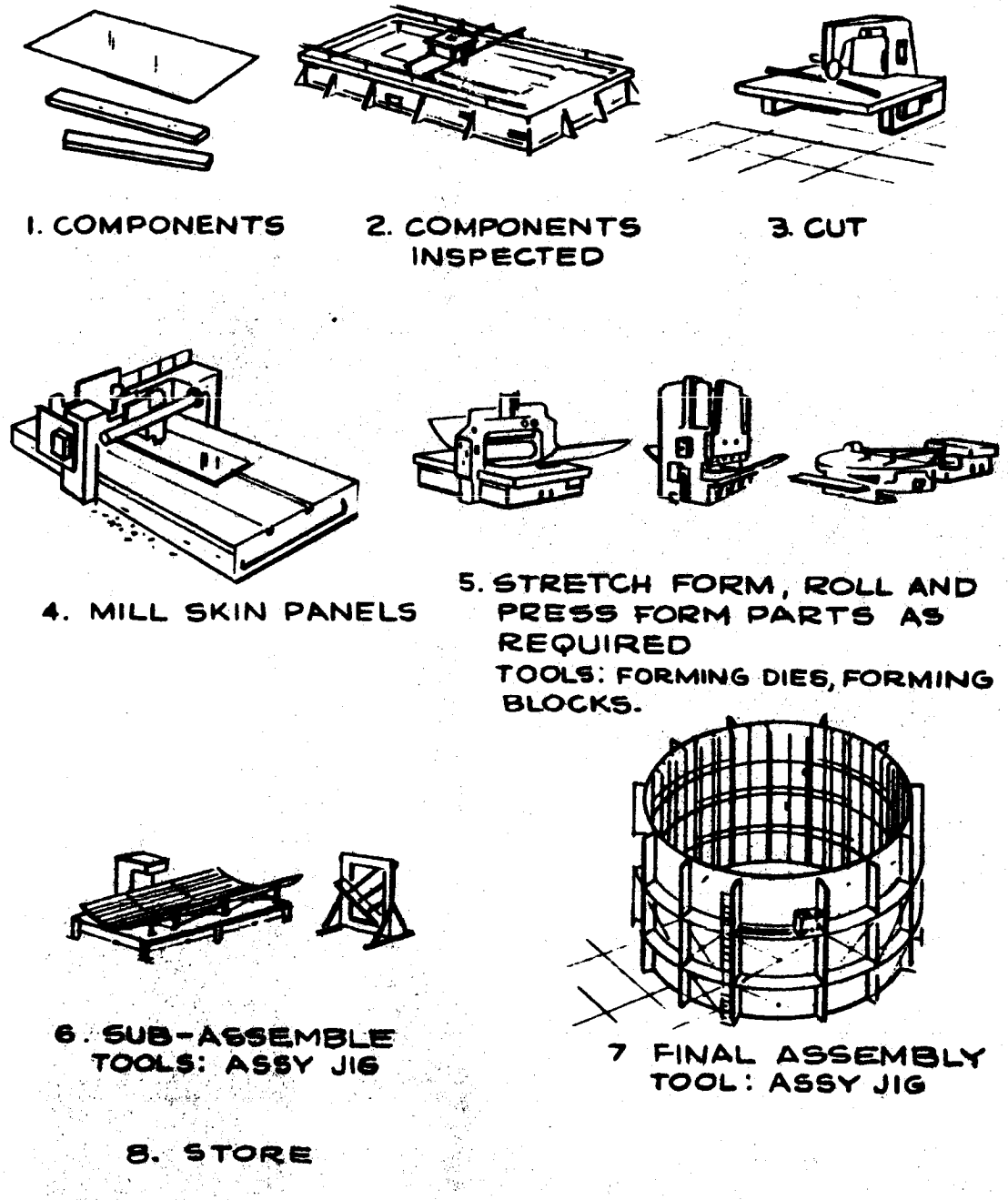



Figure 3.4.1-12 INTERTANK STRUCTURE SUBASSEMBLY
Typical Oxygen Tank Skirt and Forward and Aft Skirts

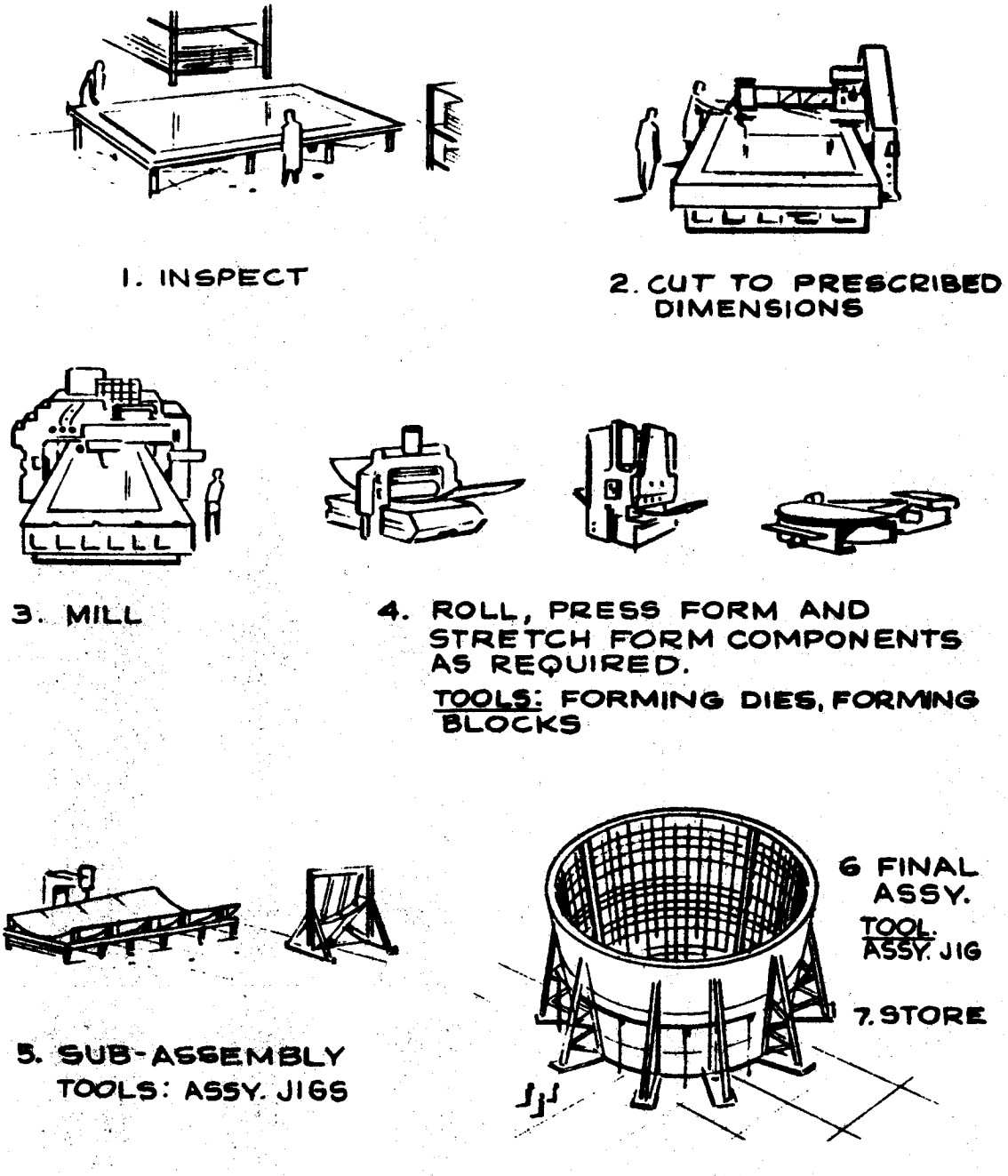



Figure 3.4.1-13 THRUST STRUCTURE

$LH_2$ Tank Assembly — The $LH_2$ tank can be assembled in a vertical jig in an operation similar to that proposed for Saturn S-IC. The major variance from Saturn will be in part size. The tank assembly operation is shown in Figure 3.4.1-14. The internal drilling and riveting operations required during final assembly will be done under stringent cleanliness specifications, and the hand tools will be provided with vacuum suction attachments to reduce chip dissemination to a minimum. Internal work platforms can be the hydraulic elevator type that adjust to the work level required. Work platforms for final aft head closeout will be of the portable type.

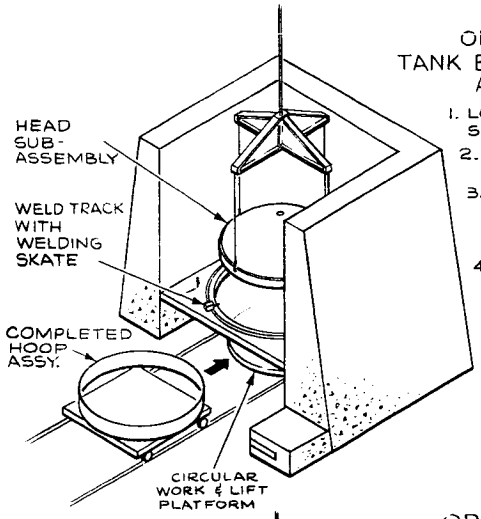
The decision to use a vertical rather than horizontal assembly jig for tank assembly was based on the fact that this procedure eliminates gravity side effects. This will be of considerable importance in assembling so large a structure. The method will also allow almost all final assembly operations at one level, thus permitting constant equipment settings for welding, placing workmen at the lowest possible level for greater safety, and creating a better situation for operation coordination.

$LO_2$ Tank Assembly — $LO_2$ tank assembly will require only that the closeout weld be made joining the Y rings of the two head subassemblies. This will be done in much the same manner as that described for the $LH_2$ tank. Since $LO_2$ is very sensitive to the presence of organic matter, stringent operating specifications will be required to prevent contamination of the tank. A complication that must be considered in assembling the $LO_2$ tank is the provision of tunneling for the $LH_2$ transfer plumbing. Fittings for this tunneling must be coordinated throughout the manufacturing operation.

Hydrostatic Test — The tanks will be hydrostatic proof tested in a special test facility in a vertical attitude. Noted failures will be repaired and the tank retested. The tanks will then be cleaned before vehicle integration. A special hydrostatic test tank will be required. It must simulate the static head of $LH_2$ by external pressure to the $LH_2$ tank. This will be a problem area.

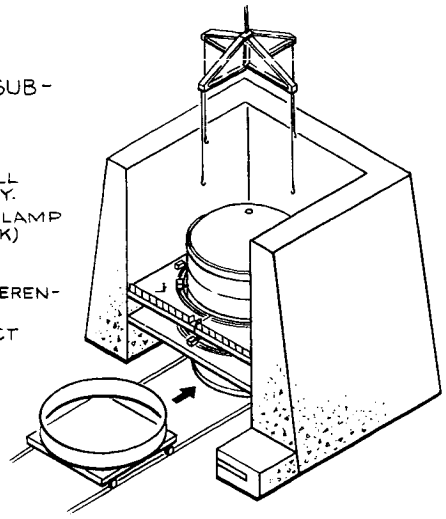
Stage Integration — The stage will be integrated in a vertical assembly facility. The operation will consist of mating the two tanks with the external structural assemblies and installation of the plumbing, electrical and electronic equipment, and insulation. Minor assemblies and engines will be installed after the integrated stage is transferred to a reusable GSE handling pallet. This pallet will accompany the stage throughout the test operations and will also have provisions to hold the interstage structure when the stage, dolly, and interstage are shipped to AMR (see Figure 3.4.1-15).

Manufacturing Test — The complete flight stage will be tested with all possible systems installed. The test will require production-type test equipment and test procedures. The tests will be functional nondestructive quality control tests for electrical and mechanical systems and will be conducted at the stage assembly



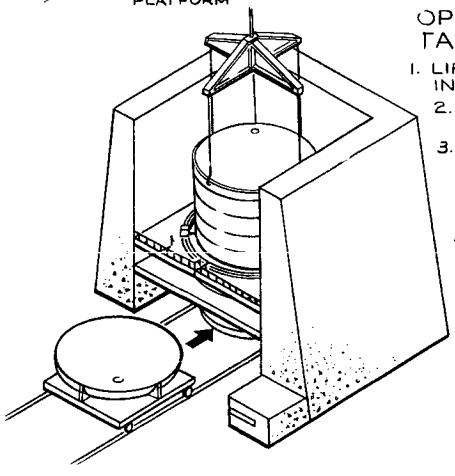

OPERATION #1
TANK BODY SHELL SUB-ASSEMBLY

1. LOAD FWD. HEAD SUB-ASSEMBLY.
2. LOAD SIDE WALL SUB-ASSEMBLY.
3. FIT PARTS & CLAMP (VACUUM CHUCK) INSTALL WELD BACK-UP BARS
4. WELD CIRCUMFERENTIAL JOINT
5. X-RAY, INSPECT
6. REPAIR



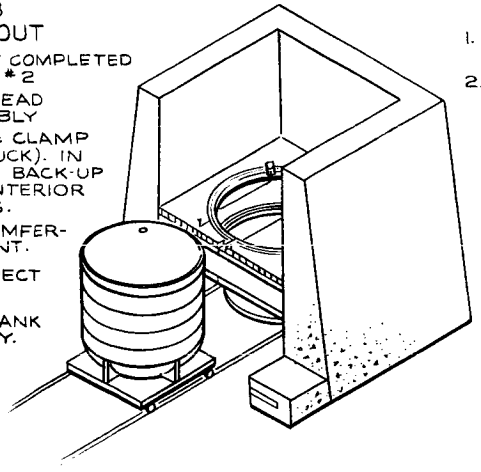
OPERATION #2
TANK BODY SHELL SUB ASSEMBLY

1. LIFT ASSEMBLY COMPLETED IN OPERATION #1
2. LOAD SIDE WALL SUB-ASSEMBLY
3. FIT PARTS & CLAMP (VACUUM CHUCK). INSTALL WELD BACK-UP BARS.
4. WELD CIRCUMFERENTIAL JOINT.
5. X-RAY INSPECT
6. REPAIR
7. REPEAT OPERATIONS 1-6.



OPERATION #3
TANK CLOSE OUT

1. LIFT ASSEMBLY COMPLETED IN OPERATION #2
2. LOAD AFT HEAD SUB ASSEMBLY
3. FIT PARTS & CLAMP (VACUUM CHUCK). INSTALL WELD BACK-UP BARS AND INTERIOR PLATFORMS.
4. WELD CIRCUMFERENTIAL JOINT.
5. X-RAY, INSPECT
6. REPAIR
7. BUY OFF TANK WELD ASSY.



OPERATION #4

1. UNCLAMP - REMOVE TOOLING FROM TANK
2. REMOVE COMPLETED TANK ASSY. FROM JIG. ROUTINE TOOL.

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TO CHEMICAL CLEANING AND HYDROSTATIC TEST

**Figure 3.4.1-14 TANK SIDEWALL AND FINAL ASSEMBLY**

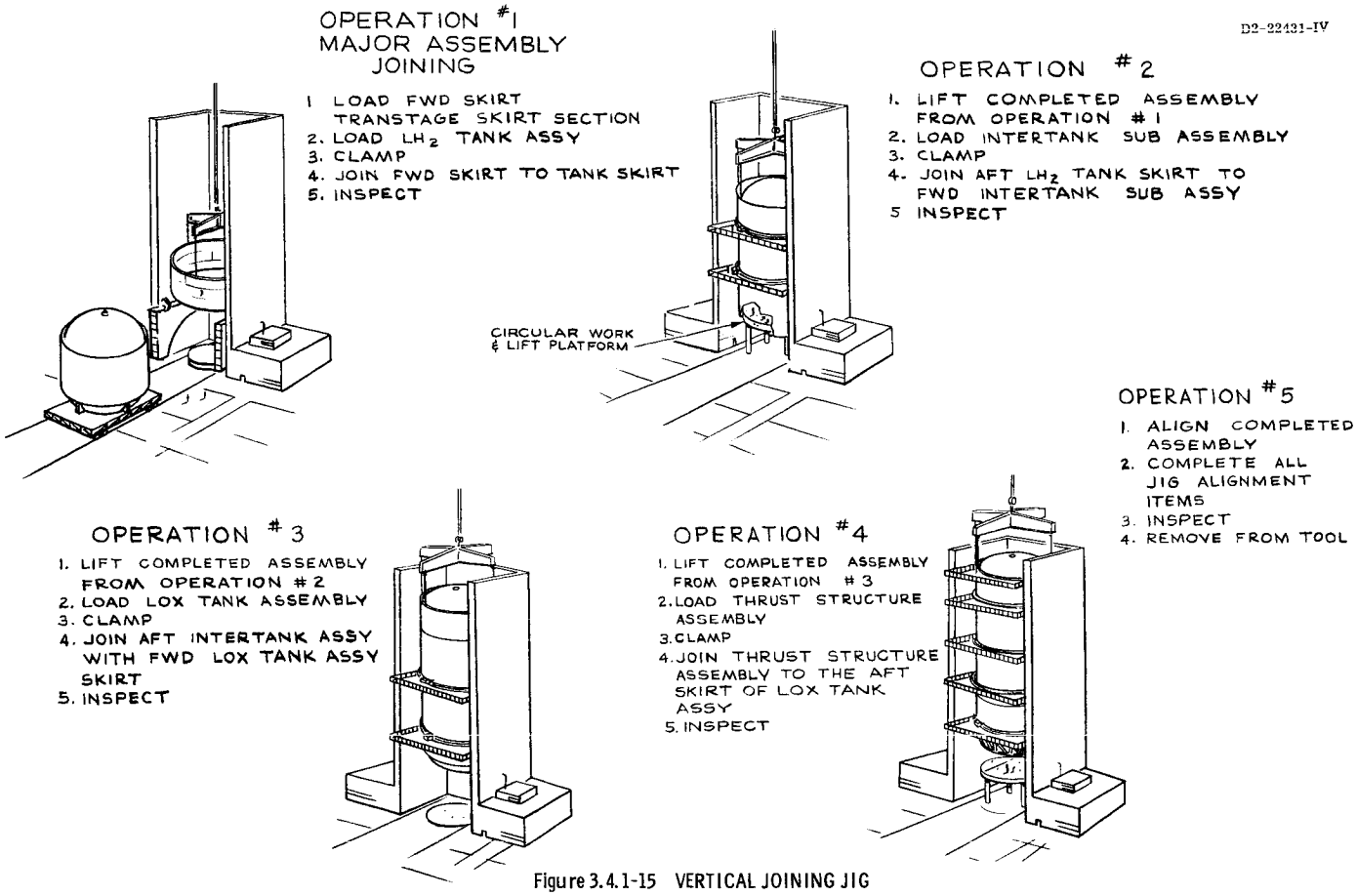


Figure 3.4.1-15 VERTICAL JOINING JIG

site. The tests will be repeated, as required, after necessary refurbishment and repair following firing tests. The development program will establish procedures and acceptance limits.

3.4.1.4.5 Manufacturing Development Requirements

The list of foreseeable manufacturing technology problems tends to emphasize welding and forming operations on the structure. The development task is defined as a scale-up of Saturn V technology. It is reasonable to expect that the scale-up task will require considerable development effort and that the development schedule will be influenced by the progress of the Saturn effort.

The forming technology development program includes the forming of head gores and integrally stiffened tank wall skins. Long lead time equipment items may require purchase prior to R&D contract award to meet parts fabrication schedules.

The welding technology will be a direct extension of Saturn development programs. Although the tank material is the same (2219 aluminum alloy), the production parts are much larger, and some development work is required to verify the processes.

Likewise, the cleaning of cryogenic tanks and lines will depend heavily upon technology developed on Saturn. Changes in internal baffle configuration and line routing, and the increased size of the assemblies in general, will require a review of cleaning technology.

To place each of the individual development tasks in the proper perspective, a more complete identification of the problem and an approach to achieving the most promising solution are provided in Table 3.4.1-9.

3.4.2 Manufacturing Facilities

3.4.2.1 Introduction

The extreme size of the NOVA vehicle will create extensive manufacturing facility (building and equipment) requirements because many operations exceed the capability of existing facilities. Another difficulty will be that certain operations could be performed in existing facilities but the product would be too large to be shipped to the launch site or next location for integration with other parts of the vehicle. In spite of these difficulties, there are many parts of the vehicle that may be manufactured in existing facilities and shipped to new facilities where they will be incorporated into larger units. In addition, existing facilities and workaround methods will have to be used in some cases early in the program to prevent delays while more efficient and effective new facilities are provided.

3.4.2.2 Summary

The facilities required for this program will be a combination of existing and new facilities as outlined in the Introduction. Maximum use will be made of

DEVELOPMENT TASKS

| PROBLEM IDENTIFICATION | DEVELOPMENT PLAN |
|---|---|
| Electron-beam weld | Determine applicability of electron-beam welding to Y-ring fabrication |
| Weld joint sensing | Survey and analyze marketed joint sensing equipment for its adaptability to joint configurations. |
| Weld joint edge preparation | Determine the optimum weld joint edge preparation for the joint configurations used. Determine weld shrinkage factors that affect detail fabrication and tool design. Establish weld schedules for the material gages in the design. |
| Adaptation of weld equipment to assembly tooling | Determine trackage and carriage adaptability of equipment. Determine the control and adjustment required to produce acceptable welds. Develop backup and chill bar configurations. Investigate the warpage problems and determine fit-up condition providing the best weld latitude. |
| Weld repair | Investigate possible defects and determine the factors that lead to successful repair of these defects. Develop weld bead removal procedures. |
| Clean $LO_2$ and $LH_2$ tanks and lines to cryogenic requirements | Establish requirements for closed-cycle cleaning equipment, evaluate various spray heads, fittings, filters, etc., and investigate methods of maintaining cleanliness of completed parts. |
| Equipment and fixtures for machining 70-foot-diameter Y ring | Design and lay out Y-ring spar milling machine. |
| Forming of tank gores | Determine, through a development test program, the bulge-form tool requirements to size tank gores. |

Table 3.4.1-9

DEVELOPMENT TASKS

| PROBLEM IDENTIFICATION | DEVELOPMENT PLAN |
|---|---|
| Forming equipment | Determine the most economical types and the quantities of equipment required to form large structural components. |
| Form 10-foot-diameter tank polar domes | Tooling requirements and the number of stages will be determined. Subscale tests will be run to establish and confirm forming parameters. |
| Weld equipment evaluation | Survey and analyze available equipment. Determine the equipment most suitable for needs. |
| Weld area stress relief | Determine methods of obtaining optimum relief of stress in weld joints. |
| Fabrication and installation of insulation | Determine processing requirements for fabricating insulating panels. Investigate assembly techniques. |

Table 3.4.1-9 (Cont.)

existing facilities to reduce program cost, to make use of existing organizations and prevent relocation of manpower, and to prevent delays encountered in obtaining new facilities. The first-stage clustering structure and skirts may be made in existing facilities because they can be shipped in sections and reassembled later. Transtage propulsion systems and TVC systems are within the size that they can be furnished from existing facilities. While some supplementary equipment items will be required, first-stage motor cases and nozzles can be furnished from existing facilities.

New facilities will be required for first-stage motor manufacturing, second-stage manufacturing, and second-stage engine manufacturing. In all cases, the products are of the size or weight that they exceed the capability of existing facilities and require access to water transportation systems for movement to the launch and test sites.

### 3.4.2.3 First Stage

Items to be manufactured for the first stage are the motors, motor cases, nozzles, clustering structure, skirts, and thrust-vector-control system (TVC). The size of the TVC components are such that they can be manufactured in existing facilities and shipped by rail or highway to the various assembly locations. The clustering structure and skirts are basic aircraft-type structural components that do not require new facilities for fabrication and assembly. The assemblies, however, are too large to ship by conventional means as unit items; they must be sectionalized and reassembled at their destination.

The first-stage motor cases are extremely large and heavy items that will require barge shipment to the motor manufacturing plant. The fabrication and assembly of the cases is within the basic capability of a number of existing ship-building facilities. These plants have the large buildings with heavy crane coverage, the water shipping access, and much of the fabricating equipment required for manufacturing these cases. Existing facilities, with some limited equipment additions, will be capable of manufacturing the battleship cases and early test cases using workaround methods. Considerable additional equipment, such as automatic welding, heat treating, and special forming and machining equipment, will be required to make the large quantity of improved flight cases required later in the program. Peak production rates may require that more than one source be used for this phase of the program or that an assembly plant be supported by other plants performing fabrication or subassembly operation. A list of new equipment requirements is provided in Table 3.4.2-1.

The nozzle for the first-stage motor can be manufactured in a number of existing facilities, but it will require transportation by water to the motor manufacturing plant. Present methods of manufacturing will require the addition of a large autoclave for bonding the ablative lining, since no facility of this size is available now.

SOLID NOVA STUDY — PHASE III
First-Stage Motor Case
Major Manufacturing Equipment

| Item | Quantity (5/Mo Rate) | Lead Time (Weeks) |
|---|---|---|
| Pressure Test Facility Complete, test pressure, 800 psi with hot-air supply for case drying (one position) for 260-inch diameter | 1 | 29 |
| Spray Facility (Paint and Oil) Complete (one position) for 260-inch diameter | 1 | 22 |
| Vertical Boring Mill, 25-foot diameter 12-foot clearance with two heads and tracer attachment | 9 | 73 |
| Vertical Boring Mill, 16-foot diameter 10-foot clearance with two heads and tracer attachment | 4 | 61 |
| Radial Drill Press, 96-inch arm | 1 | 25 |
| Portable Radial Drill Press, 72-inch arm | 1 | 25 |
| Oxyacetylene Cutting Facility, with cutting table for 12-foot by 70-foot plates and four gantry-mounted automatic cutting heads complete with accessories | 1 | 22 |
| Press Brake, Mechanical or Hydraulic, 12-foot, 0.750 capacity | 1 | 32 |
| Power Bending Rolls, 12 feet long, 0.750-inch plate roll to 260-inch diameter | 1 | 24 |
| Bulge-Forming Facility, complete with hydraulic power source, ram, die bed, and all supporting structures for 0.320-inch plate 11.3 feet, 7.7 feet by 9 feet to 260-inch diameter (gored dome sections) | 2 | 52 |
| Dry Blast Facility, complete with recovery system and four blast nozzles | 1 | 24 |
| Vacublast Portable, with one nozzle | 15 | 8 |
| Heat Treat Facility for Aging Maraging Steel, 900°F ± 25°F maximum part size 25 feet by 25 feet by 50 feet | 1 | 58 |
| Boom Manipulator, with 500-amp automatic MIG welding head 30 feet horizontal travel, 30-foot vertical travel, complete with power supply | 15 | 37 |

Table 3.4.2-1

SOLID NOVA STUDY —PHASE III
First-Stage Motor Case
Major Manufacturing Equipment

| Item | Quantity (5/Mo Rate) | Lead Time (Weeks) |
|---|---|---|
| 500-Amp Automatic MIG Welding Head Mounted on Radiagraph, complete with power supply 12-foot vertical travel and track | 5 | 24 |
| Manual TIG Welder, 500-amp, complete with power source | 40 | 12 |
| Power Driven Tank Rolls, for 260-inch diameter tanks synchronized drive full length | 10 | 31 |
| Weight and Balance Facility for Case, 260-inch diameter | 1 | 19 |
| Portable Milling Heads, 3-inch cutter with travel carriage and track | 25 | 16 |
| Portable Drill Head, 1-inch diameter capacity drill and tap, broken arm 12-foot magnetic base | 10 | 25 |
| Induction Coils and Power Source for Aging Weld Areas, 900°F for three hours (internal and external coils) | 24 | 36 |
| **First-Stage Nozzle** | | |
| Autoclave for Plastic Bonding, 350°F, 300 psi, part size 25-foot diameter by 25 feet long | 1 | 52 |

Table 3.4.2-1 (Cont.)

Complete new motor manufacturing facilities will be required for this program. It is anticipated that one or more research facilities will be constructed for the 260-inch demonstration program that will have the capability of satisfying the initial requirements for this program. These facilities will have to be expanded considerably early in the program to provide the capability of handling the production rates. The facilities required for motor manufacturing will be:

- A case processing facility where motor cases will be cleaned and the lining and insulation installed; here also, other inert operations such as mandrel preparation and maintenance will be performed;
- Raw material preparation facilities for the fuel and oxidizer will be required along with storage facilities for these materials;
- Propellant mixing facilities;
- Casting and curing facilities;
- Motor finishing facilities were nozzle installation and other operations prior to shipping the motor will be performed;
- Static firing facilities for full-scale single motors.

The motor manufacturing plant will be designed to incorporate the basic handling scheme developed for the first-stage motors. After all operations are performed at this plant, the motor on its strongback will be loaded upon a barge for transfer to the solid-motor substage assembly facility.

The solid-motor substage assembly facility will be provided along the waterway enroute from the motor manufacturing plant to the launch site. Here motors will have the lower-skirt, thrust-vector-control system, instrumentation, and other accessories installed to complete all operations that may be performed prior to erection of the motor at the launch site. Motors will be stored at this site in their environmental containers until required at the launch site. To accommodate the peak requirements for the Mars mission without building excess productive capacity, storage facilities for 39 motors will be required. The solid-motor substage assembly facility will consist of dock facilities for receiving and shipping the motors, individual hazardous work buildings, an inert material receiving inspection and work building, office and site support facilities, and motor storage facilities. Throughout this facility the motor will be handled horizontally on its strongback using the first-stage motor handling scheme. A schematic diagram of this facility is provided as Figure 3.4.2-1.

### 3.4.2.4 Second Stage

Second-stage manufacturing facilities consist primarily of the M-1 engine manufacturing facilities and the stage structure manufacturing facilities. New facilities for both of these items will be required. No data is available for the engine facilities; however, it can be assumed that large machining equipment located in a high bay crane-covered building will be required. In addition, extensive

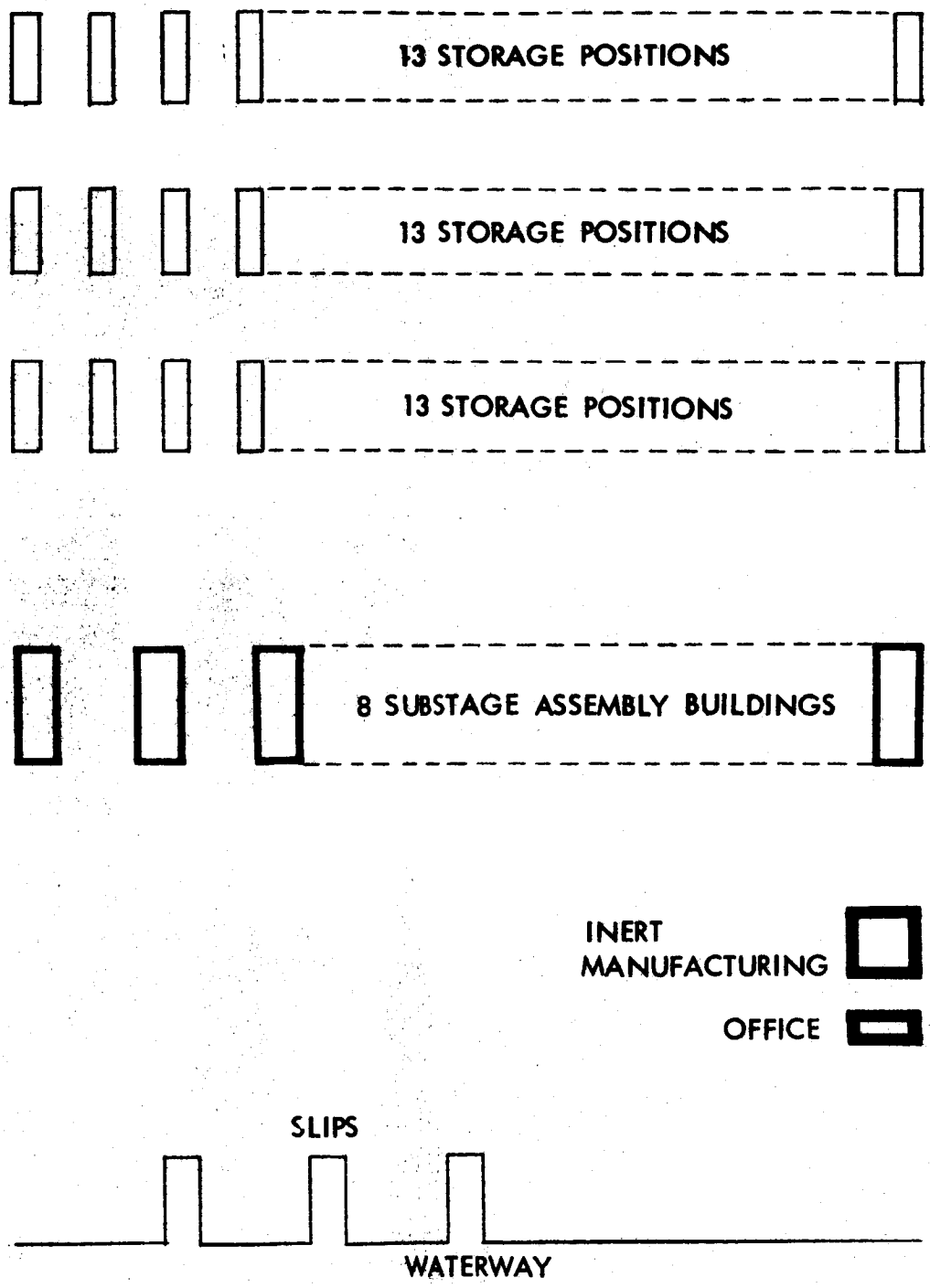


Figure 3.4.2-1 SOLID MOTOR SUBSTAGE ASSEMBLY FACILITY

engine test facilities will be required. These facilities will require access to a navigable waterway for all off-site transportation.

The second-stage manufacturing facility will be a unique facility having large high bay crane-covered areas for subassembly operations and an extremely high bay heavy-crane-covered area for final assembly, hydrostatic test and cleaning, and refurbishing of the large liquid stage. This facility would be similar to, but larger than, the facility provided at Michoud for the S-IC. Like the S-IC, maximum use of existing facilities would be made for tooling and fabrication support. However, when the part or assembly size exceeds the capability of existing facilities or transportation methods, the function would be performed at the new facility. Construction of this plant will have to precede manufacturing of the stage since no existing facilities or workaround methods can be substituted for even the earliest stages. Because the size of this facility and the equipment provided in it are specifically provided to accommodate the large diameter (and length) of this stage, these facilities will also be used to manufacture the first stage-second stage interstage and transtage structure, which are also of this diameter. A schematic layout of this plant showing floor area, building heights, and crane capacities is provided in Figure 3.4.2-2. A list of major capital equipment requirements is included in Table 3.4.2-2.

### 3.4.2.5 Transtage

Most of the components of the transtage propulsion system are of the size that they can be produced by existing facilities. This includes engines, tanks, plumbing, and accessory hardware. Existing engine test facilities are also capable of accommodating this system. The size of the stage structure, however, is the same as the major diameter of the vehicle and will, therefore, be manufactured at the second-stage manufacturing plant. Transtage propulsion units will be shipped to the Cape for installation in the structure.

SOLID NOVA VEHICLE
SECOND STAGE FACILITY

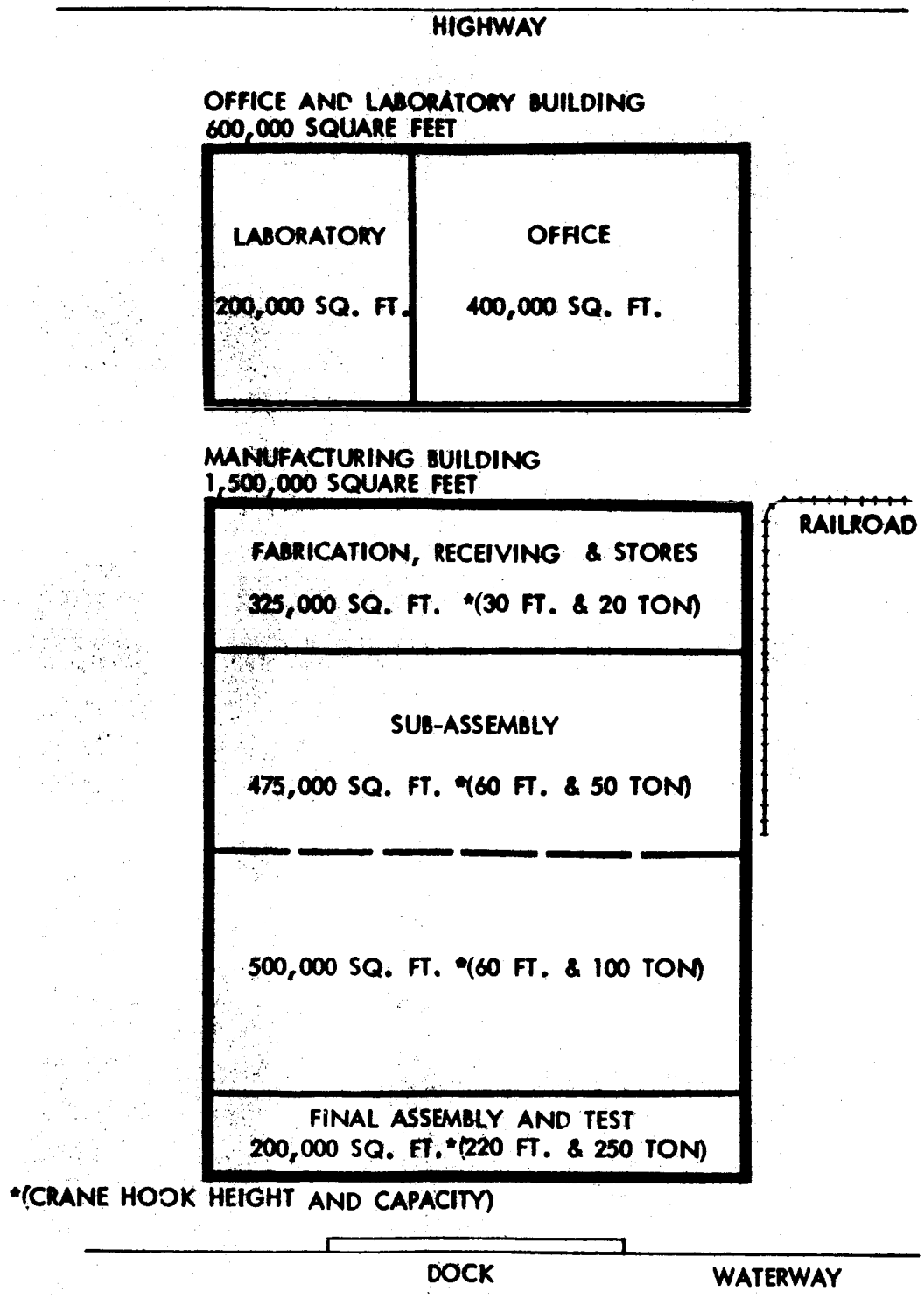


Figure 3.4.2-2 SECOND-STAGE FACILITY

SOLID NOVA STUDY — PHASE III
Second Stage
Major Manufacturing Equipment

| Item | Quantity (1/Mo Rate) | Lead Time (Weeks) |
|---|---|---|
| Skin Mill N.C. Multiple Spindle (6), 12- by 80-foot bed with vacuum chuck | 2 | 64 |
| Automatic Deburring Facility, for 36 parts 10 by 25 feet and 176 12- by 15-foot parts per month | 1 | 23 |
| Bulge Forming Facility, complete with three die positions for gores 12 feet by 15 feet by 2 inches aluminum | 1 | 52 |
| Spin Lathe, 12-foot diameter for 2-inch aluminum | 1 | 52 |
| Aluminum Chemical Mill Facility, vertical, for 12-foot-diameter head | 1 | 44 |
| Automatic MIG Welder, 500-amp, complete with power supply, wire feed to be mounted on contract tooling | 18 | 22 |
| Plate Rolls, for 12-foot width, 2-inch-thick aluminum | 1 | 30 |
| Milling Head for Edge | 16 | 18 |
| Radiant Heat Source Bank, 10 feet long for weld stress relief | 1 | 18 |
| Vertical Boring Mill, 75-foot-diameter (tool fabrication and Y-ring machining) | 2 | 72 |
| Radiant Heat Source Bank, 24 inches long, for weld stress relief | 2 | 18 |
| X-ray Equipment for Weld Inspection | 7 | 38 |
| Electron-Beam Welder, 30kw for Y-ring welding | 1 | 22 |
| Weight and Balance Facility Detail Parts and Assemblies | 1 | 32 |
| Hydrostatic Test and Cryogenic Cleaning Facility, vertical positions, assembled, tank 70-foot diameter by 200 feet high | 1 | 52 |

Table 3.4.2-2

SOLID NOVA STUDY — PHASE III
Second Stage
Major Manufacturing Equipment

| Item | Quantity (1/Mo Rate) | Lead Time (Weeks) |
|---|---|---|
| Cryogenic Cleaning Facility for Plumbing, with pressure test equipment, approximate maximum pipe size 35-inch diameter by 100 feet long | 1 | 44 |
| Painting Facility Complete, vertical | | |
| 70-foot diameter by 200 feet high position | 1 | 42 |
| 50- by 50-foot position | 2 | 42 |
| Weight and Balance Facility, position 70 by 200 feet | 1 | 32 |
| Cleaning Facility, for detail parts prior to assembly, bonding and welding maximum part size 12 by 25 feet, 500 per month plus detail structural parts | 1 | 44 |
| Curing Oven, 15 by 15 by 30 feet long for bonding, including vacuum source | 3 | 28 |
| Freon Sniffer Pneumatic Test Cart | 10 | 11 |
| Hydraulic Test Bench | 2 | 20 |

Table 3.4.2-2 (Cont.)

## 3.5 RELIABILITY

### 3.5.1 Introduction

Reliability studies have been conducted to:

- Determine the major areas of unreliability in solid- and liquid-propellant stages
- Assess the reliability of the T65D vehicle configuration
- Develop a plan by which reliability objectives can be achieved.

The T65D vehicle configuration is shown in Section 3.2.11, Figure 3.2.11-1.

The T65 vehicle, because of its size and performance, will require the development of a large amount of new equipment, manufacturing and handling technique, and operating procedures. High levels of reliability of the standard article are necessary to attain the program objectives. Consequently, there is a requirement for an extensive reliability effort in all areas of design, manufacturing, test, and use. Since much of the equipment to be developed will require reliability improvement over present levels, a reliability program with much more scope and depth must be implemented.

### 3.5.2 Summary

The distribution of flight failures by subsystem, for solid first stages and liquid second stages, was determined by analyzing the flight failure data from existing systems. It was found that propulsion and thrust vector control systems have been the major sources of flight failures. The liquid-propellant stages have experienced a higher percentage of failure than have the solid-propellant stages.

The assessed reliability of the T65D configuration is somewhat higher than can be predicted on the basis of historical data alone. This higher reliability is expected as the result of additional time for advancements in technology, additional launch operations experience, and increased emphasis on system reliability. The assessed reliability ranges from an initial value of 0.45 to an ultimate value of 0.90. A reliability program is proposed which is modeled after those being successfully applied by Boeing. Particular emphasis is placed on reliability aspects important to a low-density development and test program.

### 3.5.3 Reliability Evaluation

The reliability evaluation uses historical data, manufacturer's test and analytical data, and other analytical studies in the derivation of reliability assessments for the T65D. A more comprehensive treatment of the methodology and logic used in performing the analysis is described in Boeing document D2-20500, "Study of Large Launch Vehicles Utilizing Solid Propellants," Volume IV.

### 3.5.3.1 Method of Analysis

The method of analysis used involved examination of the distribution and types of failures which have occurred in flights of ballistic missile and space launch vehicles. Those subsystems that were shown historically to have been major areas of unreliability on current vehicles were analyzed and areas of possible improvement considered for T65D reliability predictions. These areas included advancement in technology and reliability growth as the result of experience with other vehicle systems. The overall T65D vehicle was assessed to include these improvements. Reliability growth was predicted from trends experienced on existing systems.

#### 3.5.3.1.1 Background Data

Historical data used in the analysis was derived from experience with Titan I, Atlas, Agena, Thor, Jupiter, Redstone, and Able for liquid-propellant systems. Polaris, Minuteman, Scout, and Pershing data were used for solid-propellant systems.

Analytical and test data were provided by Aerojet-General Corporation. Some of the Aerojet data are contained in "Final Report Failure Warning System for Large Solid Rockets," Report Number 0588-01F. Other inputs were provided informally. Boeing studies (D2-20500, "Large Launch Vehicles Utilizing Solid Propellants," and SSD-TDR-62-144, "Large Launch Vehicles Using Solid First Stages,") were also used as source material.

The following guidlines pertinent to reliability assessment and program schedule were used where applicable.

- The M-1 engine reliability goal of 0.99 at the end of qualification testing will be used in the reliability assessment of the flight vehicle.
- Vehicle flight reliability must be 0.75 before operational program implementation.

#### 3.5.3.1.2 Limitations of Data

Available data cannot be applied directly to the NOVA vehicle design for a number of reasons. Flight data is mostly confined to ballistic missiles and missile boosters modified for space mission launches. The missile boosters were designed for objectives other than those which must be emphasized for space vehicles. Modified missile boosters are specially selected and do not fall within the category of production articles.

The number of liquid-propellant second-stage flights is small. The total number of flights of all types of upper stages has been about 120. Liquid propellants used to date are $LO_2$/RP-1, IRFNA/UDMH, and similar propellants. Only one flight has been attempted with an $LO_2/LH_2$ second stage.

Available flight test data on solid systems was limited to 178 flights of Polaris, Minuteman, Scout, and Pershing. Flight data on large solid motors does not exist at this time. Emphasis was placed on the flight failures experienced in the first stage of current vehicles.

3.5.3.1.3 Distribution of Flight Failures

Liquid-second-stage reliabilities have ranged from 70 percent for the Titan I to 90 percent for the Able. The lower 90 percent confidence limit has ranged from 59 percent for Titan I to 80 percent for Able. The average flight reliability for the 120 second stages is about 79 percent. This compares to an average flight reliability of about 75 percent for the 427 liquid first stages.

Solid-first-stage reliabilities range from 81 percent for Polaris to 97 percent for Pershing. The lower 90 percent confidence limit is 75 percent for Polaris and 89 percent for Pershing. The average flight reliability is 87 percent for the 178 flights with a lower 90-percent confidence limit of 83 percent.

The distribution of flight failures by subsystem is tabulated in Table 3.5.3-1 for all stages. The liquid systems contained in the survey were the Titan, Atlas, Redstone, Jupiter, Thor, Able, and Agena stages. The solid systems consist of the Minuteman, Polaris, Scout, and Pershing stages. A comparison of the flight experience shows that the liquid stages have experienced a higher percentage failure in all subsystems except the mechanical thrust-vector-control subsystem. Propulsion and control systems have accounted for 82 percent of all failures in the solid stages and 67 percent of all failures in the liquid stages.

DISTRIBUTION OF FLIGHT FAILURES (ALL STAGES)
IN PERCENT OF TOTAL FLIGHTS

| Subsystem | Solid Propellant Stages | Liquid-Propellant Stages |
|---|---|---|
| Structure | -- | 1.4% |
| Control System (electrical) | 3.2% | 4.7% |
| Propulsion | 8.0% | 6.9% |
| Propellant Feed | -- | 5.3% |
| Thrust Vector Control (mechanical) | 2.9% | 1.0% |
| Separation | 0.5% | 1.4% |
| Electrical | 0.8% | 1.0% |
| Ground Support Equipment | -- | 1.7% |
| Guidance | 1.8% | 3.3% |
| Unknown | -- | -- |
| Total Flights | 372 | 565 |

Table 3.5.3-1

The distribution of flight failures by subsystem for solid first stages and liquid second stages is tabulated in Table 3.5.3-2. The table includes first-stage flights of Polaris, Minuteman, Scout, and Pershing and second-stage flights of Agena, Able, and Titan I. A higher percentage of failure was experienced in the liquid stages than in the solid stages. The propulsion and control systems accounted for 95 percent of all failures on the solid stages and 84 percent of all failures on the liquid stages.

DISTRIBUTION OF FLIGHT FAILURES (INDIVIDUAL STAGES)
IN PERCENT OF TOTAL FLIGHTS

| Subsystem | Solid Propellant First Stage | Liquid-Propellant Second Stage |
|---|---|---|
| Structure | -- | -- |
| Control System (electrical) | 1.1% | 1.7% |
| Propulsion | 5.0% | 6.7% |
| Propellant Feed | -- | 4.2% |
| Thrust Vector Control (mechanical) | 5.6% | 3.3% |
| Separation | -- | 0.8% |
| Electrical | -- | 2.5% |
| Ground Support Equipment | -- | 0.8% |
| Guidance | -- | -- |
| Unknown | 0.6% | -- |
| Total Flights | 178 | 120 |

Table 3.5.3-2

### 3.5.3.1.4 Reliability Growth Experience

The reliability growth of solid first stages and liquid second stages was investigated to establish the growth trends of existing stages. The Minuteman, Scout, Polaris, and Pershing first stages were used to represent the solids; the Able, Agena, and Titan I second stages were used to represent the liquids.

The solid-first-stage growth is shown in Figure 3.5.3-1 as a percent of successful launches. The success ratio of the Polaris stage shows a rapid growth from 0 percent at five launches to 50 percent at 10 launches. Growth continues to an 80 percent at 45 launches and remains fairly stable beyond this point. The other solid stages experience success initially, each experiencing only one failure in the quantity of launches for which data were available.

The liquid-second-stage growth is shown in Figure 3.5.3-2 as a percent of successful launches. The liquid stages experienced less success than did the solid stages. The Able stage has experienced the most success, having only three failures in 32 flights. The Titan I started high initially while the Agena

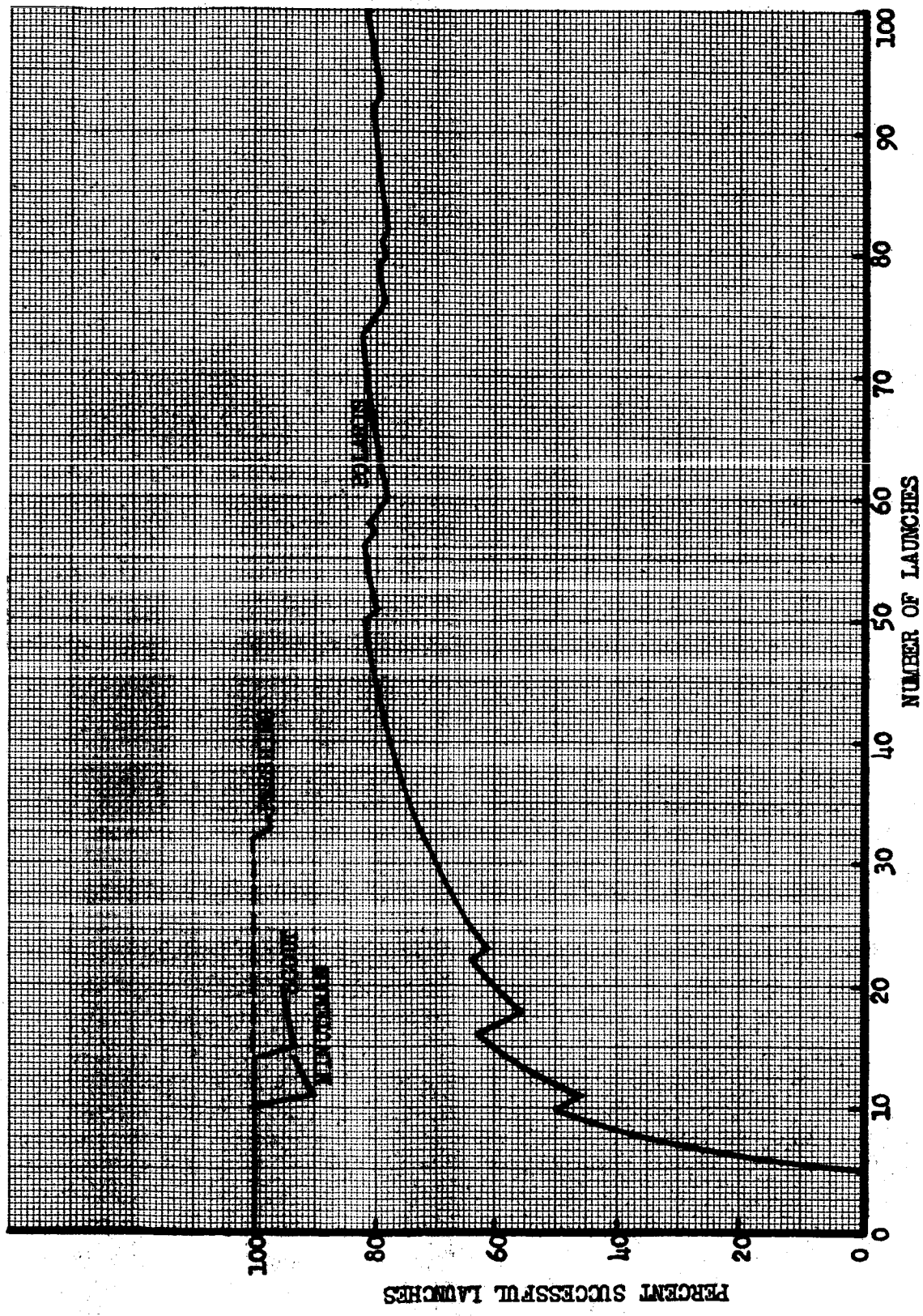


Figure 3.5.3-1 SOLID FIRST-STAGE RELIABILITY GROWTH

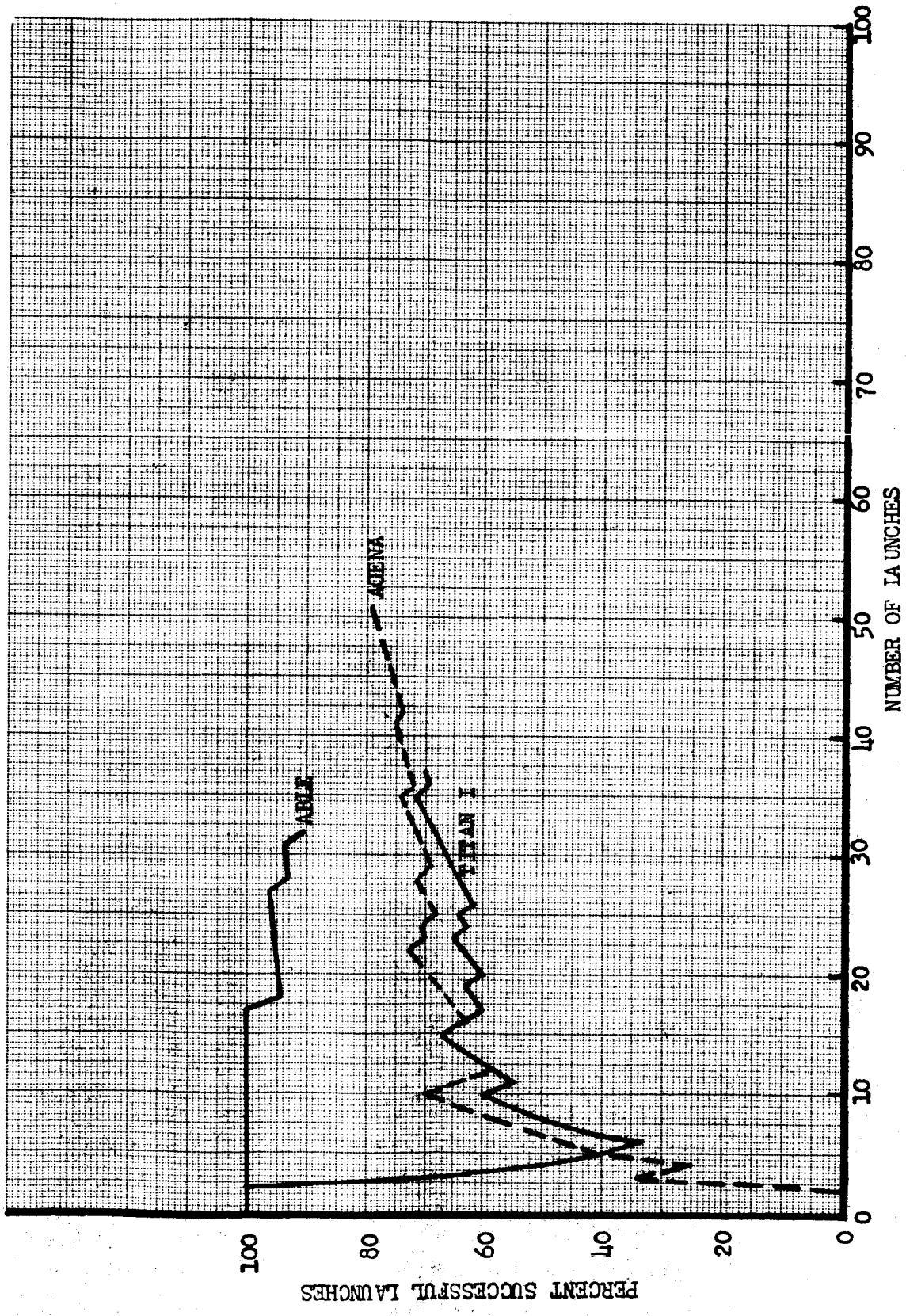


Figure 3.5.3-2 LIQUID SECOND-STAGE RELIABILITY GROWTH

started low. The Agena stage experienced a 70-percent success in the first 10 flights while the Titan I stage experienced a 60-percent success.

Comparing the growth of the solid and liquid stages we find that, with the exception of the Polaris, solids have experienced higher initial success ratios than have the liquids.

### 3.5.3.2 Reliability Assessment

The flight reliability of the vehicle systems was assessed using historical data, manufacturers' data, and NASA ground rules. Assessments were made for the initial and tenth flight. The increase in reliability from the first to tenth flight is attributed to design improvements, operating experience, and refinement of the manufacture, test, and launch operations procedures.

Reliability assessments for the T65D vehicle systems are shown in Table 3.5.3-3. The total vehicle reliability is the product of the reliability of all the vehicle systems.

RELIABILITY ASSESSMENTS FOR THE
T65D VEHICLE CONFIGURATION

| First-Stage Systems | First Flight | Tenth Flight |
|---|---|---|
| Propulsion (six 260-inch-diameter motors) | 0.854 | 0.970 |
| Thrust Vector Control (mechanical) | 0.944 | 0.976 |
| Control and Electrical | 0.950 | 0.980 |
| Instrumentation | 0.985 | 0.990 |
| Structure/Separation | 0.990 | 0.992 |
| Retrorockets (eight) | 0.960 | 0.983 |
| Stage Total | 0.717 | 0.896 |
| **Second-Stage Systems** | | |
| Propulsion (Five M-1 engines) | 0.815 | 0.941 |
| Propellant Feed and Pressurization | 0.935 | 0.965 |
| Thrust Vector Control (mechanical) | 0.985 | 0.988 |
| Control and Electrical | 0.940 | 0.975 |
| Instrumentation | 0.980 | 0.985 |
| Structure/Separation | 0.970 | 0.980 |
| Ullage Motors (four) | 0.980 | 0.990 |
| Retrorockets (four) | 0.980 | 0.990 |
| Stage Total | 0.644 | 0.812 |
| Transtage | 0.972 | 0.980 |
| Vehicle Total | 0.449 | 0.713 |

Table 3.5.3-3

Propulsion System — The observed flight success ratio has been 0.95 for first-stage solid motors and 0.93 for second-stage liquid engines. Manufacturers have predicted an initial solid-motor flight reliability of 0.97+, and an initial M-1 engine flight reliability of 0.96. The M-1 engine value is based on the M-1 engine development schedule and current liquid-rocket-engine reliability goals. The M-1 engine will achieve a reliability of 0.99 prior to the initial operational capability of the vehicle system.

Propellant Feed System — Historically, propellant feed systems have shown success ratios ranging from 0.92 to 0.97. The propellant feed system for the liquid second stage is predicted to have an initial value of 0.935. This is slightly higher than the lowest observed value.

Thrust Vector Control System — The thrust vector control (TVC) system for both liquid and solid propulsion units has been one of the major sources of flight failures. The reliability of the TVC system is dependent on the control requirements of the stage. For the T65D, control requirements do not result in excessive TVC equipment requirements in either the solid or the liquid stages. In addition, considerable experience with gimbaled systems for liquid solid motors and the M-1 engine will be acquired prior to the first NOVA launch. Therefore, improved reliability of the TVC system is predicted for the T65D, with the liquid system showing the most improvement.

Control and Electrical Systems — Historically, the control and electrical systems have been a major source of flight failures in both the liquid and solid stages. Future improvements in electronic technology will result in a trend toward higher reliabilities. However the control and electrical systems for this vehicle will be more complex than current systems. Accordingly, the initial reliability of these systems is predicted to be 0.95 for the solid stage and 0.94 for the liquid stage. These values are comparable to those for existing vehicles.

Instrumentation System — The instrumentation system includes consideration of emergency detection and crew escape systems in addition to the normal telemetry and communications systems. A fail-safe design philosophy is necessary for emergency detection and crew escape systems to provide the maximum flight crew safety without degrading mission success. The reliability of this system is assessed at 0.985 for the solid stage and 0.980 for the liquid stage. The liquid-stage system is lower because it is more complex than the solid-stage system.

Structure/Separation Systems — Historically, solid first stages have experienced no primary vehicle structure or separation failures. The liquid stages have experienced no structural failures; however, separation failures have occurred. Vehicle structure can be designed to a very high reliability if the allowables and the loads can be predicted with a high degree of accuracy or if high structural safety factors are used in the design. Improvement in the technology used to predict the structural allowables and loads is anticipated. A certain amount of structural overdesign can be tolerated; however, a certain amount of risk must

be accepted to keep structural weight down. Separation is predicted to be highly reliable because of the experience that will have been accumulated with large tandem-staged vehicles such as the Saturn I and the Saturn V. The initial reliability of the T65 systems is assessed at 0.99 for the solid stage and 0.97 for the liquid stage.

Retrorockets and Ullage Motors — The retrorockets required for stage separation are assumed to be state-of-the-art design solid motors. Capability for loss of one motor has not been assumed. The initial reliability of a single solid retrorocket is predicted to be 0.995. Reliabilities of this level have been achieved by current solid motors.

Ullage motors are predicted to achieve the same initial reliability as a retrorocket. Capability for loss of one ullage motor was not assumed for this study because of the high predicted reliability.

Transtage — The transtage consists of two storable-propellant engine systems and other auxiliary equipment necessary for operation of this stage. The engines are pressure fed and are assumed to be similar to the higher-thrust Titan II second-stage engines (RLR-AJ91-5). It was assumed that the transtage propulsion and auxiliary systems would be mature systems prior to being used in this vehicle. Therefore, an initial value of 0.972 is predicted for the stage.

### 3.5.3.3 Predicted Reliability Growth

Reliability growth is a result of design improvements and of familiarization with vehicle equipment and procedure. The rate of growth is dependent on the quantity of improvement in the design and the rate of learning.

Reliability growth for the T65D vehicle is presented as a function of the number of launches. The rate of growth is rapid for the initial launches and decreases as the number of launches increases. The growth rate is shown to be very small after approximately 50 launches. The point reliability (probability of a successful launch) and the cumulative reliability (probable percent successful) are shown in Figure 3.5.3-3.

### 3.5.3.4 Probable Number of Launches

The reliability growth curves, Figure 3.5.3-3, were used to determine the probable number of launches to achieve:

- Flight test objectives
- An initial operational reliability of 0.75
- Number of operational successes required to achieve the mission objectives

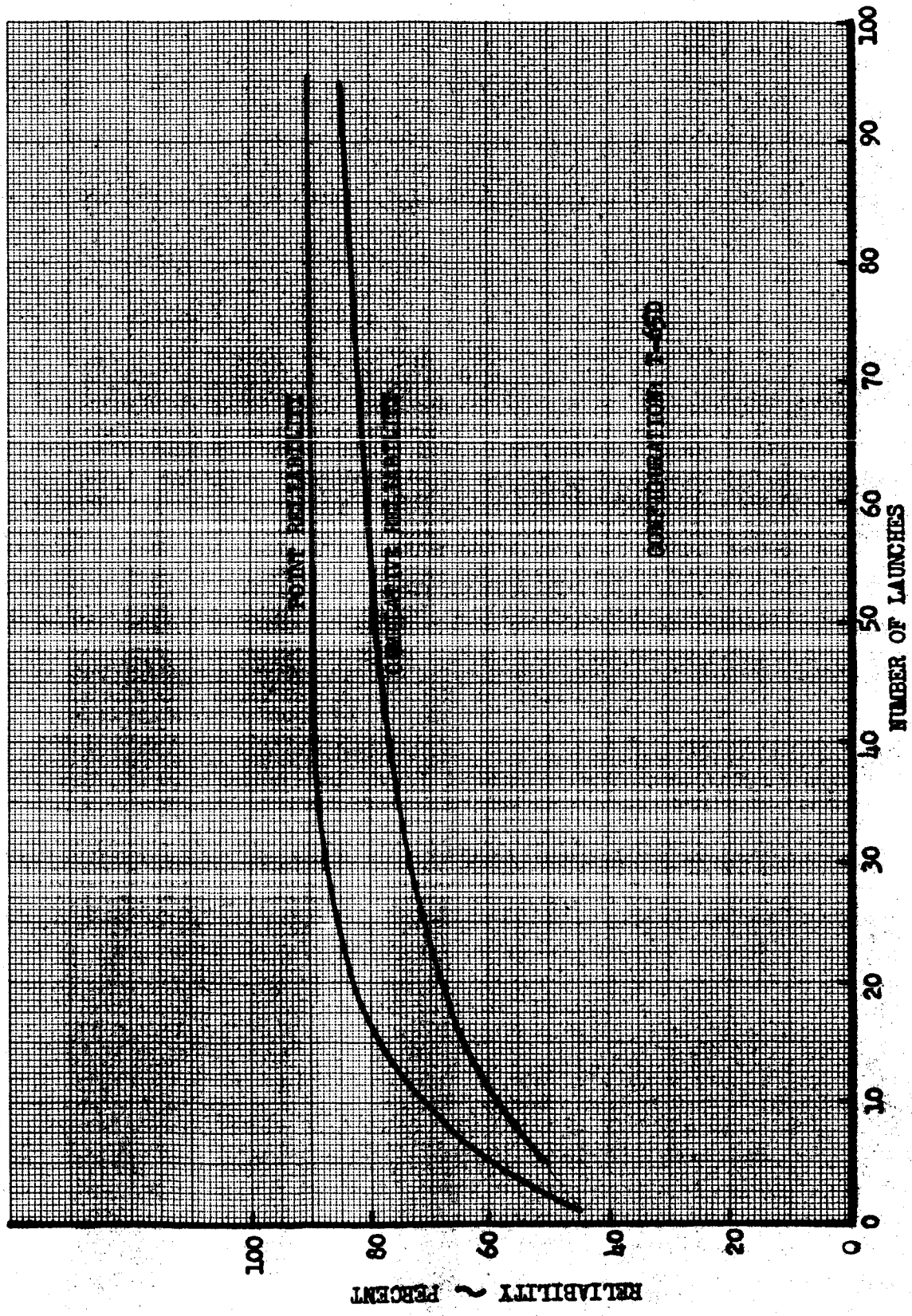


Figure 3.5.3-3 SOLID NOVA RELIABILITY GROWTH

Flight Test Objectives — The flight test objectives require a minimum of seven successful launches. The cumulative reliability growth curve was used to determine the probable number of flight test launches. The resulting number of launches was found to be 12.

Launches Prior to a 0.75 Reliability — The study ground rules require an initial operational reliability of 0.75. The probable number of launches required to achieve this goal is 13.

Operational Launches —Four basic missions were considered in this study. The missions require the placement of payloads to a 567-kilometer orbit. The probable number of launches which will be necessary to achieve the required number of successes, for each of the four missions, was determined using the cumulative growth curve, Figure 3.5.3-3. The cumulative number of successes was obtained by adding the point reliability of each flight, starting with the fourteenth flight, until the desired number of successes was accumulated.

PROBABLE NUMBER OF OPERATIONAL LAUNCHES

| Number of Required Successes | Mission Model No. (See Section 3.3.3) | Probable Total Number of Launches |
|---|---|---|
| 68 | 1 | 79 |
| 62 | 2 | 71 |
| 51 | 3 | 59 |
| 45 | 4 | 53 |

Table 3.5.3-4

## 3.5.4 Reliability Program Plan

### 3.5.4.1 Introduction

The overall objective of the NOVA reliability program is to meet or exceed the reliability requirements of the vehicle and its support equipment during the program from initial specification of requirements through operational use. It is recognized that the problem of ensuring mission reliability is essentially a problem of disciplining decisions, and the general method of assurance of reliability is to concentrate an intensive analysis and review effort on all aspects of the design and development program. More specifically, this includes studies of the feasibility of meeting reliability requirements within the constraints of performance, cost, and development time; trade studies of the reliability effects of design changes and benefits of design simplification or function duplication; the review of designs, specifications, and hardware source selections; continuous reliability data analysis to determine cause and effect relationships; reliability test planning, and the identification and correction of failures. By these means it is expected that the level and rate of growth of reliability can be controlled according to the requirements of the program.

Many gross assumptions have been made to arrive at the predictions of the reliability of the new subsystems and steps must be taken very early in the development program to validate all assumptions by planning a reliability program to direct appropriate action onto all potential problem areas. The details of the reliability program depend on the details of the overall NOVA program, but enough is known of the vehicle configuration and problem areas for a broad program base to be set down.

The first part of the plan establishes the feasibility of obtaining the reliability levels and growths predicted by analyzing the T65D development program actions and the historical progress with similar subsystems. The second part of the plan briefly summarizes the general actions necessary in the areas of reliability support to assist the design and development functions to realize the required levels of reliability.

The engineering problem associated with the reliability improvements required can be stated in quantitative terms relative to the accumulated experiences with ballistic missile systems. Reductions in subsystem failure rates to between 15 and 90 percent of the experienced rates are predicted, but improvement will be slow with some subsystems. Predictions are based on assessments of the probable advances in the state of the art which have already reduced subsystem failure incidences by as much as 90 percent and on considerations of the differing missions of military and space systems. For example, the primary considerations with ballistic missiles are schedules and payloads, while space system programs place costs, reliability, and safety as primary factors.

Reliability improvements are required at all levels of new hardware and equipment currently under development. Many functions, such as costing, scheduling, and maintainability, depend on the realized reliability of the various equipment and systems; therefore, the reliability organization must continuously monitor the level and growth of reliability by the analysis of all test results.

The reliability estimates used to cost this program have been based on level of effort because reliability development forms an integral part of all development programs and, except in cases where critical reliability problems arise, the reliability part of the work cannot be costed separately.

### 3.5.4.2 Reliability Growth and Action Requirements

Figure 3.5.4-1 shows the failure incidences that have been predicted for units (e.g., one engine) of a subsystem of the T65D configuration compared with the historical incidences of failure. Historical data is based on the results of some 525 missile flights. This shows the magnitude of the predicted reductions in unit failure probabilities. Figure 3.5.4-2 shows the relative distributions of total failure probability among the major systems (e.g., five engines) compared to historical data gathered from more than 600 missile flights. This shows that relative reliability is expected to depend on relative system complexity.

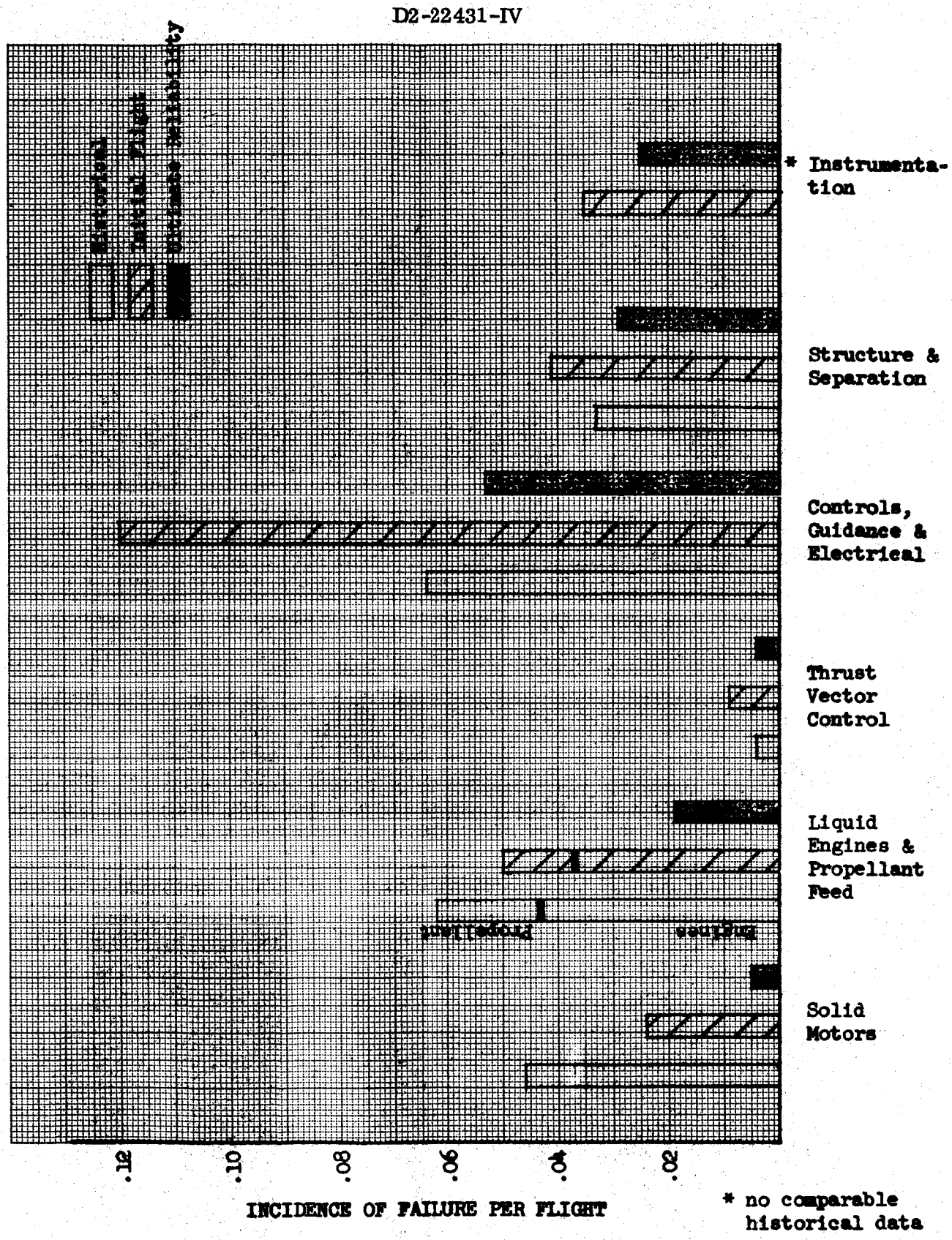


Figure 3.5.4-1 HISTORICAL AND PREDICTED T65D UNIT INCIDENCE OF FAILURE

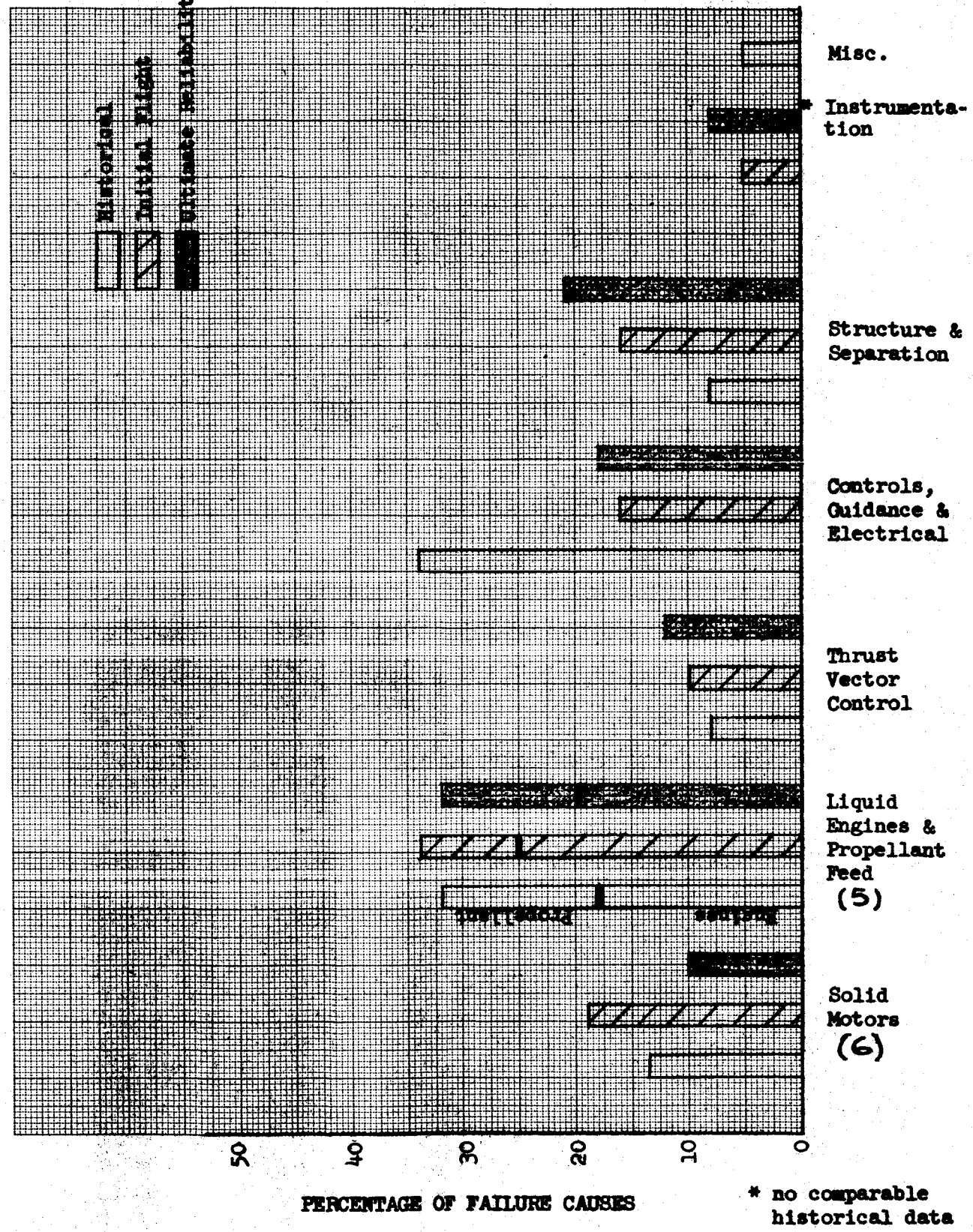


Figure 3.5.4-2 DISTRIBUTION OF SYSTEM FAILURES

Historically, guidance and controls comprise the most complex systems in missiles and the largest proportion of failures have been attributed to these systems. In the NOVA vehicles, the multiple-engine propulsion systems will be the most complex systems and are expected to contribute the most serious reliability problems.

Table 3.5.4-1 shows the predicted reliability growths more clearly by showing the historical failure rates as though they were equal, thus emphasizing the predicted reductions.

PREDICTED RELIABILITY GROWTH

| | Historical | Initial Flight | Ultimate |
|---|---|---|---|
| Liquid Engines | 100 | 85 | 30 |
| Solid Motors | 100 | 35 | 10 |
| Propellant Feed | 100 | 70 | 35 |
| Thrust Vector Control | 100 | 300 | 150 |
| Guidance and Controls | 100 | 170 | 70 |
| Structure and Separation | 100 | 120 | 85 |

Table 3.5.4-1

For comparison, Table 3.5.4-2 shows the observed reliability growths on missile subsystems in similar relative terms.

OBSERVED RELIABILITY GROWTH

| | Early | Current |
|---|---|---|
| Liquid Engines | 100 | 20 |
| Solid Motors | 100 | 70 |
| Propellant Feed | 100 | 10 |
| Guidance and Controls | 100 | 75 |
| Auxiliary Systems | 100 | 100 |

Table 3.5.4-2

These comparisons may be used to analyze the following major subsystems from the reliability standpoint.

### 3.5.4.2.1 Solid Motors

Data from tests and flights of a 60,000-pound-thrust motor that is still under development were used as a basis for comparison. The degree of optimism shown by the predicted reduction in failure rate from an initial 1 in 40 firings to 1 in 200 firings stems from the development program plans of the manufacturers. They consider that all failure modes of solid motors are now known

and that the primary means of ensuring reliability will be essentially quality-control actions. However, a concerted design analysis and review effort will be necessary, and a comprehensive test program is proposed. A total of seven full-diameter (260-inch) motors will be tested during the development program. Two of these will be shortened cases. All test motors will be fully instrumented to obtain maximum information and to enable all problems to be eliminated in the 36-month program. In addition, five PFRT tests are expected to increase reliability.

3.5.4.2.2 Liquid Engines

The M-1 engine is under development for NASA, and high reliability is a primary requirement. Other NOVA study contractors have studied the development program for the M-1 and conclude that a static-test program of 700 tests will be necessary to achieve the 0.99 reliability goal. As shown in Table 3.5.4-2, considerable improvements have been achieved with Atlas and Titan engines as a result of redesign, better understanding of the controls of materials and manufacture, and general improvements in the state of the art. Not the least of these advances is the ever increasing amount of experience gained by a widening group of specialists and companies who contribute to engine developments. The predicted reliability growth to 0.99 prior to first NOVA flight will be the result of some 60 months of continuous development.

3.5.4.2.3 Thrust Vector Control

Two quite different systems will be required for the first and second stages that will provide different deflection rates and load-handling capabilities. The forces required of the actuators will exceed any currently obtained in mobile systems and the hydraulic flow rates far exceed those required in present applications. Therefore, the predicted failure rates are considerably higher than those experienced on ballistic missiles. To ensure the reliability of thrust-vector-control systems, trade studies must be completed to determine the optimum system configurations without accepting any unreasonable reliability risk. Static motor firings should also test the thrust-vector-control systems by gimbaling the nozzles during the test.

3.5.4.2.4 Propellant Feed and Pressurization

Very large improvements in the reliability of the propellant feed and pressurization systems have been recorded and it is expected that continuation of the systems development programs will benefit the NOVA program.

3.5.4.2.5 Guidance and Control

In the past, guidance and control systems have been a major cause of unreliability in spite of considerable advances in the equipment used. The major reason is that reductions in size and weight of guidance and control components

have been used to increase payload and range, rather than to permit design for redundancy to increase system reliability. However, a 25-percent reduction in failure rates has been observed. The NOVA guidance and control systems will be more complex and must operate for longer periods than the systems used in ballistic missiles. Problems of sensing flight deviations may be experienced because such problems as body-bending oscillations and vibrations cannot be completely analyzed by simulation testing before the actual flight-test program. However, reliability improvement from a failure incidence of about 1 in 10 flights to 1 in 20 flights is predicted.

3.5.4.2.6 Instrumentation

The group of instrumentation systems will be expected to accumulate a larger proportion of failures than in the past (15 percent, as compared to 2 percent). This results primarily from the need for safety and crew-escape systems. At present, it is assumed that the payload stage has escape capability built into it and therefore requires an appropriate warning signal from a sensing and computing system. A reliability problem will result from the number of sensors required, which could be over 100 depending on how a motor emergency is to be detected. Duplication of functions must be provided to reduce the probability of faulty actuations resulting from sensor malfunctions. A comprehensive test and flight simulation program will be necessary to develop the instrumentation and safety systems to provide adequate response and sensitivity. Studies of the mechanization of emergency detection systems have been completed by solid-motor and liquid-engine manufacturers. Provided such systems can be designed to be fail safe, they will not affect mission reliability since a crew escape requirement is automatically a mission abort or failure.

3.5.4.2.7 Other Systems

Reliability problems will result from the difficulty of separating the stages when large masses must be decelerated, and from the combined effects of small elements of failure risk that exist in such areas as the structure and auxiliary power systems. The structure will be extensively tested in static and dynamic modes, including acceleration, shock, vibration, and acoustics, and in simulated flight environments (as far as is possible with such large vehicles). In the area of auxiliary power systems, studies must be conducted to determine the maximum power requirements at any instant throughout the flight.

3.5.4.3 Reliability Actions

To ensure that reliability receives proper emphasis throughout all phases of the program, the reliability organization must be represented at all levels of management and engineering effort. The reliability plan may, therefore, be divided into sections on management and engineering.

3.5.4.3.1 Management Plan

The responsibility for reliability is based on the concept of holding each function responsible for quality in its own function. However, in accordance with efficient program management, the overall reliability organization should have a separate management having wide responsibilities and reporting to top management. For example, one element of the Saturn reliability program relationship is shown in Figure 3.5.4-3. Such an organization illustrates how reliability receives proper emphasis and direction while eliminating unnecessary duplication of effort and communications problems. The detailed nature of the reliability organization for the NOVA program would depend on the requirements of the overall NOVA program organization.

3.5.4.3.2 Engineering Plan

A primary requirement of the reliability program is that it be fully integrated into the program effort. Major milestones are shown on Figure 3.5.4-4. A definitive list of tasks is a part of normal reliability plans. This is omitted because the program is not yet sufficiently detailed.

When the design has become final, there is little scope for major improvements of reliability; therefore, the engineering effort will be concentrated on making tangible contributions to the design by the completion of trade studies, design reviews, and reliability analyses of all designs and design proposals. After design finalization, the reliability program will operate primarily to ensure that reliability growth results from the development program, and that no regressive trends are permitted in vehicle and system reliability. The reliability organization will maintain continuous surveillance of the program to complete trade studies of the reliability implications of changes to designs and specifications. A reliability analog or block diagram of the system will be continually updated using all test data obtainable to determine the need for redesigns, tests, or changes in other areas. This data will also be useful in detailing spares requirements, facilities, and test equipment.

Criteria Establishment — The criteria against which the reliability performance can be judged must be identified. This will include criteria for the flight vehicle and the ground support system as well as appropriate sublevels. Typical of these criteria are the mission profile (including environmental requirements) test methods, and hardware acceptance. The reliability criteria must be documented with the other design and development criteria.

Trade Studies — The early phases of product design, including analysis of requirements, system synthesis, and system selection, are potentially the most fruitful areas for the introduction of high-reliability concepts. In addition, it is the only time when reliability changes can be made at a reasonable cost, because as the program progresses all changes must bear the additional cost burden of the expanding program. Trade studies with the specific objective of

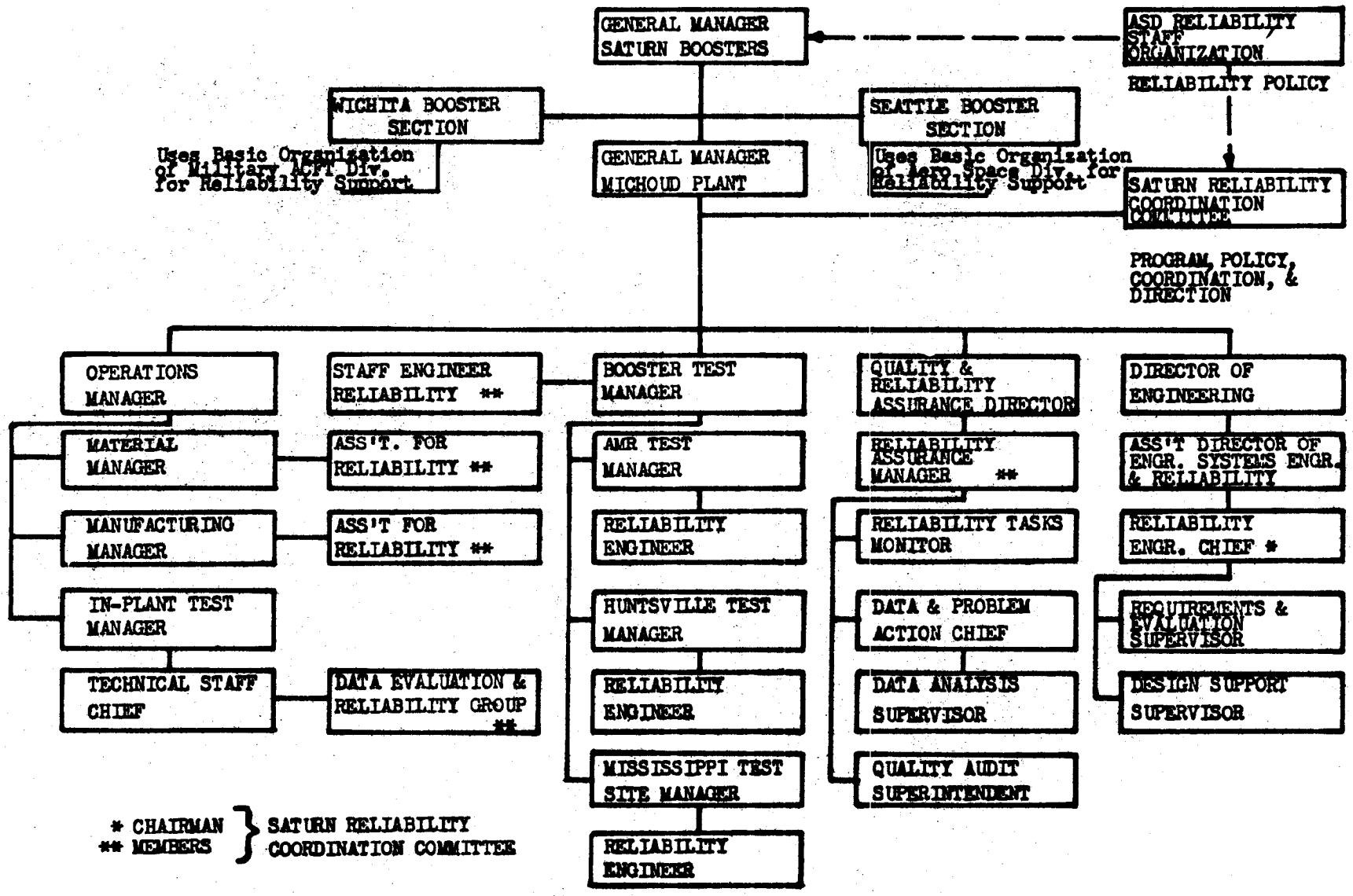


Figure 3.5.4-3 RELATIONSHIPS OF RELIABILITY ORGANIZATIONS
Saturn Program

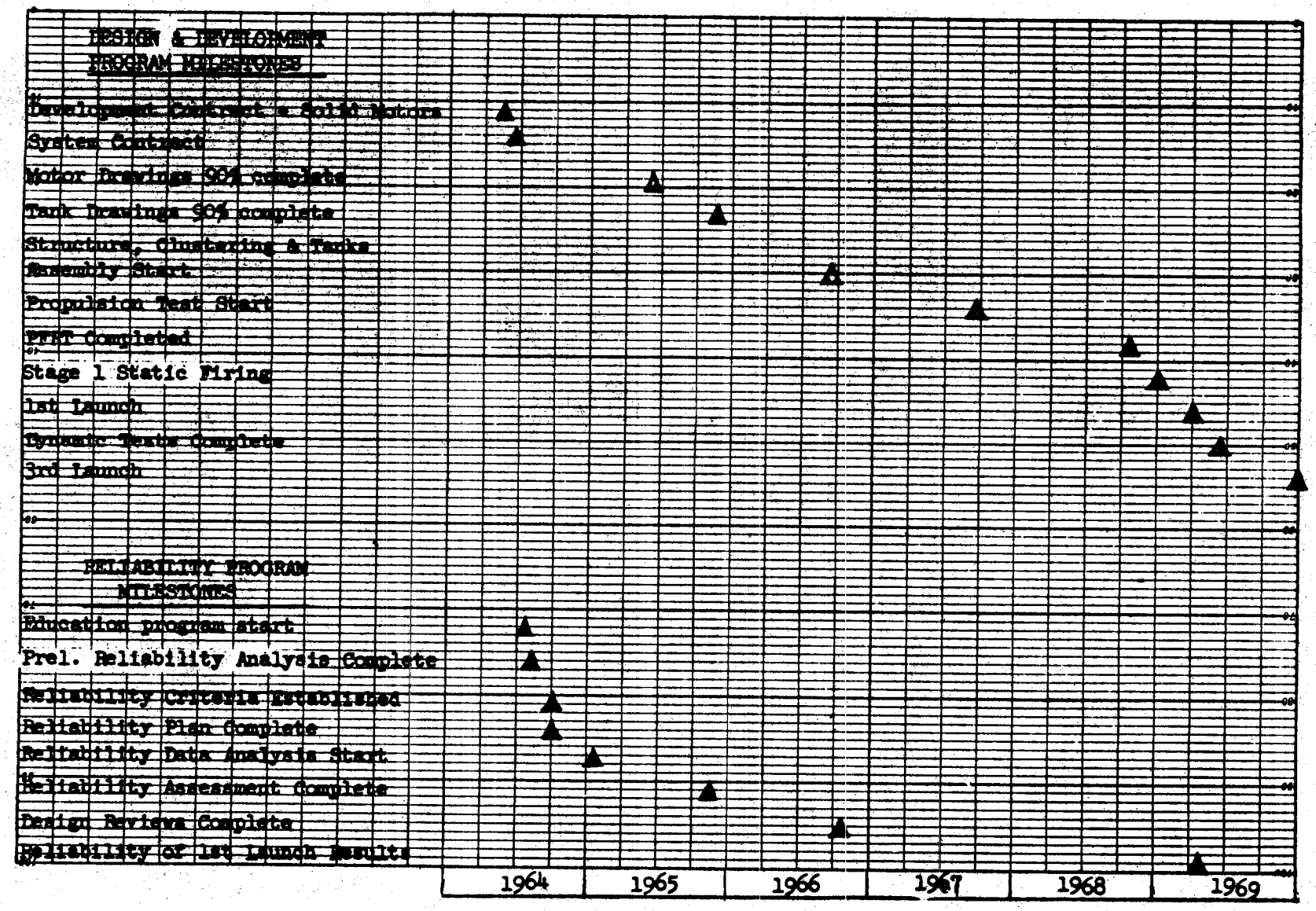


Figure 3.5.4-4 PROGRAM SUMMARY SCHEDULE — T65

maximizing reliability must be scheduled and completed at certain stages during the design and development.

Design Support — The reliability of a system is essentially dependent on the quality of design. The designer is responsible for this quality; however, reliability engineers must provide continuous support to provide data, including comparative reliability information, on concepts, hardware, processes, and procedures. The design quality should be subject to continuous reliability monitoring.

Reliability Assessment — The reliability requirement for the complete system must be apportioned among the various subsystems and components. This function must be completed by reliability analysts who maintain a reliability model of the system by comparing the reliability requirements with the reliability assessments. In addition to the probability analysis, a failure mode and effect analysis must be performed. Based on these analyses, a criticality evaluation must be conducted.

Reliability Growth — Hardware generally exhibits reliability growth from estimates based on the first vehicle configurations. Some growth will accrue naturally from such factors as personnel familiarization with the equipment and the development of better methods and controls, but major growth of reliability can only be achieved by a concentrated effort in all areas to eliminate all reliability problems. Appropriate actions such as design improvement studies, personnel education programs, and equipment specification reviews must be directed toward achieving reliability growth. Figure 3.5.4-5 shows an estimate of the reliability growth potential of the T65D vehicle.

Critical Area Identification —System problems that individually appear to pose no great problem may collectively become a major cause of unreliability. Extensive analytical evaluation prior to and during design and the continuous feedback and analysis of operating data will assist in the identification of such problem areas. Inputs to this function may be derived from prior experience, vendor tests, acceptance and inplant tests, and checkout and flight testing. Machine data reduction methods should be used where possible to assist in the speed of information feedback and analysis. A continuous review process must be conducted to ensure that no cause and effect relationships are overlooked and that no such relationships are erroneously detected with detrimental effects.

Test Planning — A primary function of all system tests is to determine or verify satisfactory reliability. Because of the high costs of conducting tests of vehicles such as NOVA, all tests must be planned to fulfill the needs of a maximum number of engineering functions. Since the original reliability predictions were based on data derived from quite dissimilar systems, it will be necessary to obtain data to substantiate or refute the assumptions made at as early a date as possible in order that design changes or adjustments to

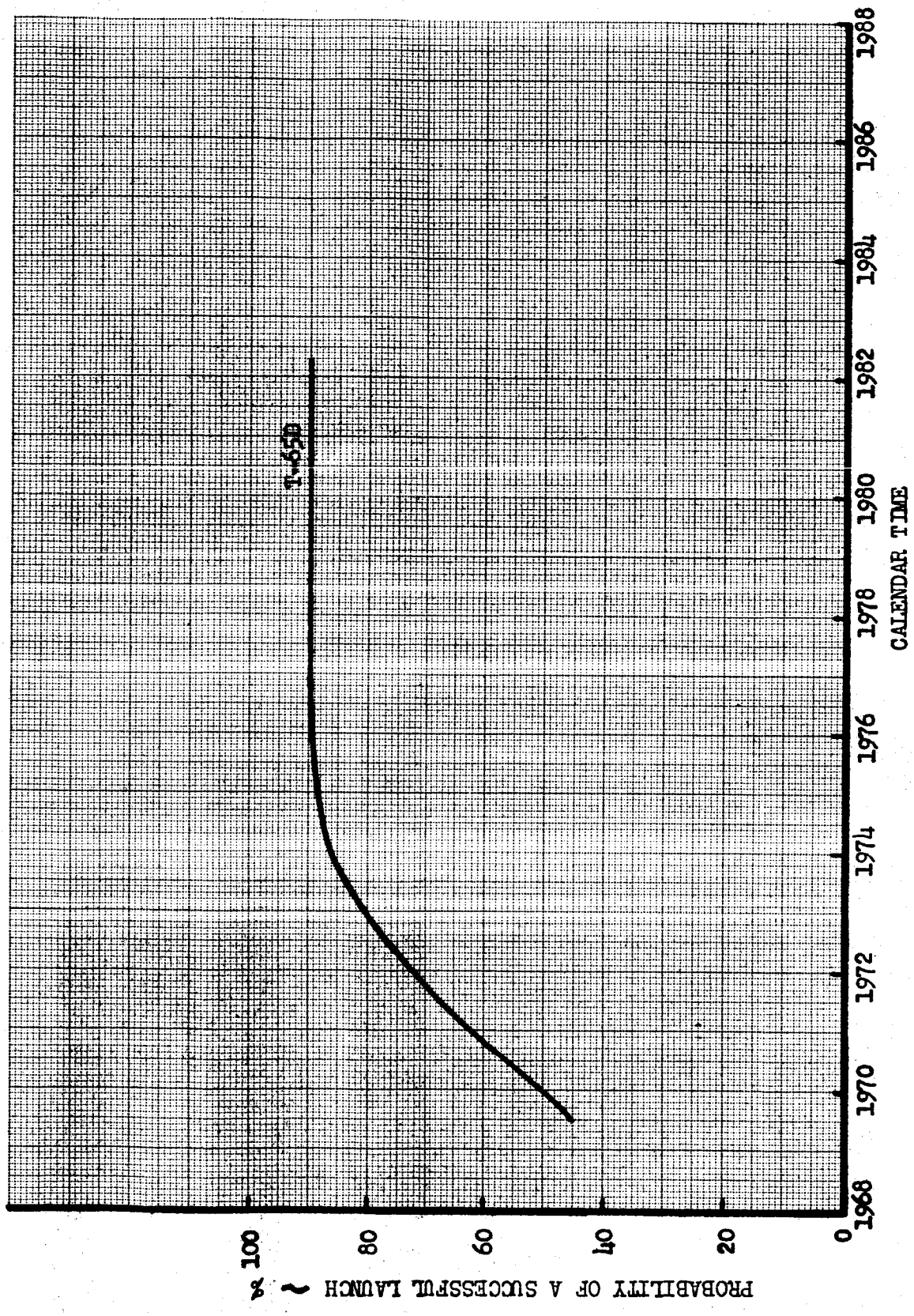


Figure 3.5.4-5 SOLID NOVA RELIABILITY GROWTH

schedules or requirements, etc., may be made at a similarly early date. To ensure this, reliability data requirements will be an integral part of the test plans.

Design Reviews — The complete design, including all specifications must be reviewed at stipulated intervals throughout the program. These reviews comprise a further check that all recommended changes have been incorporated and that no detrimental effects have been introduced. A series of basic check lists must be used to provide the formal procedure and to provide a standard format for the review boards. Figure 3.5.4-6 shows the relationship of the design review to the other basic engineering-reliability tasks.

Specifications — The reliability organization will establish the reliability success criteria from the specifications furnished by the customer and these will be used in the preparation of system, subsystem, and component specifications and also in test planning. All specifications having an effect on reliability must be subject to reliability review and approval.

Supplier Reliability Control — The reliability organization must screen all potential suppliers to ascertain their capability to furnish consistently reliable and quality products. During source-selection reviews, each potential supplier's reliability plans and organization will be analyzed to determine that the supplier recognizes the importance of reliability and has the necessary controls to ensure the reliability of his products. Equipment produced by suppliers and subcontractors must be subjected to the same reliability disciplines as would be applied to the equipment if it were produced by the prime contractor. (See Figure 3.5.4-7.)

Failure Analysis — All failed parts must receive sufficient analysis to identify and correct the cause of failure. The analysis of test results must recognize the difference between laboratory tests and mission conditions. Coordination must be maintained with part suppliers to assist them with analyses and reliability improvement programs. As an example of a typical failure-analysis operation, Figure 3.5.4-8 shows one element of the Saturn project failure analysis and corrective action cycle.

Manufacturing Variance Control — Variance control must be used to minimize degradation of design reliability during manufacturing inspection and test processes. The objective of this program is to ensure that variations in the final product are consistently maintained within the limits established by the designer. This will be accomplished by review of process control specification requirements and test planning, including analysis of potential tolerance accumulation. There must be periodic audits of these functions to ensure adherence to the requirements.

Indoctrination and Training — Achievement of NOVA system reliability requirements necessitates the assignment of technically qualified personnel in all phases of the program. Reliability training programs will form part of the indoctrination program for all personnel assigned to the NOVA program. However, special reliability training will be provided only to those whose task assignments are critical to reliability.

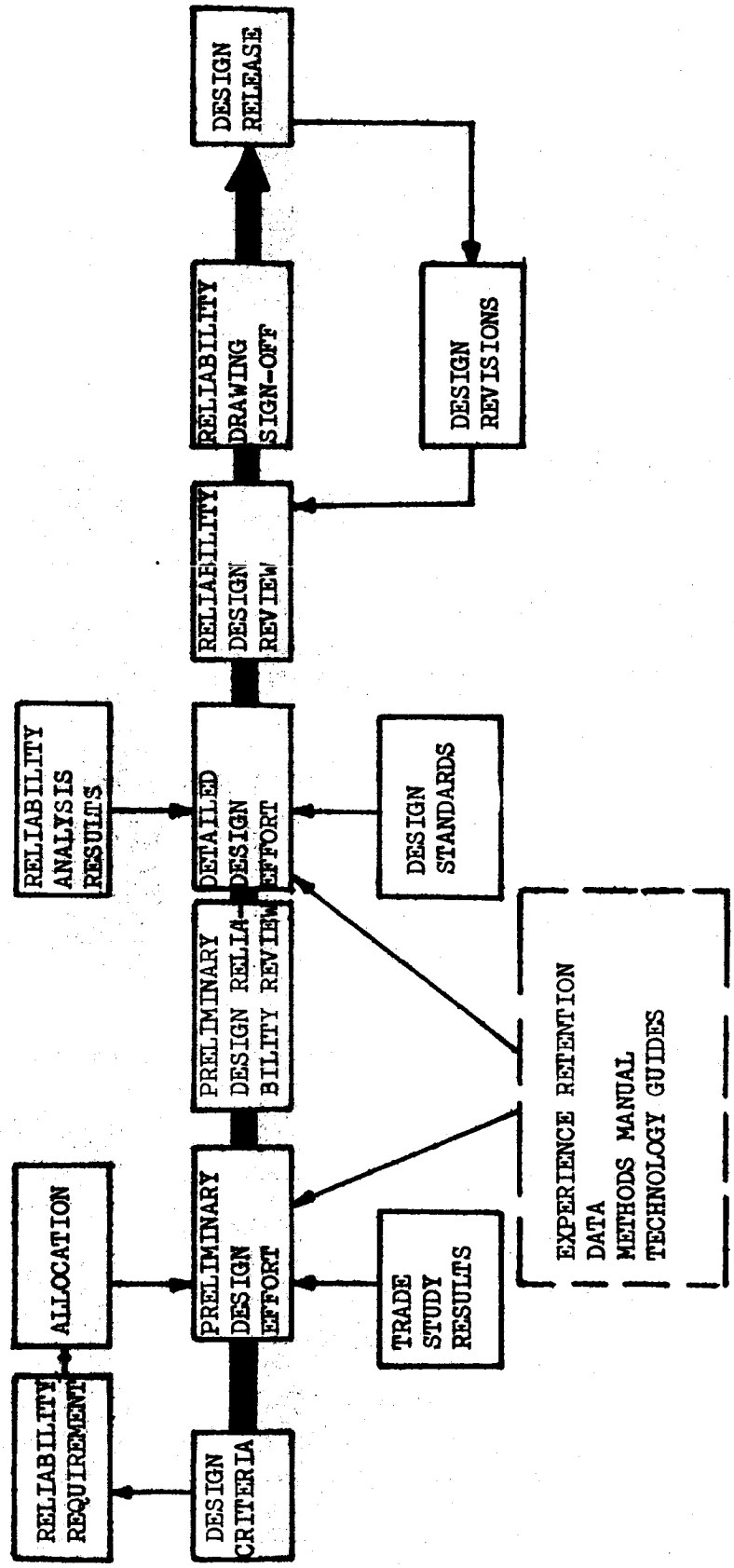


Figure 3.5.4-6 DESIGN REVIEW

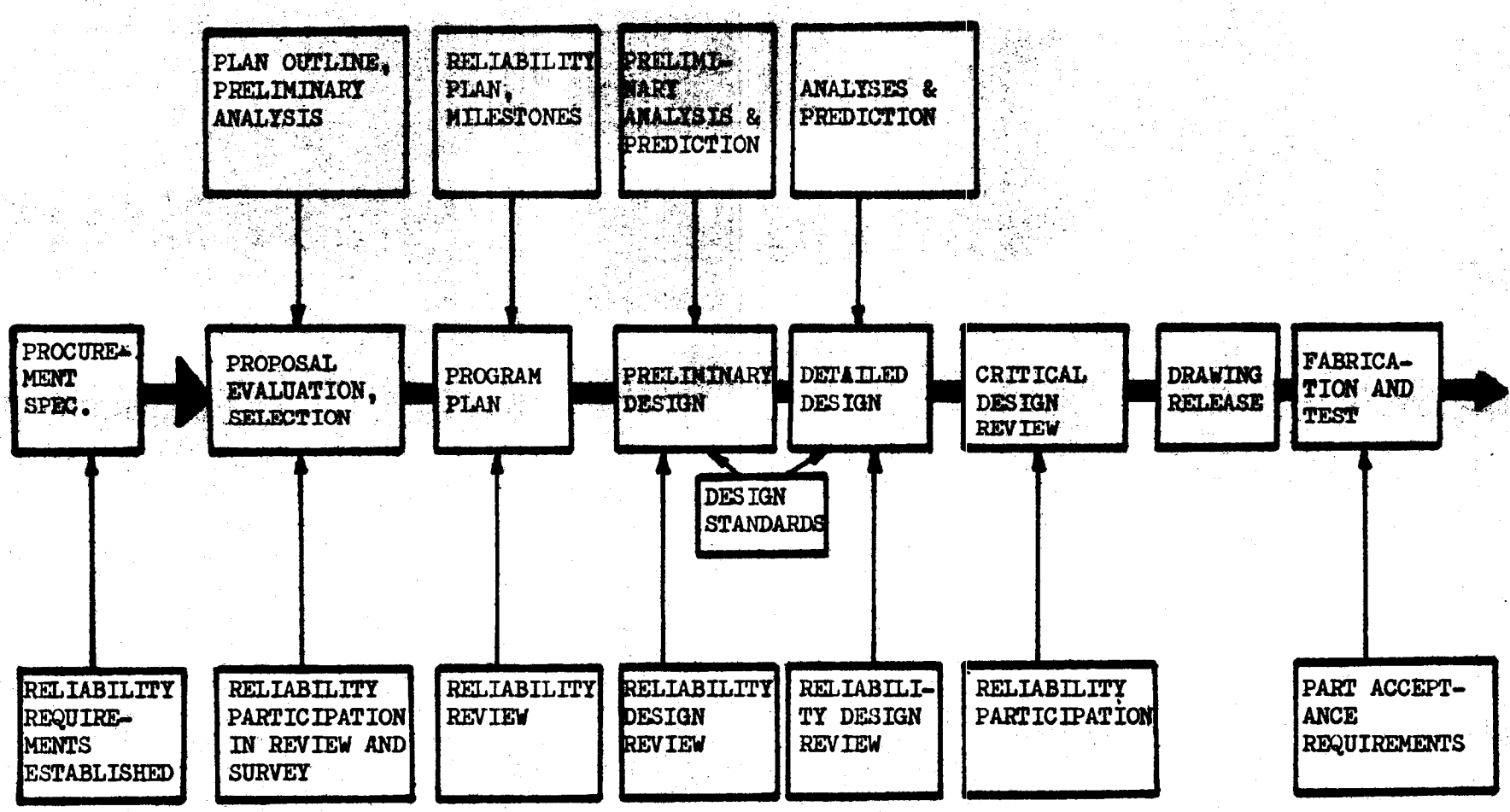


Figure 3.5.4-7 SUPPLIER RELIABILITY ACTIONS AND CONTROLS

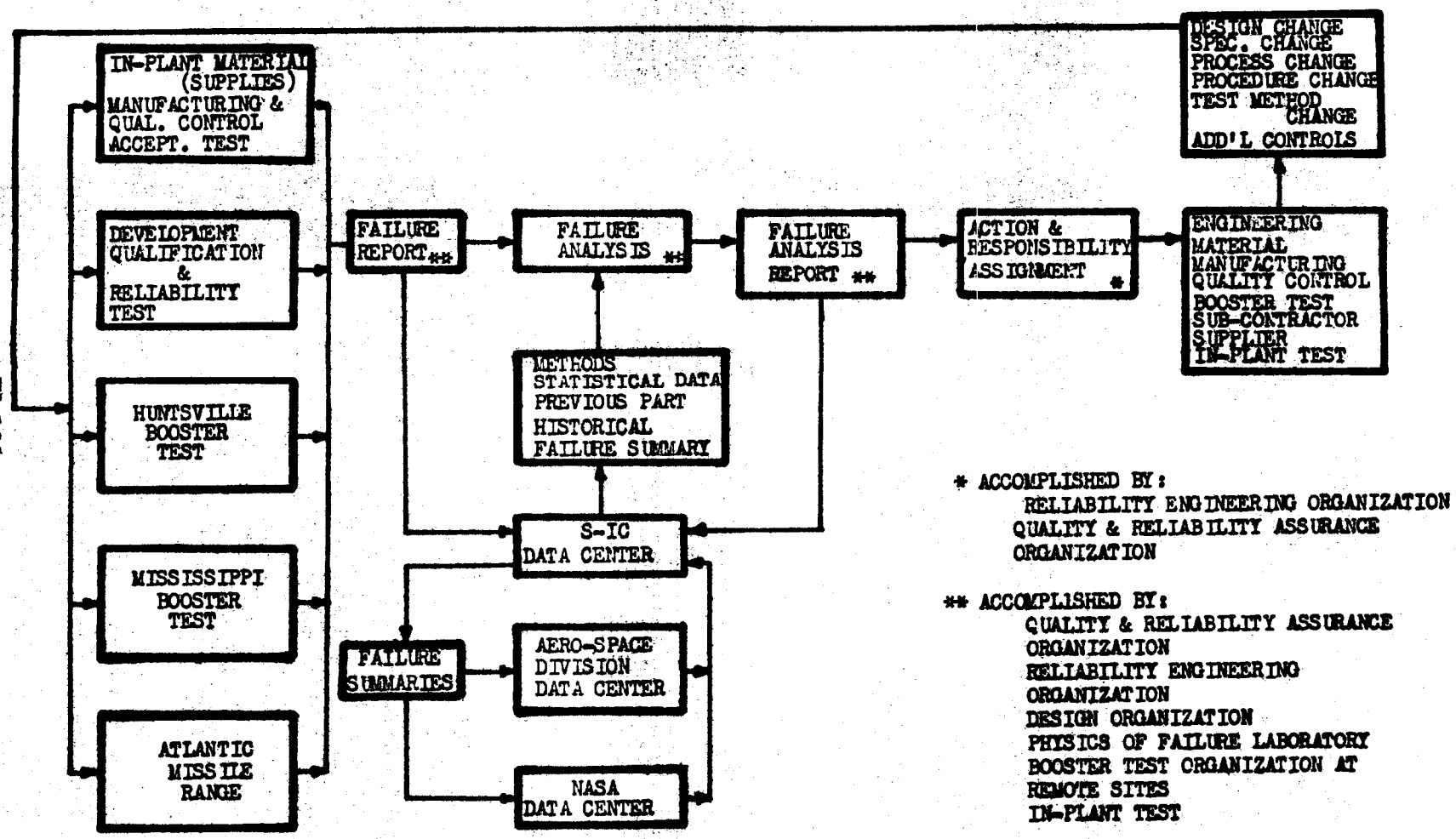


Figure 3.5.4-8 FAILURE ANALYSIS AND CORRECTIVE ACTION

## 3.6 DEVELOPMENT TEST PROGRAM

### 3.6.1 Introduction

This section discusses the ground and flight tests essential to the development, evaluation, and verification of the T65 vehicle systems. The discussion consists of a general survey of the overall test program to identify tests that will have critical hardware or facility requirements. The second-stage development captive firing tests (see 3.6.3.12) and the flight test program (see Section 3.6.4) represent major portions of the program and are discussed in greater detail.

Few of the tests are unique to the T65 or to other NOVA-class vehicles, but are of concern as a function of size of hardware and facilities. The size problem is particularly apparent in the full-size vehicle dynamic test (see 3.6.3.6).

### 3.6.2 Summary

The development test program survey has revealed a number of individual tests having potential pacing influence on the NOVA program. These individual tests affect the manufacturing and delivery schedules of several suppliers, require complex facilities, and require special handling and transportation. Tests can be varied by alternate solutions which offer potential savings of time and/or funding. The various detail test programs can be resolved only after detail study beyond this initial survey.

The following tests, in particular, require detailed study.

- Dynamic Model Test —This test must be studied in conjunction with the vehicle dynamic test to support and possibly reduce the effort on the full-size tests.

- Vehicle Dynamic Test — This full-size test represents a major undertaking and a and as such warrants effort to accomplish an economical solution to the anticipated problems.

- Vehicle Structural Tests — These tests represent effort and complexities approximately equal to the dynamic test.

- Solid Motor Substage Firing Tests —Since there is to be no full first-stage captive firing test, the substage tests require inclusion of all possible equipment and the best possible simulation of stage environment.

### 3.6.3 Ground Test Program

A survey of the ground test portion of the development program was conducted to identify critical tests and to evaluate the general aspects of the overall test program from elementary materials tests through full-size vehicle tests.

#### 3.6.3.1 Air Loads Model Tests

Purpose — To evaluate the need for fairings and/or pressure seals between motor cases to avoid turbulence-induced loads. To determine aerodynamic characteristics of the vehicle and pressure distribution over the vehicle.

Hardware — Scaled model, rigid except for load elements (strain gage flexures) to measure steady and unsteady loads caused by turbulence. Requires provision for installing fairings. Pressure transducers must be installed for load determination.

Facilities — Transonic and supersonic wind tunnels.

#### 3.6.3.2 Ground Wind Loads Model Test

Purpose — To determine ground wind design conditions.

Hardware — Scaled model with simulated flexibilities. Model of vehicle housing or structures which may influence ground wind conditions. Requires provision for varying wind direction.

Facilities — Low-speed pressurized tunnel.

#### 3.6.3.3 Flutter Tests

Purpose — To determine experimentally the flutter boundaries of panels and shells of the liquid stages and fairings which may be included in the first stage.

Hardware — Panel specimens and scale models of cylinders with proper stiffness distribution. Tests are not required where analysis shows sufficient margin between flutter boundary and flight trajectory.

Facilities — Subsonic, transonic, and supersonic wind tunnel flutter testing facilities.

#### 3.6.3.4 Slosh Tests — Second Stage and Transtage

Purpose — To develop baffle requirements for the liquid tanks and to obtain frequencies and damping coefficients for control-system design.

Hardware — Scale model of liquid tanks with provisions for varying baffle configurations.

Facilities — Tank support structure, electronic shaker, and data recording system.

3.6.3.5 Dynamic Model Test

Purpose — To provide preliminary experimental data early in the program on bending modes and frequencies of the complete vehicle and staged vehicle for dynamic loads analysis and control system design. To evaluate shaker system requirements for full-size dynamic test.

Hardware — Scale model (e.g., 1/10 size) with proper mass and stiffness distribution. The model should be able to represent each flying unit (as stages are dropped). Fuel loadings require simulation.

Facilities — Support stand with a soft support system for the model and an electronic shaker system.

3.6.3.6 Vehicle Dynamic Test — Full Scale

Purpose — To evaluate the stage and vehicle design in simulated operational conditions. To determine bending modes and frequencies of the vehicle for dynamic loads analysis. To determine the structural transfer function for control-system design.

Hardware — Full-size vehicle duplicating final vehicle mass and stiffness. Requires means of simulating fuel loading conditions.

Facilities — Vehicle facility requirements are assumed to be similar to and scaled up from the Saturn I and V experience. Support stand structure requires a soft support system for the vehicle and a shaker system. Mississippi Test Facility is assumed as test site.

Discussion — Dynamic test data must be obtained during the ground-test program or the flight-test program. Usually a ground test offers the most satisfactory means of obtaining the desired data. To obtain satisfactory data by flight test usually requires additional flight-test vehicles. The size (Figure 3.6.3-1), cost, and complexity may be prohibitive for ground test of NOVA-size vehicles; consequently, the ground test and the various alternates, including flight tests, should be evaluated against the expected results.

The first stage, in full-size hardware, presents major handling, facility, and cost problems. To investigate various flight times from launch to tailoff by various propellant loadings (inert) appears to be an unreasonable burden on hardware, casting, and handling facilities. Incremental loading cannot be readily simulated by water. Tests utilizing empty cases offer the least burden on facilities and offer a realistic configuration for one point in the flight.

The second-stage fuel loadings utilizing hydrogen or oxygen impose large safety risks. Simulation of the hydrogen, in particular, reduces confidence in the test

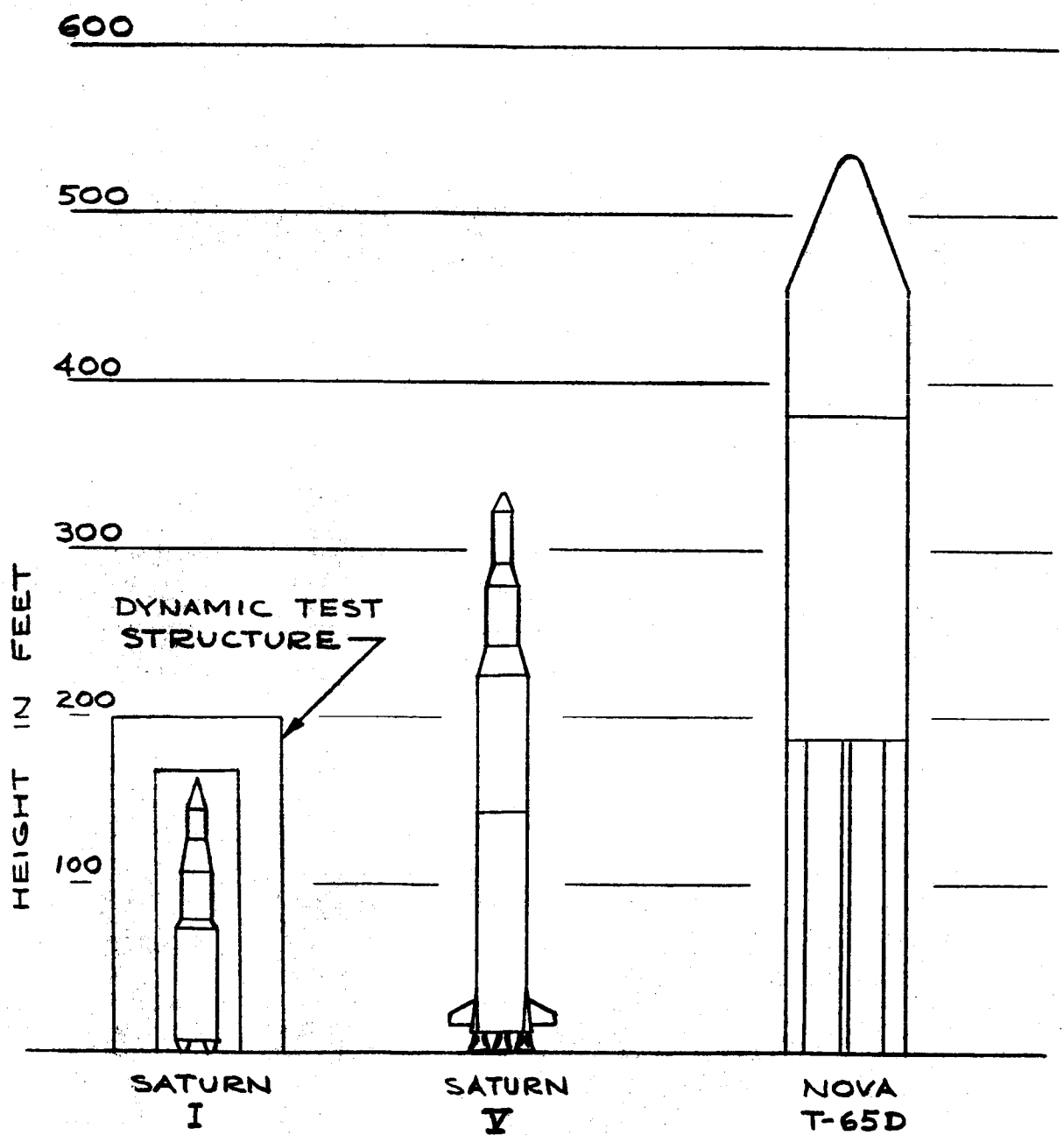


Figure 3.6.3-1 VEHICLE COMPARISON

results. Test substitutes become a series of trades of load weights, load concentration, load centers, cryogenic effects, and slosh effects. As with the first stage, the empty tank plus fuel mass simulation represent the only realistic test possibilities which are readily apparent.

The transtage testing appears to be attainable but has relatively little effect on the vehicle.

Payload configurations have the effect of multiplying the number of tests by approximately the number of configurations.

Detail study of the dynamic testing problems is required. Study may show that the model tests can be correlated to dynamic tests of a full-size vehicle.

### 3.6.3.7 Strength Allowables Tests

Purpose — To determine experimentally the allowable strength, stress concentration, and deformation of detail parts, typical joints, compression panels, etc., early in the design stage to obtain adequate and efficient structure.

Hardware — Fabrication of conceptual designs, including significant variables, of items similar to the following:

- Case structure portions
- Liquid tank and intertank test panels
- Interstage structure portions
- Actuator attachments including local structure

Facilities — Manufacturer's site assumed. Structural test facilities required, including fixtures, instrumentation, and data-reduction facilities.

### 3.6.3.8 Vehicle Structural Tests

Purpose — To evaluate the structural integrity of the vehicle. To confirm design analyses by applying proof, yield, and ultimate loads in the form of single or combined loads of bending, torsion, shear, pressure, etc.

Hardware — Full-size structural hardware to be tested by the stage and/or structural component. The following represent major items to be tested:

- First stage, including interstage*
- Second stage, including interstage*
- Transtage*
- Base skirt structure

*Inert or empty

- Solid motor case*
- First-stage link structure
- First-stage transition skirt
- Cluster cross beam
- Interstage
- Second-stage thrust structure
- Second-stage tank*
- Transtage thrust structure
- Transtage tanks*
- Auxiliary motor cases (retro, ullage, pressurization)*
- Auxiliary motor thrust structure
- Fluid lines
- Auxiliary tanks

Facilities — High-bay building to house the veritical first stage (approximately 230 feet) plus strongback fixture for vehicle restraint and application of loads. Further study may permit reduction of height requirements to the minimum of approximately 170 feet plus fixtures required for the vertical second-stage test.

Hydrostatic test facilities are required to provide static pressure loads for tanks and cases during the structural tests of the first and second stages. Hydrostatic test facilities will be required to proof test all pressure containers produced (tanks, cases, pressure bottles).

Components can be considered for test at many sites: manufacturer's site, stage assembly site, Mississippi Test Facility, MSFC, and other locations.

### 3.6.3.9 Solid-Motor Development Firing Tests

Purpose — To develop and evaluate the performance of the solid motor and launcher-retained ignition system element in captive firing tests. To evaluate emergency detection systems, if used.

Hardware — Subscale motors and full-size development, PFRT, qualification, and/or acceptance motors, including cases, nozzles, and prototype aft-end ignition system element.

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* Inert or empty

Facilities — Test stand, thrust structure, data recording, processing equipment, laboratories, and other facilities normally associated with solid-motor firing tests. Motor temperature conditioning equipment is required. Testing is assumed to be at manufacturer's site. Facilities are assumed to be largely existent or adaptable from the large solid-propellant rocket motor program.

### 3.6.3.10 Stage Development Captive Firing Tests — Solid Substage

Purpose — It is proposed to test a single motor as a simulated substage to develop and evaluate the thrust vector control (TVC) system, the structural system, base heating protection, and portions of the stage which may be affected by the firing environment. (Solid substage checkout tests are discussed in 3.4.1.3.)

Hardware — Full-size development, PFRT, qualification, and/or acceptance motors. Stage components to be full-size hardware or portions of hardware. TVC development hardware is required and is assumed to require more tests than other stage subsystems. A minimum of six TVC tests is assumed during the motor and stage test programs. A minimum of one substage test is assumed.

Facilities — Testing is assumed at motor manufacturer's facility as extension of the motor development program. Additional requirements include TVC evaluation equipment. Motor thrust pad must be adapted to cluster structure or interstage thrust faces. Support and tie-down features must be included for noncontinuous portions of structure, base-heat shields, etc. Soft mounting should be considered.

### 3.6.3.11 Engine Development Firing Tests — Second Stage and Transtage

Purpose — To develop, evaluate, trouble-shoot or rerate engines for the second stage and/or transtage. Requirements and facilities will be largely a function of the engine development status relative to other vehicle programs at the time of program initiation. Testing may be conducted at the engine manufacturer's test site and/or the Mississippi Test Facility.

### 3.6.3.12 Stage Development Captive Firing Tests — Second Stage

Purpose — To develop and evaluate the performance of the second-stage design as an operating system. (Stage checkout tests are discussed in 3.4.1.4 and stage-acceptance firing tests are discussed in Section 3.3.5.)

Static Test Stand Activation — Prior to second-stage propulsion system development firings at the Mississippi Test Facility, the facility must be checked out with simulated flight hardware to ensure proper and safe operation of facilities and equipment. Initial checks of the test-stand propellant storage facilities and loading equipment, the pressurant system, automatic checkout equipment, communications equipment, instrumentation, and deflector cooling water and deluge systems will be partially completed. These checks will verify that all elements of the complex are functional and that the stand is ready for checkout with the

stage. The Propulsion Development Vehicle (PDV) will then be installed in the test stand, and propellant cold flow development testing will be initiated.

Prior to the first hot static firing, 17 weeks have been allowed for stand/stage checkout and cold flow developmental testing of the propulsion development vehicle (see Figure 3.6.3-2). Verification tests, paralleling the propellant cold flow tests conducted during propulsion subsystem testing, will be performed during initial stand/vehicle integration tests. Special emphasis will be placed on the safe handling and development of emergency procedures for use with the live propellants that will be used during static firing.

After completion of the propulsion development testing at the No. 1 static test stand, the Propulsion Development Vehicle will be refurbished and updated into a more flight-configured vehicle. It will then be used to check out Static Test Stand No. 2 (Figure 3.6.3-3). After Stand No. 2 checkout, development tests will be continued utilizing the PDV. This additional period will provide increased confidence in systems operating characteristics and will provide additional reliability data.

The second-stage static test schedule, including acceptance tests of flight units, is shown in Figure 3.6.3-3. Flight Units 2 through 13 are processed through the MTF, beginning on a 4-month test period and eventually requiring 3 months per stage for Unit 10 and on. Acceptance firing tests are described in Section 3.3.5. The first flight-weight second stage (GTV) is utilized for AMR facility checkout (described in Section 3.6.4) and therefore does not require static testing prior to initial shipment to AMR. This stage will be checked only for propellant cold flow tests at MTF.

Stand utilization and schedules are based on vehicle requirements to support the launch schedule at AMR. Static-test-stand refurbishment time as shown in Figure 3.6.3-3 represents "total down time" between scheduled static tests.

Second-Stage Development Firings — The final phase of propulsion development testing and the first integration of stage subsystems in an operating environment will occur during development firings of the PDV at MTF. The program will progress in two steps. The first will include tests directed towards determining and resolving major problems in propulsion-system design. The second step will place emphasis on the evaluation of stage reliability, or systems confidence levels.

Test Configuration — The initial configuration of the nonflight (PDV) stage may include pre-PFRT engines, a minimum electrical network, nonflight-weight tanks, prototype propulsion subsystems, and special safety provisions. As subsystems and components in flight configurations become available, the nonflight stage will be updated to approximate the flight stages more closely.

Test Objectives — Test objectives for the propulsion system development testing will include:

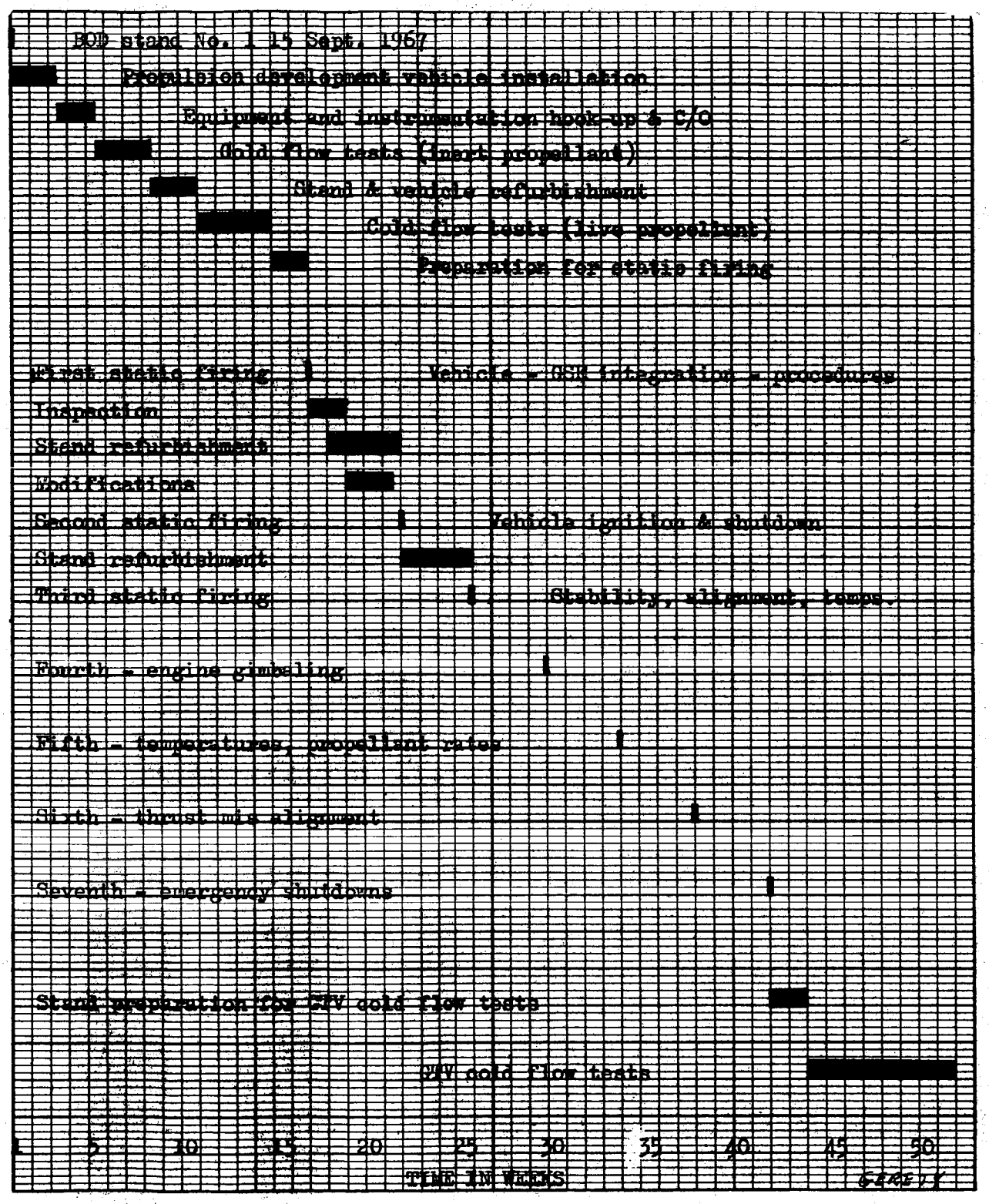


Figure 3.6.3-2 MTF STATIC TEST STAND NO. 1
T65 Second Stage

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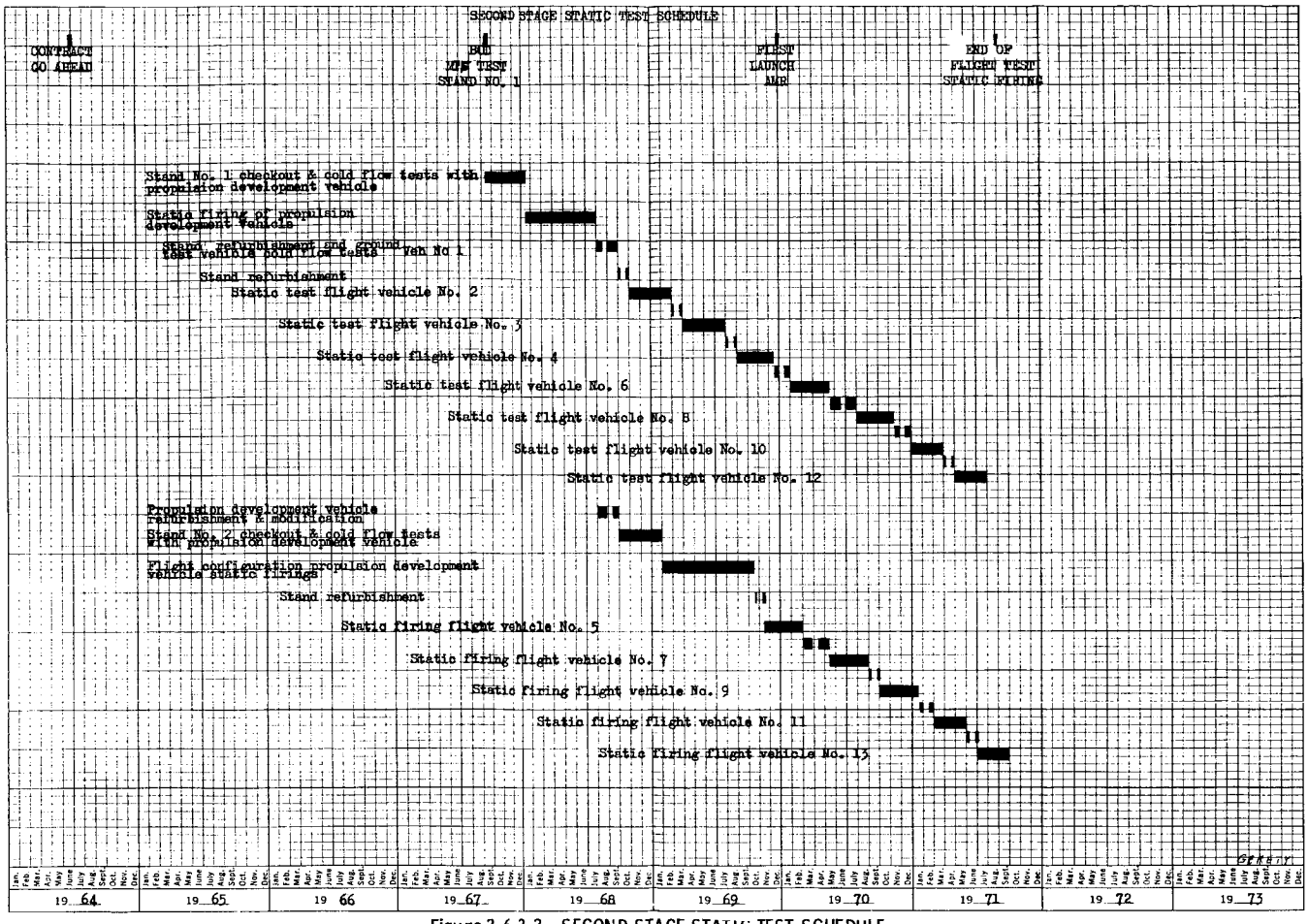


Figure 3.6.3-3 SECOND STAGE STATIC TEST SCHEDULE

- Determination of multiple engine starting and shutdown transients and development of techniques for start and shutdown
- Evaluation of the propellant servicing system, including emergency propellant drain operations
- Determination and resolution of heating problems in engine areas
- Evaluation of the propellant feed and pressurization design and its effect on multiple engine operation
- Determination of purge and environmental requirements
- Evaluation of GSE, including the automatic checkout equipment
- Evaluation of the malfunction-detection sensors
- Accumulation of initial reliability statistical information
- Investigation of critical performance tolerance levels

Test Operations — Initial testing will be with short-duration (approximately 20 second) firings of the stage. As experience and data are gained, the duration will be increased, with full-duration firings made as soon as practicable. A high test rate has been programmed early to gain maximum information for use in the design of the early flight stages. As shown in Figure 3.6.3-2, a period of 6.5 months has been allocated for the initial phase of development test firings.

During the propulsion development firing period, the data acquired will pertain to the propulsion system and will include such information as thrust chamber pressures, propellant flow rates, propellant tank pressures, pump pressures, temperatures, and speed. During later testing, test instrumentation will be expanded to obtain information relating to the telemetry system, the electrical band power switching circuitry, the staging electronics, and the stage environmental and purging systems.

An average firing rate of one per month is planned to provide maximum stage performance data prior to the launch of the first NOVA with a live second stage while still allowing sufficient time for analysis of the test data and for refurbishment. Testing at higher rates may be required occasionally to resolve the problems uncovered during stage acceptance testing or to evaluate the corrections prior to incorporation in a flight stage.

Prior to each test, the stage will be thoroughly inspected and a check made of instrumentation, electrical networks, the propulsion system (including engines), the flight control system, etc. After each test, the stage and its systems will again be inspected and checked for damage incurred as a result of the test. The test data will be analyzed and required changes to the stage will be made prior to subsequent testing. To prevent delay in the program, changes to the stage will be made without removal from the test stand whenever possible.

Stage Reliability Testing — One of the purposes of the test program is to establish confidence in the performance and reliability of the stage. Careful planning for the extraction of the maximum reliability data from virtually all testing activities will be required.

The equivalent of approximately 18 full-duration static-test firings are planned prior to the first flight to provide sufficient data to establish confidence in flight success. Components and subsystems will undergo independent qualification testing and these results, coupled with accumulated static firing and flight data, will be used in the assessment of reliability achievement throughout the program.

During static-firing tests of the PDV, variations of critical performance tolerance limits (such as low battery voltage, pressure switch settings, valve opening or closing time, propellant mixture ratio, and thrust vector system response) will be used to check the effect on stage performance and operation. Laboratory analysis of failed items, correlated with the exact conditions of test previous to failure, will assist in the identification of problem areas. This information will supply the basis for reliability improvement.

### 3.6.3.13 Transtage Acceptance Captive Firing Tests

Purpose — To verify that each flight stage is operational and acceptable for assembly into a launch vehicle. This test is to be performed on all units prior to assembly into a launch vehicle (flight test and production vehicles).

Hardware — Complete operational stage with all possible systems preinstalled and checked out, ready for short-duration and/or full-duration firings. Stage development tests will establish procedures and acceptance limits.

Facilities — Firing test stand, checkout equipment, data recording and processing equipment, fuels, etc. Mississippi Test Facility is assumed; however, MSFC or manufacturer's test site may be used.

### 3.6.3.14 Subsystem and Component Tests

Purpose — To develop and evaluate materials and equipment for vehicle integrity. To confirm analyses; to survey capabilities in operational environment; to determine reliability.

Hardware — Full-size hardware of prototype or production quality and environmental simulation consistent with test purposes. The following represent a sampling of typical items to be tested:

- TVC System (each stage)
- Actuators
- Servovalves

- Guidance System
- Telemetry
- Cryogenic Insulation
- Flex Couplings (bellows) in Fluid Lines
- Valves
- Pumps
- Accessory Power Systems
- Pressure Regulators

Facilities — Manufacturer's site. This level of testing is generally within the scope of the various suppliers and manufacturers although new and/or enlarged facilities will be required for most items. Many of the facilities will also be used for component acceptance testing. Trouble-shooting facilities for certain components will be desirable at Mississippi Test Facility and/or at the launch site. Duplication of facilities should be limited to items not readily returnable to the manufacturer.

### 3.6.3.15 Ordnance Tests

Purpose — To evaluate the ability of ordnance systems to perform their functions. To determine the effect on adjacent components.

Requires — Segments of, or full-size structural portions and the systems representing the following typical ordnance items:

- Stage Separation

  First to second stage
  Second to transtage
  Transtage to payload

- Destruct

  First stage
  Second stage
  Transtage
  Individual pressure containers

Facilities — Remote and/or revetment area. Simple fixtures, with the exception of a live firing-destruct (if planned) of a solid motor. Tests can be at several sites: manufacturer's site or special remote sites.

### 3.6.3.16 Transportation and Handling Tests

Purpose — To evaluate the capability and compatibility of ground equipment in actual service.

Testing — Transportation of the 260-inch solid-propellant (inert and live) motors from the manufacturer's site to the motor static test site, to the substage assembly site, and to the launch site requires a special transporter. The conceptual design of such a transporter appears in 3.3.6.2. Tests to ensure the design adequacy of the transporter must be performed. These tests will be performed on the transporter at the manufacturer's site using an inert motor and will include axle load tests, structural tests, safety features in case of component failure, etc. In addition, barge transportation tests will be performed to demonstrate safe loading, unloading, and travel of the motor by barge. Stability during inclement weather will be demonstrated. Handling tests of the inert motor and transporter will also include evaluation of hoisting and/or erection methods, such as required at the AMR launch building and as may be required at the manufacturing site.

Transportation tests of the second stage are intended to prove the compatibility of handling equipment and procedures, and will be based on transportation operations used in the following flow sequence:

- Assembly of the stage on the transporting pallet
- Inplant checkout of the stage
- Transport of the stage and pallet to MTF
- Hot-firing test of the stage at MTF
- Post-test refurbishment of the stage
- Transport of the stage and pallet to AMR for launch operations

During handling and shipping of the second stage, the pallet and stage are inseparable. Therefore, a test program will be required to certify the pallet for service. As the Propulsion Development Vehicle (PDV) is assembled on the pallet, the pallet will be instrumented for structural, stability, loading, and safety tests. Upon completion of these tests, the PDV and pallet will be loaded into a transportation barge and extensive testing of the barge stability during this mode of transportation will be undertaken.

### 3.6.4 Flight Test Program

#### 3.6.4.1 Scope of Operations

Flight test operations will consist of all activities at AMR pertaining to the NOVA vehicle during the flight test program. These activities will include the receiving and inspection of the stages and other flight components (substage level), the checkout and integration of the launch building with the NOVA Ground Test Vehicle (GTV), the planning and execution of a flight test program, and the processing of flight test data.

Based upon an analysis of test requirements and objectives, the T65 test program will require 7 successful flights. A successful flight is defined as one in which 80 percent or more of the programmed flight objectives are realized. The configuration, mission, and test requirements for each flight in the test program are outlined in Tables 3.6.4-1 and 3.6.4-2.

As noted in Table 3.6.4-1, payloads are incorporated on the flight vehicles after the second successful flight, provided the confidence of achieving launch vehicle test objectives will not be degraded.

Table 3.6.4-2 outlines the research and development flight test requirements. The various phenomena that will be investigated under each of the test headings are as follows:

- Stability and Control — vehicle or stage static stability
- Structures — structural bending, air loads, surface heating, base heating, acoustics, vibrations, cluster loads, and interstage loads
- Propulsion — ignition, thrust termination, rocket motor parameters, thrust vector, propellant flow and pressure, and retrorockets
- Performance — velocity, altitude, space position, accelerations (three axis), and attitude
- Subsystems — guidance and control signals, communications, environmental control, electric power, hydraulics, and staging
- Integration — ground handling equipment, servicing, checkout equipment, assembly fixtures, launch control console, and stage-to-stage integration

### 3.6.4.2 Receiving and Inspection

It is anticipated that the first-stage motors and clustering structure, the second stages, and the payloads will all arrive at AMR by barge. Proper scheduling of unloading and transfer operations will be required to facilitate dock-area access for other stage arrivals and to prevent excessive tug standby time. Each component or stage will be equipped with environmental control equipment to eliminate degradation during shipment. The transportation environmental instrumentation data will be removed and analyzed to determine whether any adverse environmental conditions were incurred enroute.

During the inspection phase, overall verification of each stage is planned, rather than detailed subsystem testing, because:

- Complete detailed tests will have been accomplished on each stage or component at the factory and static test facility. Therefore, these are delivered to AMR as flight items.
- Stringent reliability requirements imposed by equipment design specifications will minimize in-process equipment failures at AMR.

## NOVA FLIGHT TEST OBJECTIVES

| Flight | Configuration Stage 1st | 2nd | 3rd | Mission and Basic Objectives |
|---|---|---|---|---|
| 1 | Live | FD | FD | Nominal design trajectory; first-stage gross performance |
| 2 | | Live | FD | Nominal design trajectory; second-stage gross performance, staging, first-stage performance monitor |
| 3 | | | 1 | Maximum maneuver conditions; booster structural loads, guidance and control (225-km orbit is secondary objective) |
| 4 | | | 1 | Nominal trajectory with thrust differentials; booster performance, guidance and control, stability |
| 5 | | | 2 | 225-km orbit; staging, guidance and control (transfer from 225-km orbit to 567-km orbit is secondary objective) |
| 6 | | | 2 | 567-km orbit; orbit transfer, orbit injection, transtage performance and guidance and control, and launch system gross performance |
| 7 | | | 2 | 567-km orbit; orbit transfer, transtage guidance and control, subsystems evaluation and propulsion |

FD Flight dummy

1 Possible research or scientific space payload, without compromising booster test

2 Transtage with usable, unmanned payload

Table 3.6.4-1

NOVA R&D FLIGHT TEST REQUIREMENTS

| FLIGHT | Stability and Control | Structures | Propulsion | Performance | Subsystems | Integration |
|---|---|---|---|---|---|---|
| 1 | $P_1$ | $P_1$ | $P_1$ | $P_1$ | $S_1$ | $S_1$ |
| 2 | $P_2$ | $P_2$, $S_1$ | $P_2$ | $P_2$, $S_1$ | $S_{1,2}$ | $P_{1,2}$ |
| 3 | $P_{1,2}$ | $P_{1,2}$ | $S_{1,2}$ | $P_{1,2}$ | $S_{1,2}$ | $S_{1,2}$ |
| 4 | $P_{1,2}$ | $S_{1,2}$ | $P_{1,2}$ | $P_{1,2}$ | $P_{1,2}$ | $S_{1,2}$ |
| 5 | $S_{1,2,3}$ | $S_{1,2,3}$ | $P_2$ | $P_{1,2,3}$ | $P_{1,2,3}$ | $P_{1,2,3}$ |
| 6 | $P_3$ | $S_{1,2,3}$ | $P_3$ | $P_{1,2,3}$ | $P_{1,2,3}$ | $S_3$ |
| 7 | $P_3$ | $P_3$ | $P_3$ | $P_3$, $S_{1,2}$ | $P_3$ | $S_3$ |

P = Primary

S = Secondary

Subscript number indicates stage

Table 3.6.4-2

- Modifications will be restricted to those mandatory for mission success.
- Complete vehicle compatibility will be the end objective at AMR and test activities will be directed to achieve this as quickly as possible.

Storage provisions will permit environmentally controlled conditions for vehicle components for extended periods of time.

### 3.6.4.3 Launch Building/Launch Vehicle Compatibility Tests

After launch building ground support equipment installation, calibration, and checkout has been completed, the launch building will be tested for compatibility with the launch vehicle by the use of a Ground Test Vehicle (GTV). The GTV will be used to check out the design and construction of the launch building, to indicate necessary modifications, and to familiarize operations personnel with equipment and procedures. Physical clearances, hoisting loads, etc., that are applicable to expected NOVA components will have been simulated during the facility-activation period, prior to the launch building/GTV compatibility test.

The GTV will consist of an inert first stage, a flight-configured second stage, and a flight-configured transtage. A simulated payload of the maximum expected dimensions will be included. The GTV configuration has been chosen to ensure that a complete checkout of the facility may be completed under minimum hazardous conditions and to reduce potential delays in processing the launch vehicle. By using inert first-stage motors, no significant hazardous conditions exist until the second stage is fueled with $LH_2$. This approach allows a better distribution of work force during the checkout period, a more useful personnel training period, and will also provide for a more thorough electronic checkout period. In addition, it will be possible to recycle the second stage and the transtage for refurbishment, static test, and subsequent launch.

The GTV first stage will consist of one 260-inch flight-configured motor filled with inert propellant and five 260-inch flight-configured empty motor cases. The clustering structure will be flight-configured hardware. No major modifications to this structure are anticipated, as the design and manufacture will have been checked out as a result of static and dynamic testing. Test instrumentation and subsystems that will be monitored and/or serviced during normal prelaunch operations will be required (or simulated) to provide launch building/launch vehicle control center compatibility tests. Electronic checkout equipment is discussed in Section 3.2.7.6. All normal RF and/or hard-line connections as well as servicing umbilicals will simulate actual flight hardware. The second stage of the GTV will be the first manufactured flight-weight second stage. This stage will have undergone cryogenic propellant cold flow static testing at MTF (Section 3.6.3) prior to shipment to AMR. At the completion of the checkout of Launch Buildings 1, 2, and 3, this flight stage will be recycled to the manufacturer for refurbishment prior to static firing and launching. The transtage of the GTV will be of similar quality to the GTV second stage and will follow a similar flow path.

After launch-building calibration and checkout and other activation testing has been completed, the launch building will be prepared for the compatibility test. As shown in Figure 3.6.4-1, 4.5 months have been programmed to complete the compatibility testing of each launch building with the GTV. The sequence of operations will be as follows:

- Installation of first-stage motors (two empty cases, then inert motor followed by three empty cases)
- Cluster structure installation
- Installation of blackbox or real instrumentation and equipment to simulate "live" first-stage performance for checkout purposes
- Checkout of launch building with first stage
- Completion of necessary modifications
- Installation of second stage
- Checkout of launch building (dry) with second stage
- Checkout of launch building with second stage using restricted quantities of inert liquid cryogenics ($LN_2$); practice of emergency procedures
- Completion of necessary modifications
- Checkout of launch building with second stage using $LH_2$ and $LO_2$; practice of emergency procedures
- Purge of second stage to remove $LH_2$ and $LO_2$
- Completion of necessary modifications
- Installation of transtage; facility checkout to follow steps similar to those used for the second stage
- Installation of dummy payload — maximum size
- Installation of simulated ordnance devices on GTV
- Installation of auxiliary equipment necessary for launch (i.e., first-stage exhaust deflector, etc.)
- Dry launch run to develop launching procedures
- Removal of GTV from Launch Building 1 by dismantling. The GTV will be refurbished where necessary and routed to Launch Building 2 for its checkout. Launch Building 1 will be prepared for assembly and launch of the first vehicle.

### 3.6.4.4 Flight Test Program

Reliability figures indicate that 13 launches will be required to achieve seven successful launches. If all the test objectives are achieved prior to the 13th vehicle, remaining test vehicles could be used for man-rating the launch vehicle

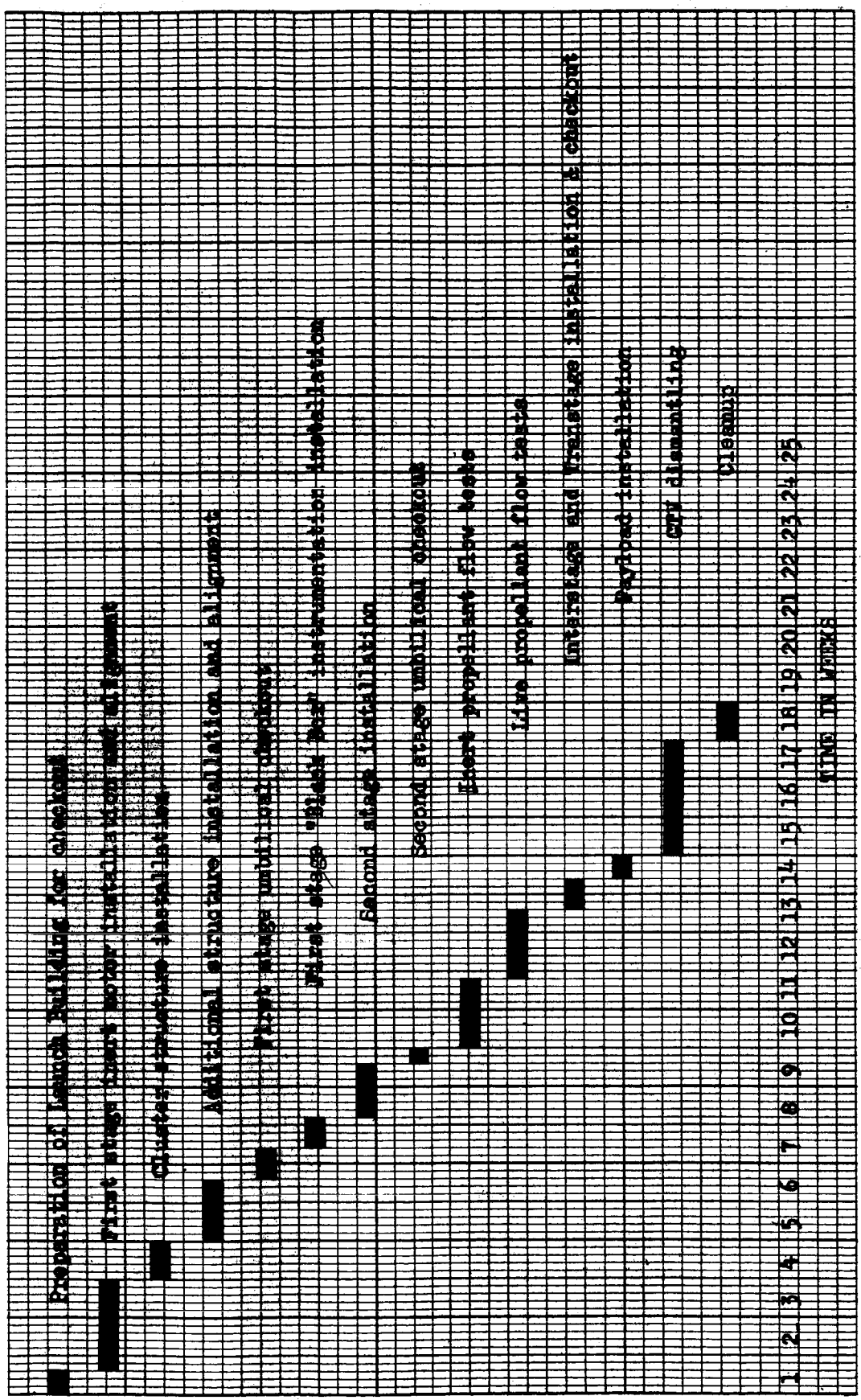


Figure 3.6.4-1 LAUNCH BUILDING CHECKOUT
Ground Test Vehicle

or in the operational program. A calendar flow diagram for the flight test program is shown in Figure 3.6.4-2. Ample time has been allowed between each test flight for analysis of data from the previous flight and the incorporation of any necessary modifications into subsequent test-flight configurations. Significant milestones of the flight-test program schedule are:

- Solid motor on-dock times at AMR
- Second stage on-dock at Mississippi Test Facility (MTF)
- Second-stage static firing tests at MTF
- Receiving and inspection — AMR
- Prelaunch operations — AMR
- Launch building refurbishment and modifications
- Launch building/GTV integration dates
- Vehicle launch dates

A typical launch-vehicle processing schedule, representative of the third flight test vehicle, is shown in Figure 3.6.4-3. Tasks to be accomplished during each time period, and required flow times, are indicated. The time required for the accomplishment of the various tasks will decrease as personnel experience level increases and procedures become more accurately defined.

During the assembly and checkout of the vehicle, some components will require modification or replacement as a result of component malfunction or mission requirement changes. These alterations will be completed in the launch building if possible, or on a remove and replace basis, whichever will least affect the overall launch schedule.

Since the total vehicle and launch complex networks come together for the first time in the launch building, an all-systems integration test (including an RF-electrointerference test) will be planned as the final step in the integration process. This test will also form the basis for final vehicle acceptance and verification of readiness for final countdown operations.

The flight evaluation task consists of five specific elements:

- Analysis of mission objectives, planned boost trajectories, and systems performance requirements to establish data requirements
- Preparation of evaluation procedures
- Reduction of data and completion of computations
- Conduct of preliminary flight evaluations
- Conduct of final flight evaluations

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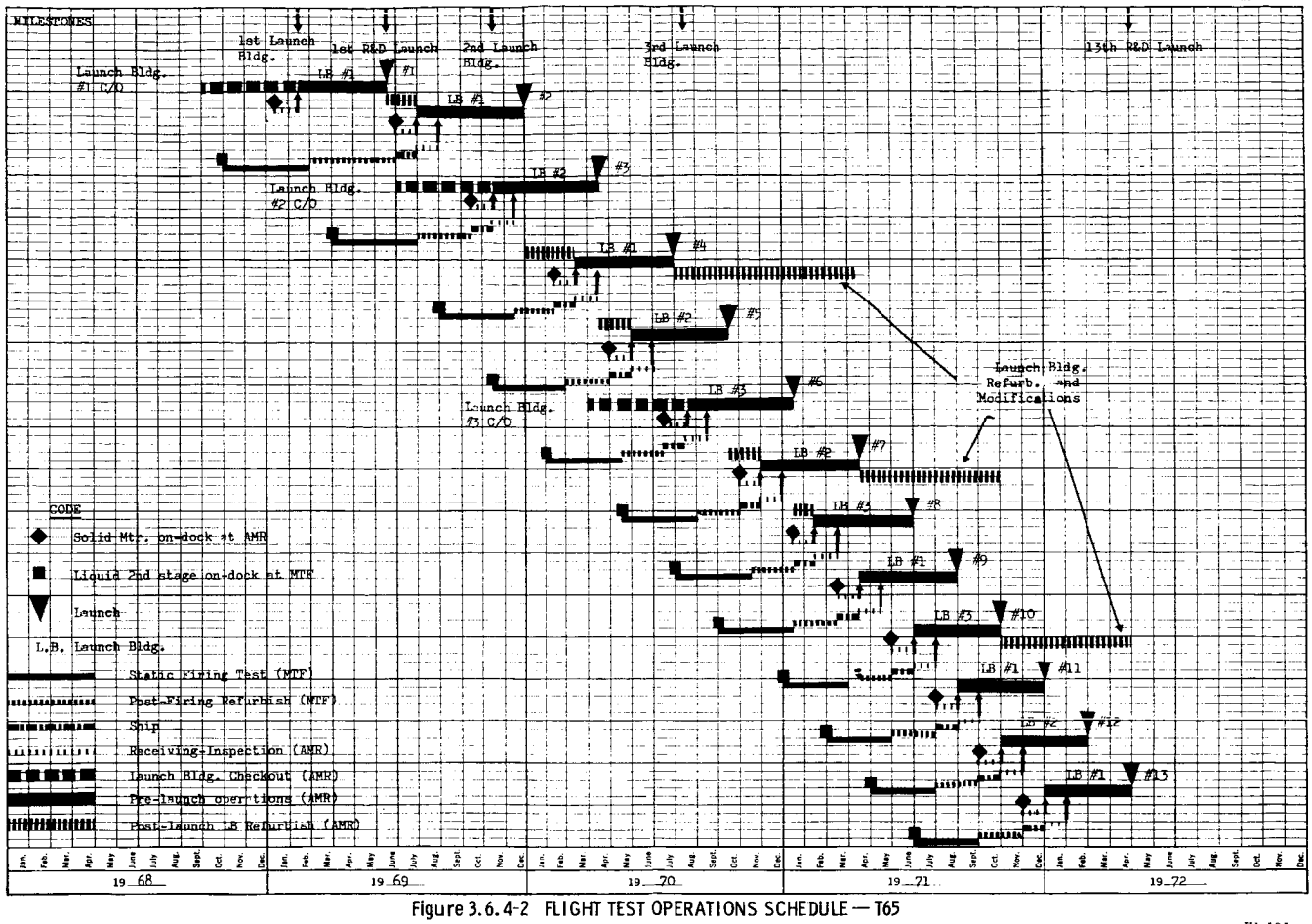


Figure 3.6.4-2 FLIGHT TEST OPERATIONS SCHEDULE — T65

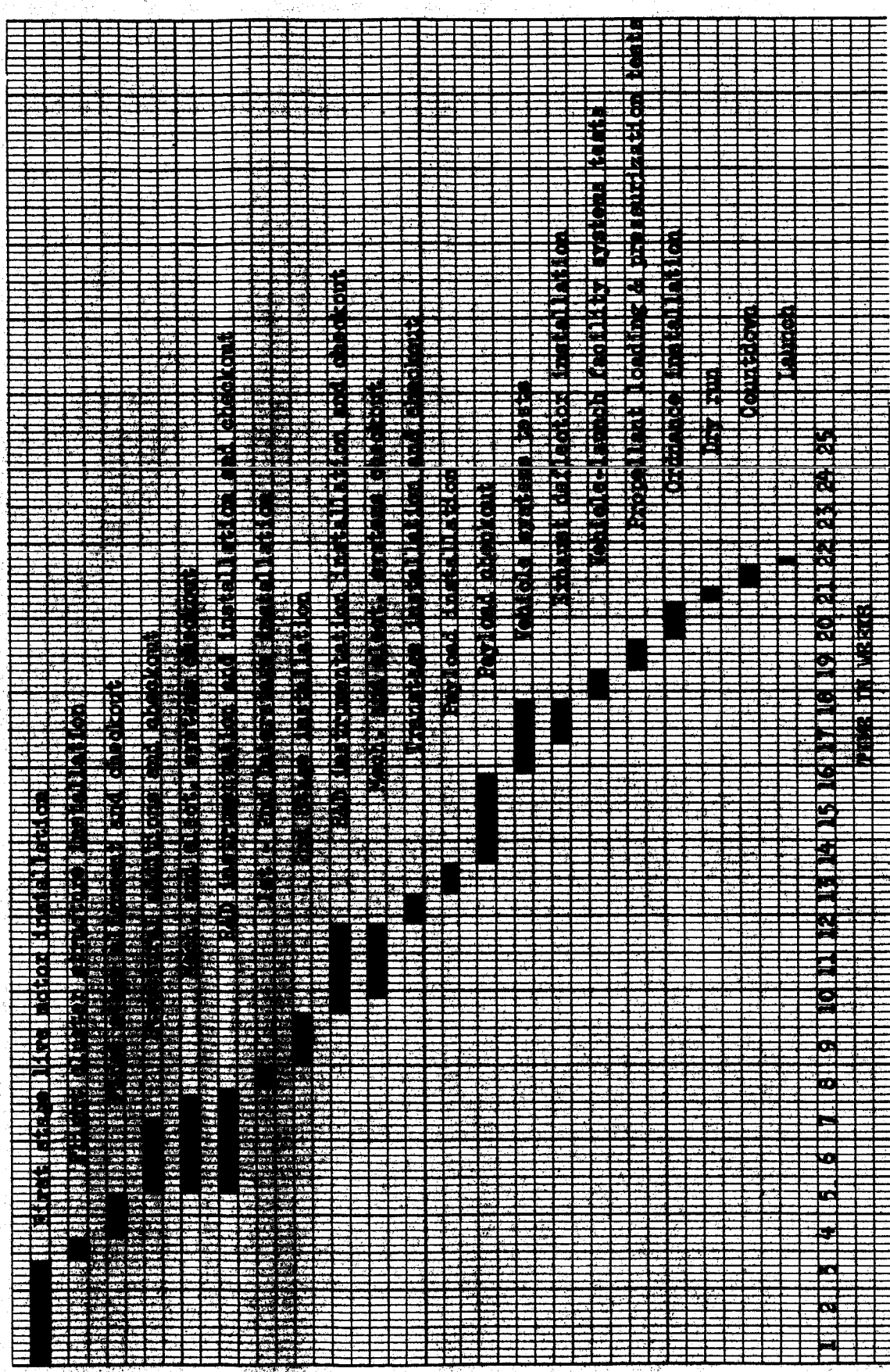


Figure 3.6.4-3 LAUNCH PREPARATIONS
Flight Test Vehicle

A data requirements document will be prepared for each flight. It will consist of two parts, the first defining the stage external data (meteorological, tracking, and photographic) to be provided by range facilities, the second defining the internal telemetry which will identify measurement numbers, measurements and sensor types, range of measurements, error allowances, flight sequencing and periods, etc.

An evaluation procedures document will define data-reduction requirement, procedures, and computation techniques; will describe plans and schedules, nominal values and expected limits of various parameters (temperatures, pressures, flow rates, etc.), nominal trajectory, and flight sequences; and will provide an analysis of instrumentation system accuracies for each launch.

Incoming flight data will be processed to provide quick-look time-history plots of all data channels. Special cross-plots of two or more data channels and, in particular, a "most probable" three-axes postflight "trajectory" will be required.

A preliminary flight evaluation report will be prepared within 10 days after launch and will emphasize critical inflight performance and environment parameters and present the data necessary to substantiate the observations or conclusions made.

A detailed flight evaluation will be completed within 45 days after each launch. It will be based on a thorough, quantitative analysis of the data and will contain all reduced data, a description of stage systems and subsystems performance, flight environment encountered, inflight sequences, and total vehicle performance.

### 3.6.4.5 Flight Test Facility Requirements (AMR)

Operational launch facilities will be used during the R&D flight test program. These are described in Section 3.3.7. In addition, the following support facilities are required:

- Support shops (sheet metal, welding, tubing, electrical, metallurgical, etc.)
- Office space (test management, planning, records, data processing and analysis, etc.)
- Range or base support (tracking, security, safety, and medical, etc.)

## 3.7 DEVELOPMENT PLAN

### 3.7.1 Introduction

This section defines the basic plan for the T65D program. The design, development, manufacturing, facilities, and test programs have been evaluated to establish flow times and interrelationships of major work packages. The basic plan is presented in the form of a Program Summary Schedule, Figure 3.7.1-1, and a PERT network, Figure 3.7.1-2. The basic plan presents certain noncritical items in minimum detail (e.g., transtage) or omits the item (e.g., retrorockets) to reduce the detail complexity of the graphs. These and other noncritical items will require inclusion in schedules and networks before implementation of a detailed program control system.

The development plan is based on the supporting operations discussed in Section 3.3.4, including the guidelines and assumptions stated in 3.3.4.1. In addition, the following guidelines and assumptions have been used:

- System contract award date is assumed to be July 1, 1964.
- M-1 engine development is based on data from Lewis Research Center, dated January 8, 1963 (Confidential), and is consistent with NASA Memo "Advanced and Unconventional Engine Data," dated January 15, 1963 (Confidential). (See Figure 3.7.1-3.)
- Test stands for propulsion, structural, and dynamic tests are assumed to be at the Mississippi Test Facility (MTF).
- Requirements for a solid-motor manufacturing plant are assumed to be available when required in the Southeast.
- Major facility construction is assumed to be required for second-stage manufacture.

### 3.7.2 Summary

The R&D phase is scheduled for completion after the seventh successful launch on or before the thirteenth flight test, 7 years and 10 months after contract go-ahead. Initial operational capability (IOC) will be two months later, in July 1972. The PERT analysis has defined the critical program path through the second flight-test launch with second-stage activities critical for a major part of the time. The analysis has also revealed that certain lesser paths will require close surveillance.

### 3.7.3 Program Summary Schedule

The Program Summary Schedule, Figure 3.7.1-1, presents the T65D program calendar requirements from system contract award on July 1, 1964, through IOC on July 1, 1964. The manufacturing completion schedule for the

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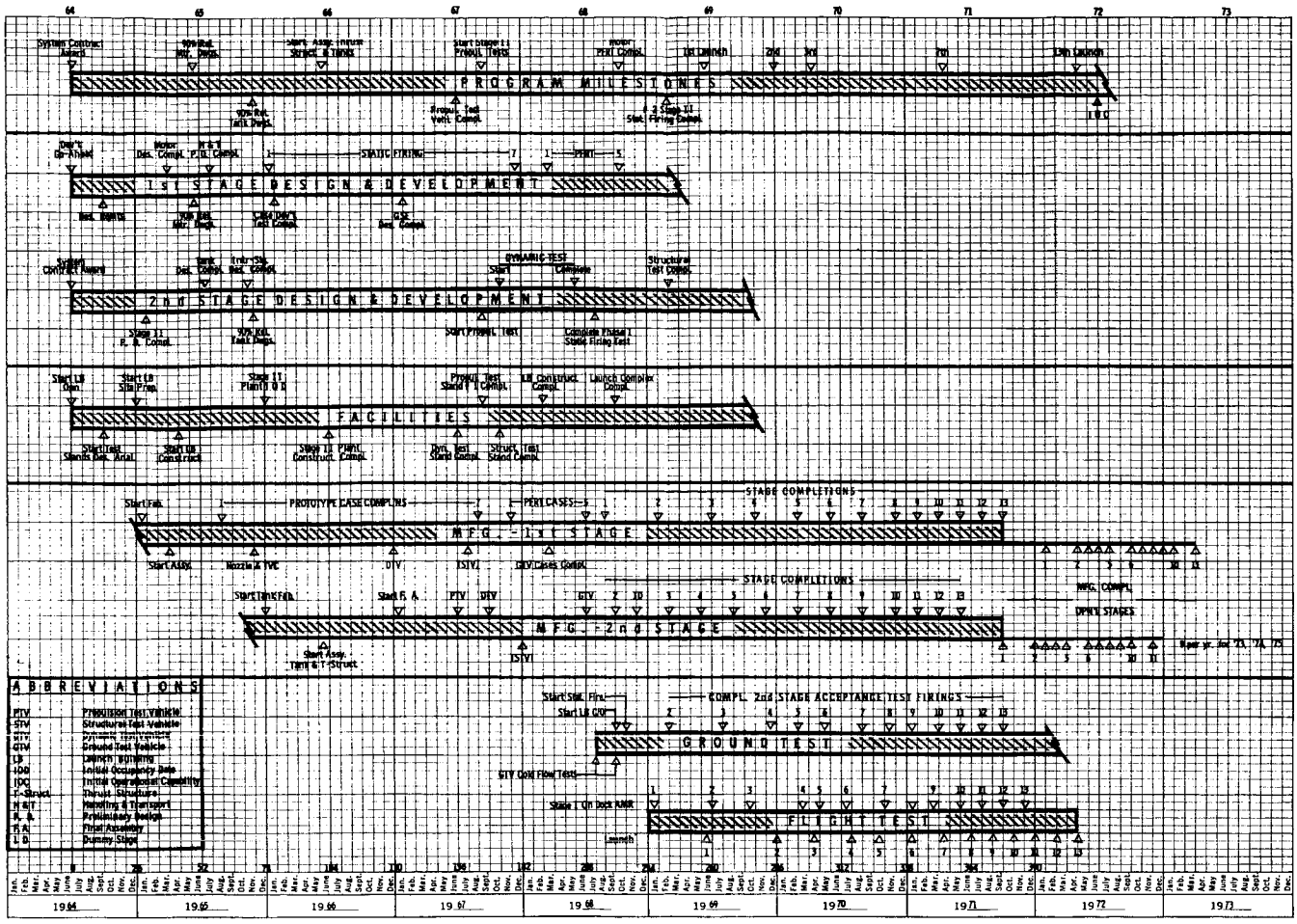
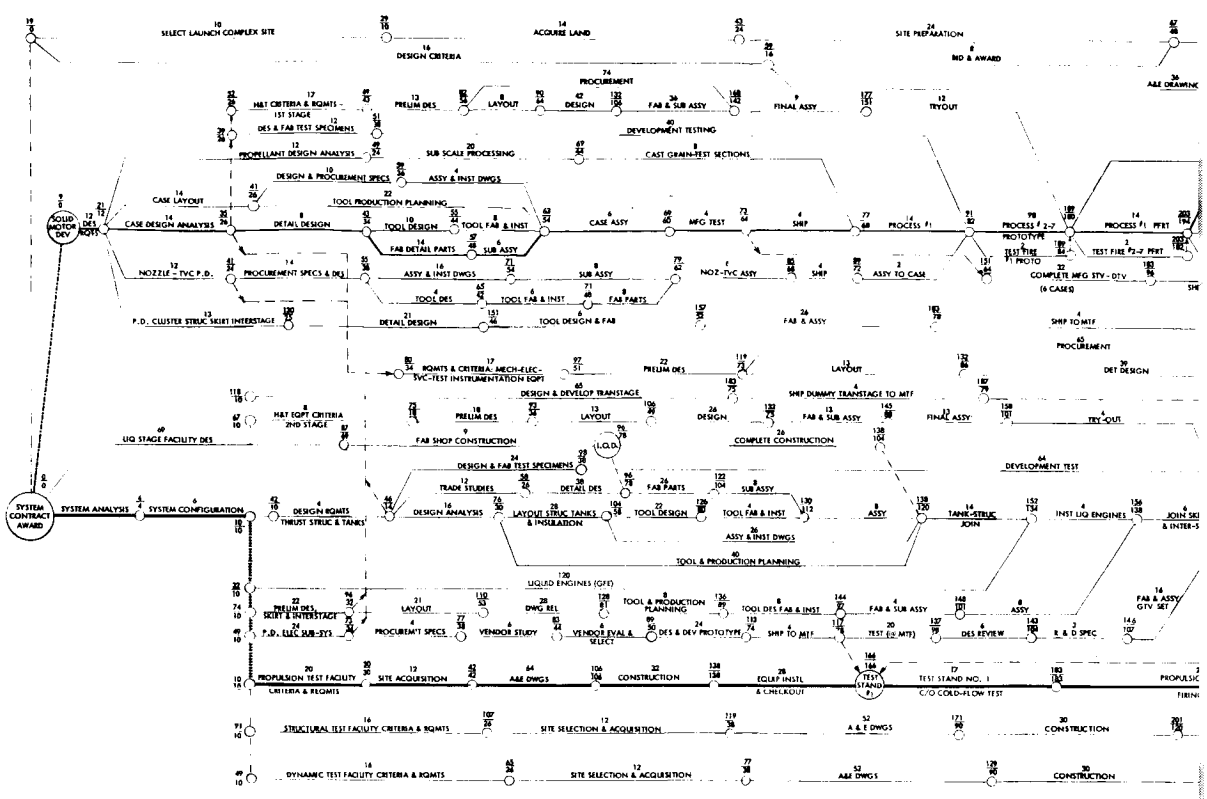



Figure 3.7.1-1 DEVELOPMENT PROGRAM SUMMARY SCHEDULE — T65


SELECT LAUNCH COMPLEX SITE
ACQUIRE LAND
SITE PREPARATION
DESIGN CRITERIA
BID & AWARD
PROCUREMENT
H&T CRITERIA & RQMTS - 1ST STAGE
PRELIM DES
LAYOUT
DESIGN
FAB & SUB ASSY
FINAL ASSY
TRYOUT
DES & FAB TEST SPECIMENS
DEVELOPMENT TESTING
PROPELLANT DESIGN ANALYSIS
SUB SCALE PROCESSING
CAST GRAIN-TEST SECTIONS
DESIGN & PROCUREMENT SPECS
ASSY & INST DWGS
CASE LAYOUT
TOOL PRODUCTION PLANNING
SOLID MOTOR DEV
CASE DESIGN ANALYSIS
DETAIL DESIGN
TOOL DESIGN
TOOL FAB & INST
CASE ASSY
MFG TEST
SHIP
PROCESS F1
PROTOTYPE
FAB DETAIL PARTS
SUB ASSY
NOZZLE - TVC P.D.
PROCUREMENT SPECS & DES
ASSY & INST DWGS
SUB ASSY
NOZ-TVC ASSY
SHIP
ASSY TO CASE
COMPLETE MFG STV - DTV
(6 CASES)
TOOL DES
TOOL FAB & INST
FAB PARTS
P.D. CLUSTER STRUC SKIRT INTERSTAGE
DETAIL DESIGN
TOOL DESIGN & FAB
FAB & ASSY
SHIP TO MTF
PROCUREMENT
RQMTS & CRITERIA: MECH-ELEC-TVC-TEST INSTRUMENTATION EQPT
PRELIM DES
LAYOUT
DET DESIGN
DESIGN & DEVELOP TRANSTAGE
SHIP DUMMY TRANSTAGE TO MTF
H&T EQPT CRITERIA 2ND STAGE
PRELIM DES
LAYOUT
DESIGN
FAB & SUB ASSY
FINAL ASSY
TRY-OUT
LIQ STAGE FACILITY DES
FAB SHOP CONSTRUCTION
COMPLETE CONSTRUCTION
L.O.D.
DESIGN & FAB TEST SPECIMENS
DEVELOPMENT TEST
TRADE STUDIES
DETAIL DES
FAB PARTS
SUB ASSY
SYSTEM CONTRACT AWARD
SYSTEM ANALYSIS
SYSTEM CONFIGURATION
DESIGN RQMTS THRUST STRUC & TANKS
DESIGN ANALYSIS
LAYOUT STRUC TANKS & INSULATION
TOOL DESIGN
TOOL FAB & INST
ASSY
TANK-STRUC JOIN
INST LIQ ENGINES
ASSY & INST DWGS
TOOL & PRODUCTION PLANNING
LIQUID ENGINES (GFE)
PRELIM DES SKIRT & INTERSTAGE
LAYOUT
DWG REL
TOOL & PRODUCTION PLANNING
TOOL DES FAB & INST
FAB & SUB ASSY
ASSY
FAB & ASSY GTV SET
P.D. ELEC SUB-SYS
PROCUREMENT SPECS
VENDOR STUDY
VENDOR EVAL & SELECT
DES & DEV PROTOTYPE
SHIP TO MTF
TEST (@ MTF)
DES REVIEW
R & D SPEC
PROPULSION TEST FACILITY CRITERIA & RQMTS
SITE ACQUISITION
A&E DWGS
CONSTRUCTION
EQUIP INSTL & CHECKOUT
TEST STAND F1
TEST STAND NO. 1 C/O COLD-FLOW TEST
STRUCTURAL TEST FACILITY CRITERIA & RQMTS
SITE SELECTION & ACQUISITION
A & E DWGS
CONSTRUCTION
DYNAMIC TEST FACILITY CRITERIA & RQMTS
SITE SELECTION & ACQUISITION
A&E DWGS
CONSTRUCTION

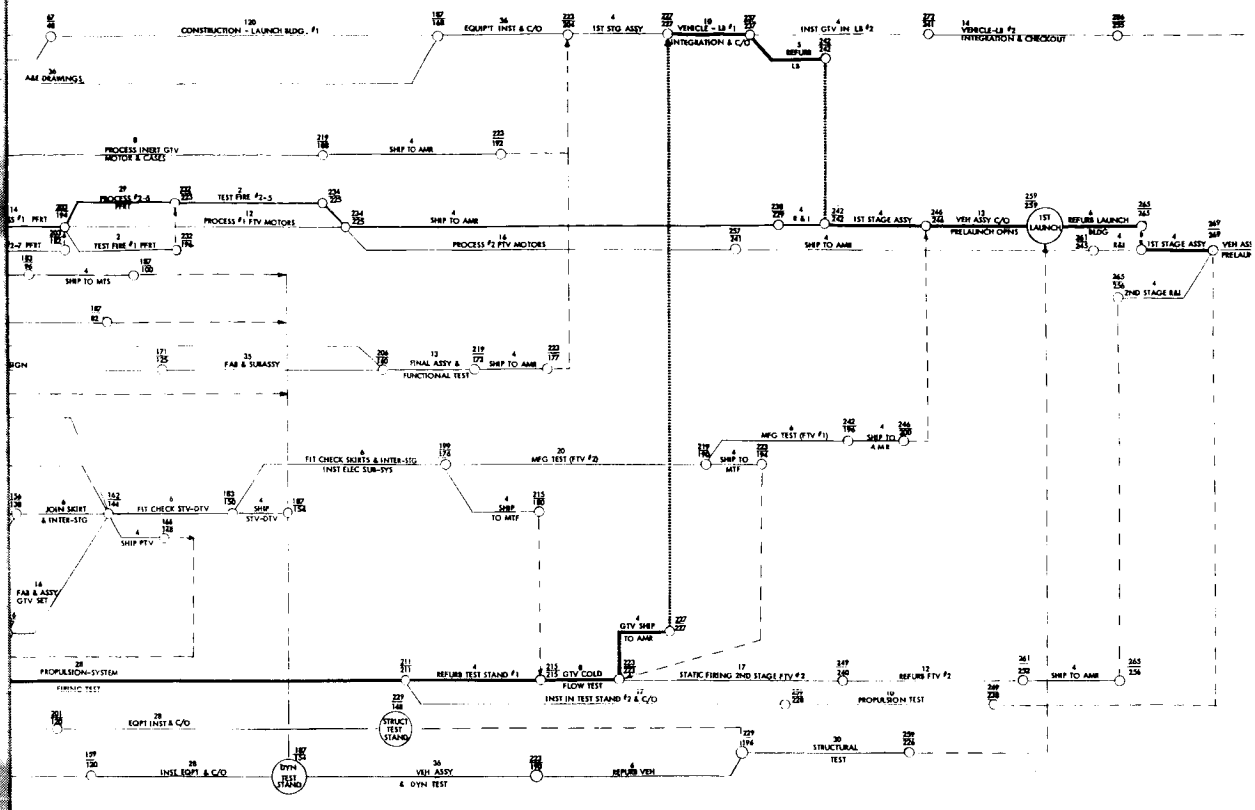
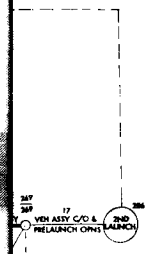
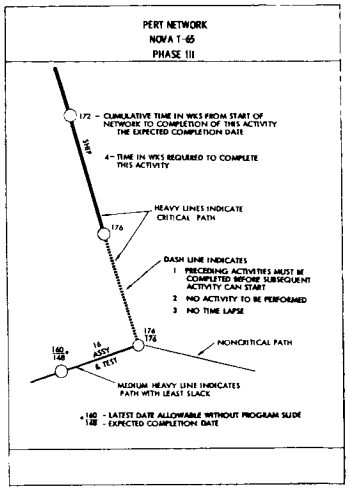



Figure 3.7.1-2 SOLID NOVA PERT NETWORK


17
VEH ASSY C/O &
PRELAUNCH OPNS
2ND
LAUNCH


PERT NETWORK
NOVA T-65
PHASE III
172 - CUMULATIVE TIME IN WKS FROM START OF NETWORK TO COMPLETION OF THIS ACTIVITY THE EXPECTED COMPLETION DATE
4 - TIME IN WKS REQUIRED TO COMPLETE THIS ACTIVITY
HEAVY LINES INDICATE CRITICAL PATH
176
DASH LINE INDICATES
1 PRECEDING ACTIVITIES MUST BE COMPLETED BEFORE SUBSEQUENT ACTIVITY CAN START
2 NO ACTIVITY TO BE PERFORMED
3 NO TIME LAPSE
176
176
NONCRITICAL PATH
160
148
16
ASSY
& TEST
MEDIUM HEAVY LINE INDICATES PATH WITH LEAST SLACK
+160 - LATEST DATE ALLOWABLE WITHOUT PROGRAM SLIDE
148 - EXPECTED COMPLETION DATE

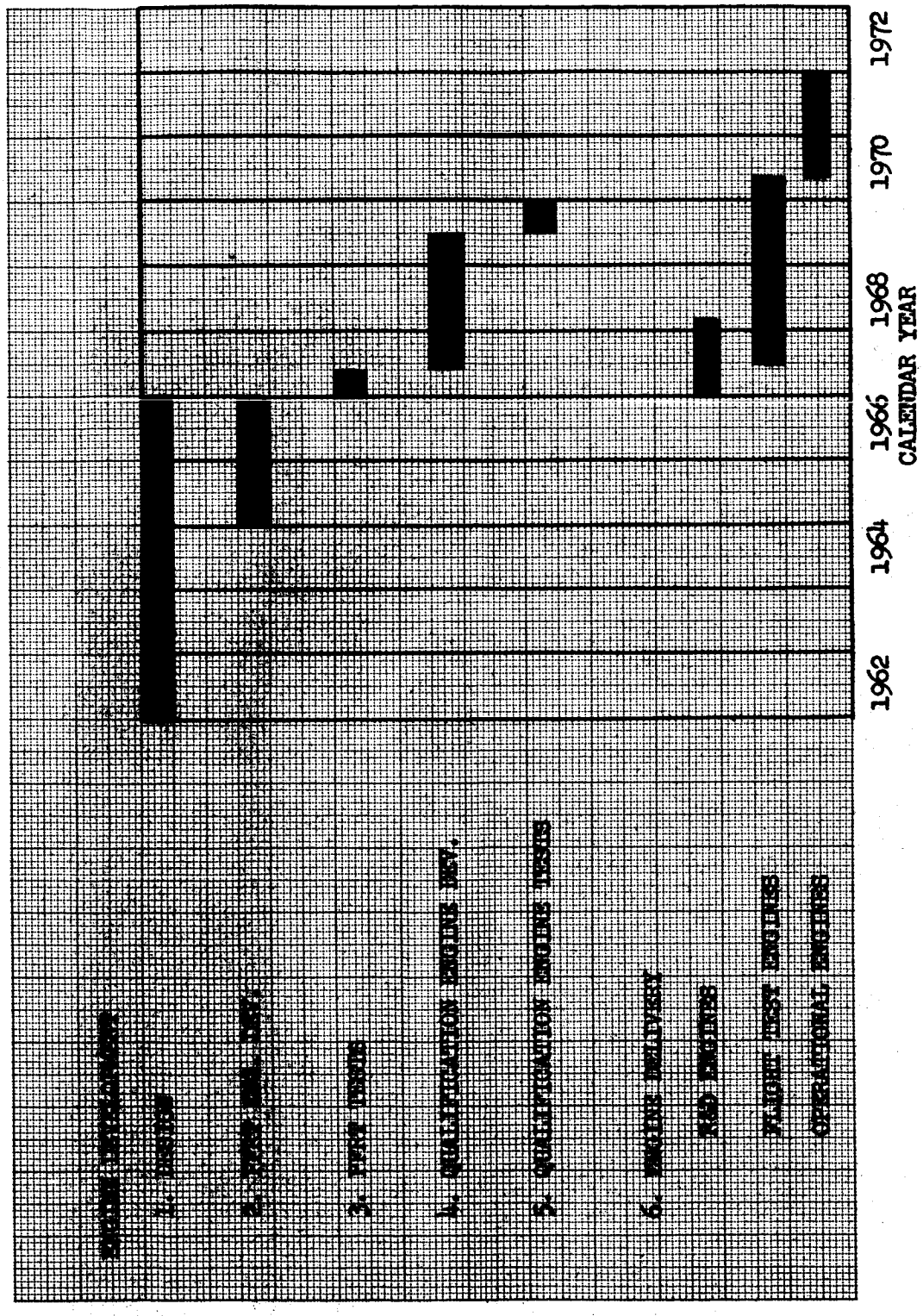



Figure 3.7.1-3 M-1 PROPULSION SYSTEM DEVELOPMENT SCHEDULE

operational program is also indicated. The various phases of the program are discussed in other sections of the report; however, it should be noted that complete vehicles are scheduled for use in structural test, dynamic test, and checkout of the launch building. For these vehicles the first-stage cases will be supplied empty except for one inert-loaded case, which will be used on the ground test vehicle (GTV) for transport, handling, and launch-building checkout. Initial planning assumes that the structural and dynamic tests will both be accomplished on one vehicle. Sufficient time has been made available in the schedule, however, for the production of an extra vehicle, structural test vehicle (STV) because of the probability that detail schedule reviews will show that two vehicles are required for these two tests. The necessity for a second vehicle for these tests will require a second set of tooling and equipment for production of first-stage motor cases to maintain this schedule.

### 3.7.4 PERT Network

The PERT network, Figure 3.7.1-2, presents the T65D program planning and control system from system contract award through the second flight-test launch. This period represents the most critical portion of the development program.

The critical path is indicated on the PERT network chart by heavy lines. None of the tasks on this path can be delayed or extended without causing a month-for-month slide in the completion of the program. The tasks in the critical path are summarized below:

| Task | Task Flow Time (In Weeks) | Completion Date | |
|---|---|---|---|
| | | Calendar | Weeks After Go-Ahead |
| Second-Stage Propulsion Test Stand | 156 | Sept. 1967 | 166 |
| Stand Checkout and Second-Stage Propulsion Tests | 49 | July 1968 | 215 |
| Ground-Test-Vehicle Propellant Flow Test | 12 | Oct. 1968 | 227 |
| Launch-Building Checkout and Refurbishment | 15 | Jan. 1969 | 242 |
| Vehicle Assembly, Prelaunch Operations, and Launch | 17 | June 1969 | 259 |
| Second Launch Operation | 27 | Jan. 1970 | 286 |

It should be noted that tasks on the "least-slack path" can absorb only a 9-week delay before, in turn, becoming critical. The tasks involved are indicated by medium heavy lines and are concerned with the development of the solid motors for the first stage.

The PERT network is concluded at the second launch with the use of the first live second stage in the 286th week after contract award. The schedule for completion of tasks subsequent to that date is indicated in the Program Summary Schedule, along with the time phasing of the tasks grouped together as related functions.

### 3.7.5 Major Subsystem Schedules

#### 3.7.5.1 First-Stage Development

The schedules for first-stage development are presented in Figure 3.7.5-1 through 3.7.5-4, covering cases, nozzles and TVC, propellant and cluster structure, and manufacturing, respectively. They are based largely on data supplied by solid-propellant manufacturers considered to be major contenders for the 260-inch-motor development program, the contract for which is now pending. The longest flow time requested by the manufacturers was used to ensure consistency in conservatism with the rest of the schedule. A flow-time reduction of up to 9 months is deemed feasible with reasonable increase in risk or cost.

As indicated by the PERT network, Figure 3.7.1-2, motor development, as a part of the solid first stage, is on the least-slack path. This operation can absorb a maximum of 9 weeks delay before, in turn, becoming critical. With regard to first-stage development only, the effect of a reduction in flow time of critical path tasks is shown below:

| Reduction | New Critical Paths |
|---|---|
| 9 weeks | Currently defined least-slack path |
| 26 weeks | Nozzle TVC development |

From the above, it will be noted that a 9-week reduction in flow time of the currently planned critical path will cause first-stage development to become pacing. It would then require a subsequent reduction of an additional 17 weeks, for a total of 26 weeks, before nozzle TVC development would become pacing.

As indicated on the case development schedule, R&D static firing is conducted with a total of seven cases, the first two of which will be short cases, and the last five, full length. PFRT will be conducted with the next five rocket motors, for a total of 12 used during the development program. The overall flow time for motor development through PFRT is 51 months. The production of Flight

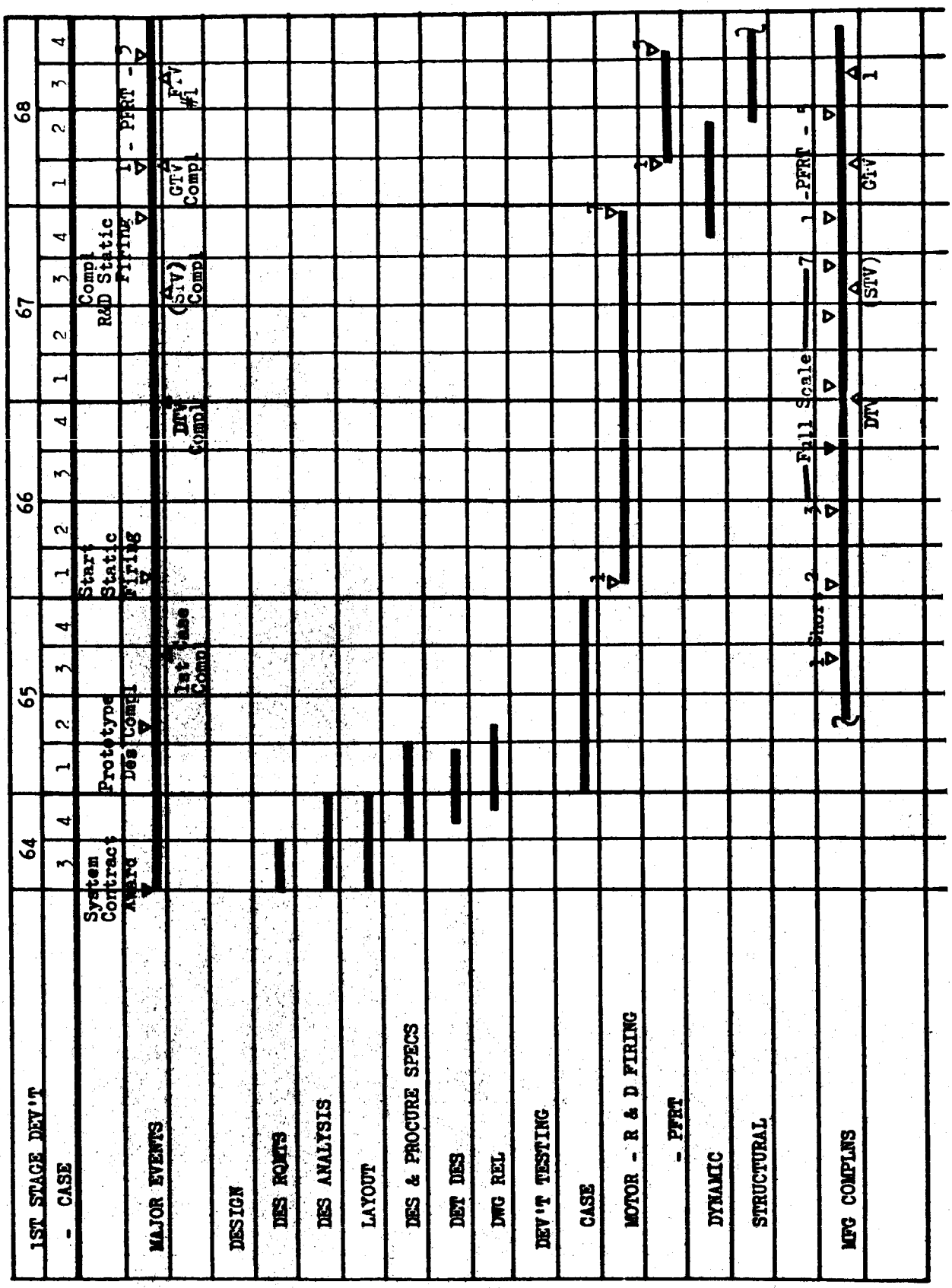



Figure 3.7.5-1 FIRST STAGE DEVELOPMENT SCHEDULE (Case)

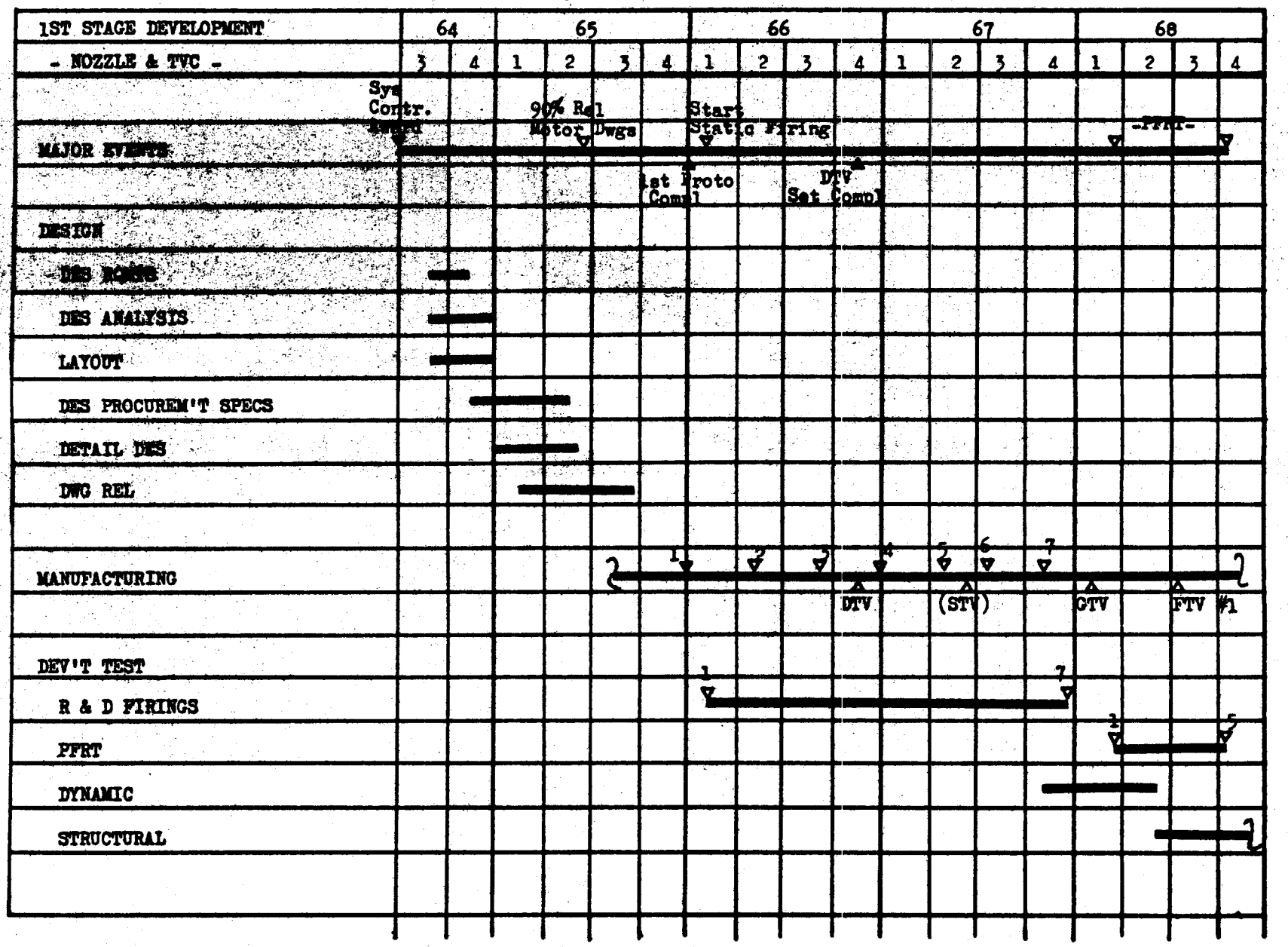



Figure 3.7.5-2 FIRST STAGE DEVELOPMENT SCHEDULE
(Nozzle and TVC)

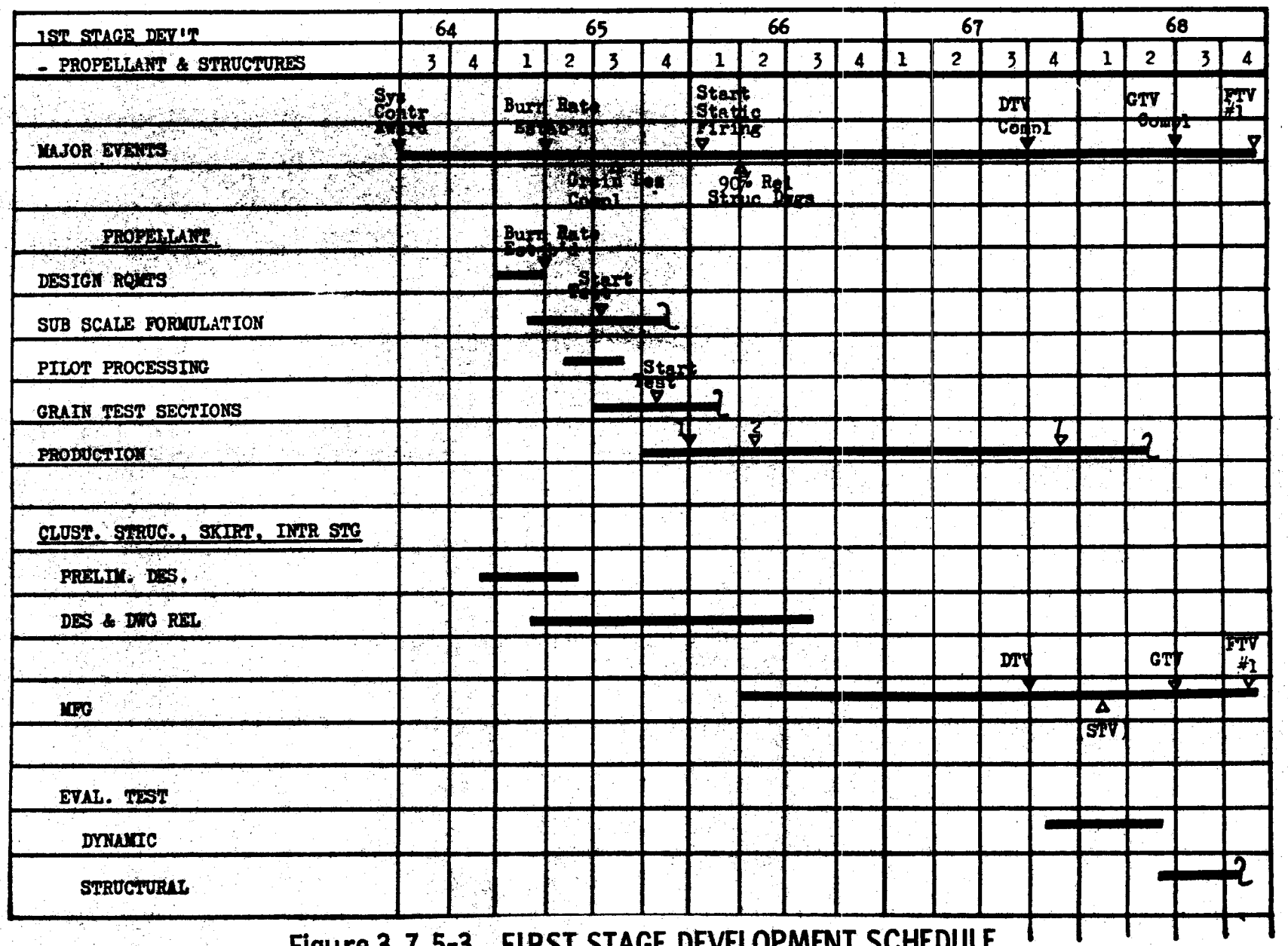



Figure 3.7.5-3 FIRST STAGE DEVELOPMENT SCHEDULE
Propellant and Structures

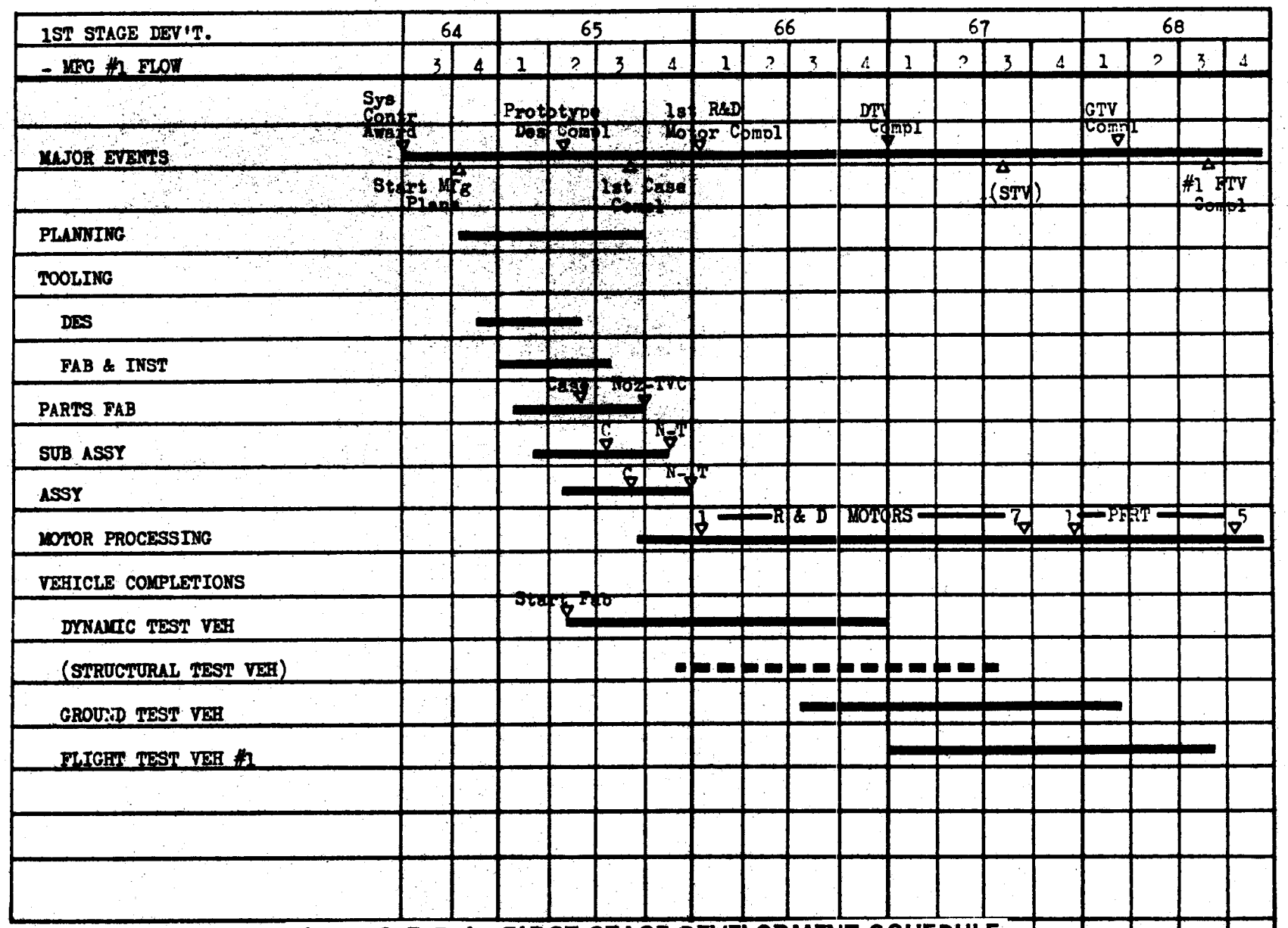



Figure 3.7.5-4 FIRST STAGE DEVELOPMENT SCHEDULE
Manufacturing No. 1 Flow

Test Vehicle Number 1 is included in this time period, and is completed 1.5 months prior to the fifth PFRT firing to provide a smooth buildup in motor manufacturing operations.

### 3.7.5.2 Second-Stage Development

Adequate time is available for all second-stage development operations (see Figures 3.7.5-5 through 3.7.5-7). With regard to the second stage only, the effect of flow-time reduction in the currently planned critical path tasks are shown below:

| Reduction | New Critical Paths |
|---|---|
| 18 weeks | Fabrication shop construction |
| 22 weeks | Liquid-engine development |

### 3.7.5.3 Ground Support Equipment

The ground support equipment (GSE) development schedule is shown in Figure 3.7.5-8. As indicated by the schedule, GSE development does not begin until the first quarter of 1965 — after the completion of design of most of the major subsystems. The first set of GSE is shipped directly to AMR. Initial requirements for manufacturing plant operations will be provided by existing equipment or in-plant development. Slack time of 46 weeks, however, allows sufficient time to produce much of the in-plant and test-stand requirements. Earlier completion of handling and transportation equipment for the first-stage motors is avoided by using the same pit for casting, curing, and test firing. Floating drydocks or barges can be rented if required for both first and second stages.

### 3.7.5.4 Facilities

Because of the size of the NOVA vehicle, new facilities are required for most major subsystems. The initial requirements for the first stage, however, are assumed to be available as a result of the 260-inch-motor development program now pending.

The time required for construction of second-stage Propulsion-Test Stand Number 1 (see Figure 3.7.5-9), coupled with its subsequent full-time utilization, results in these related tasks becoming the critical path. The transfer of the propulsion-test vehicle in continued propulsion tests to Test Stand Number 2 solves the critical utilization problem. However, material reduction in flow time for these operations seems unlikely without resorting to two-shift operation or overtime.

The Initial Occupancy Date (IOD) of the second-stage facility of January 1966, delays second-stage fabrication by 14 weeks. Eighteen weeks of slack time

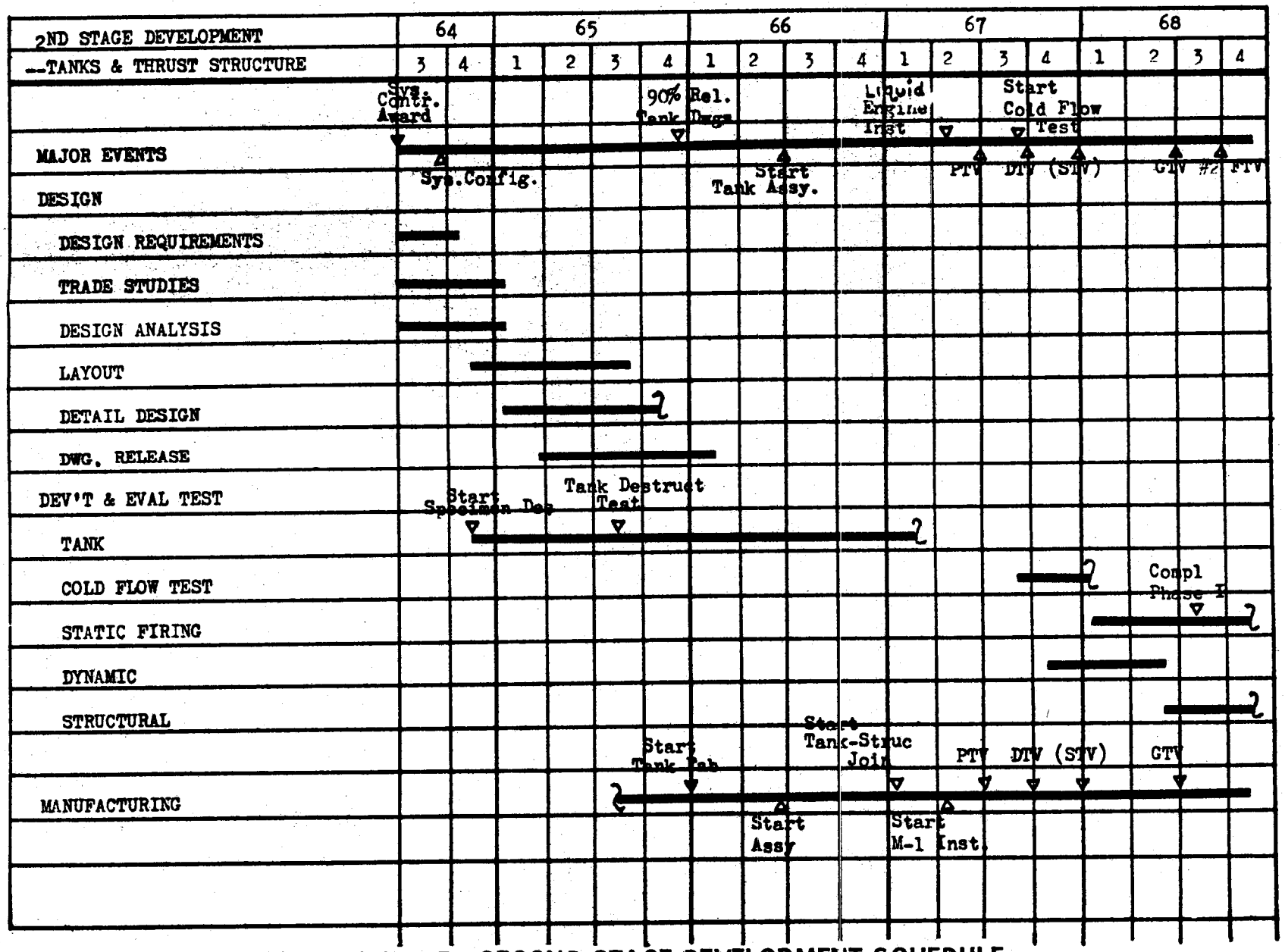



Figure 3.7.5-5 SECOND STAGE DEVELOPMENT SCHEDULE
Tanks and Thrust Structure

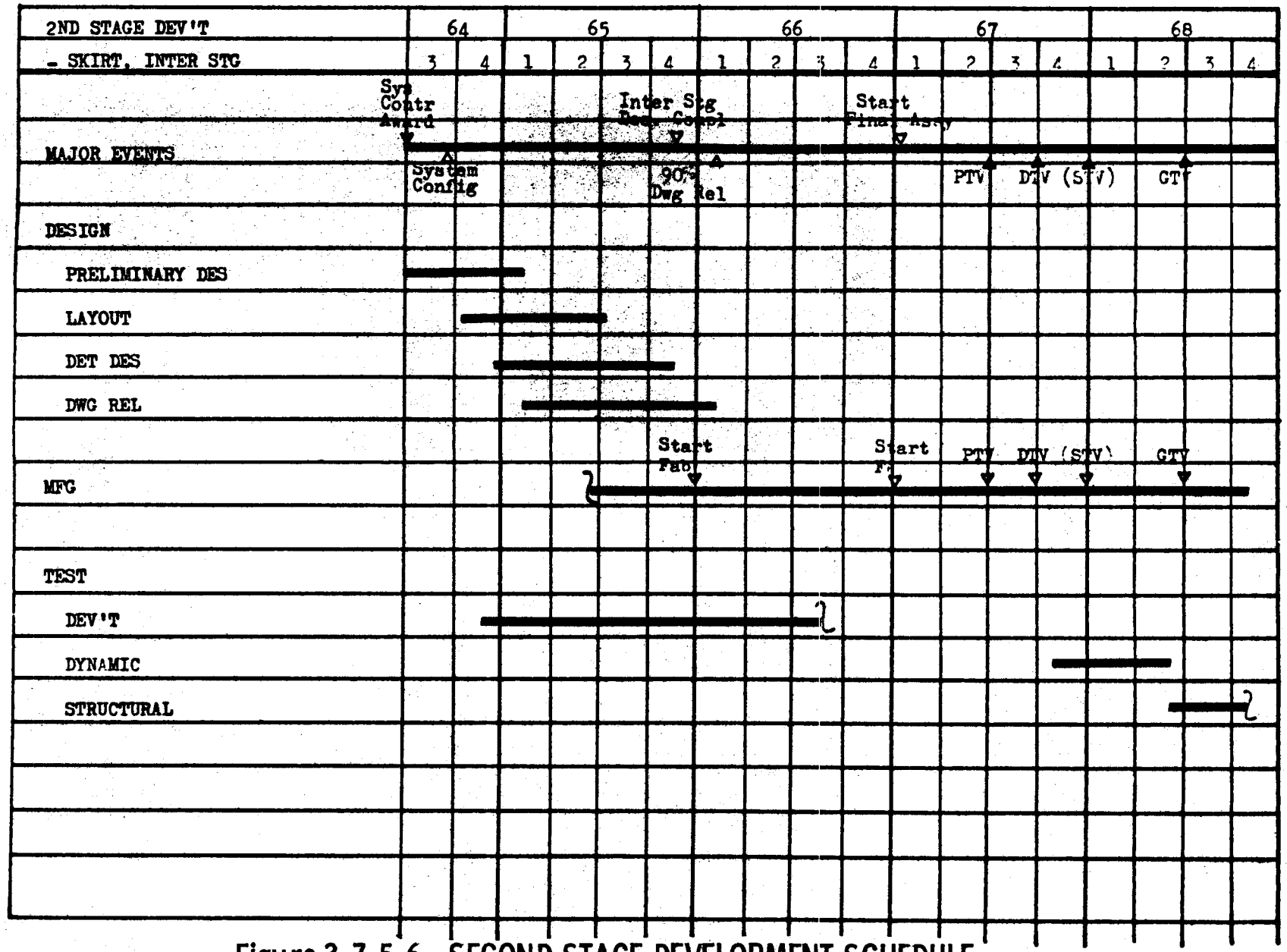



Figure 3.7.5-6 SECOND STAGE DEVELOPMENT SCHEDULE
Skirt and Interstage Structure

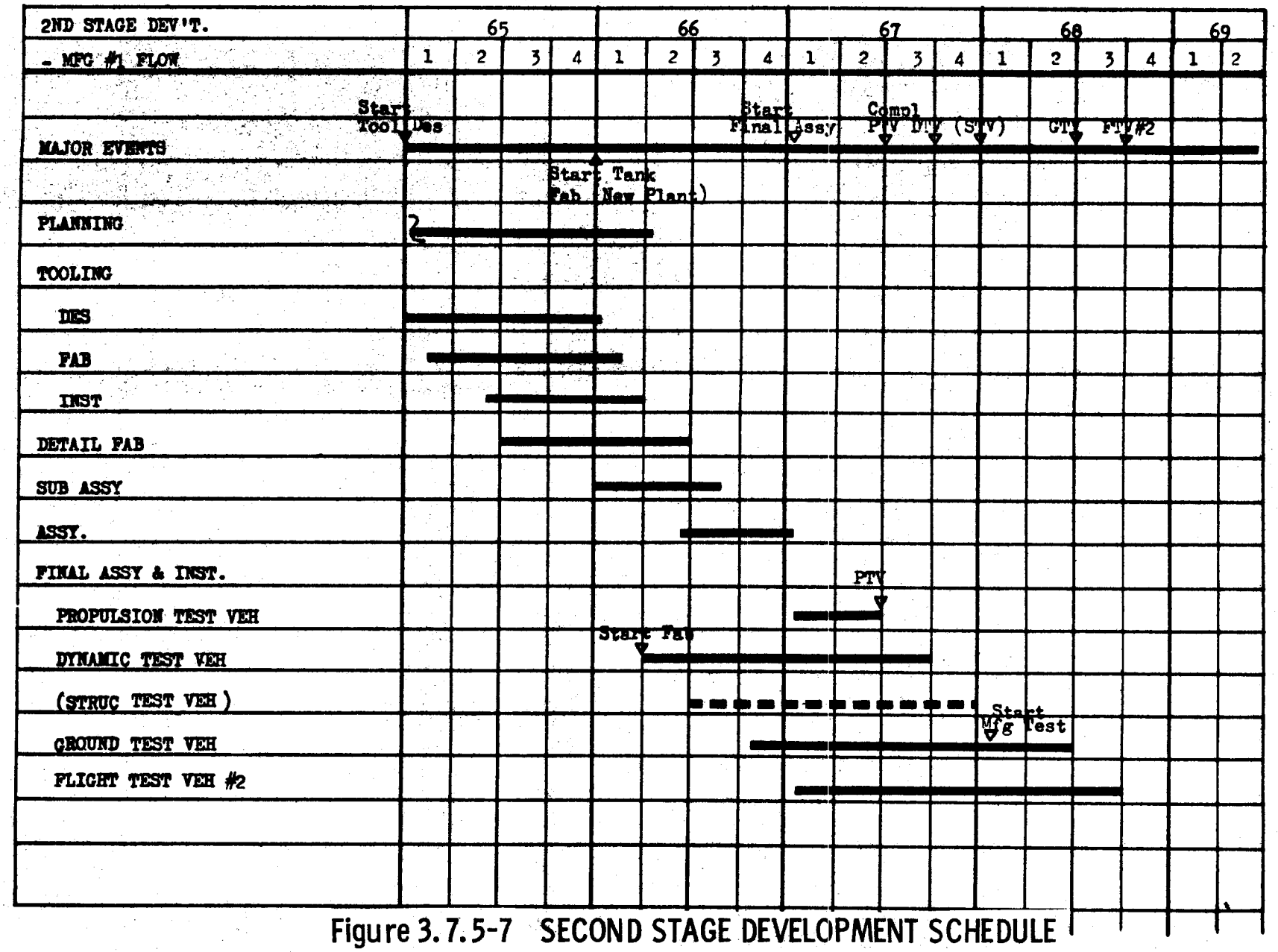



Figure 3.7.5-7 SECOND STAGE DEVELOPMENT SCHEDULE
Manufacturing No. 1 Flow

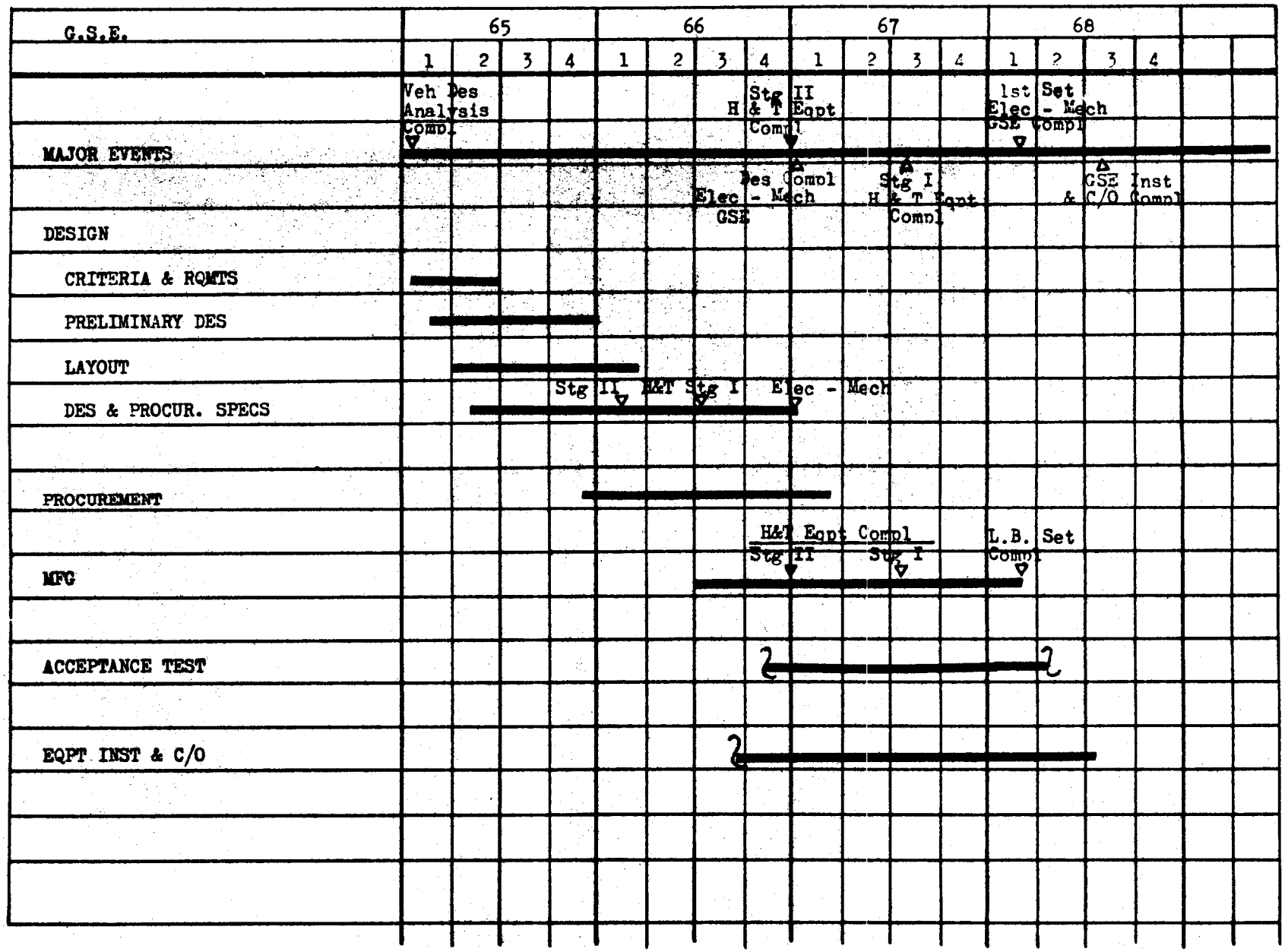



Figure 3.7.5-8 DEVELOPMENT SCHEDULE
Ground Support Equipment

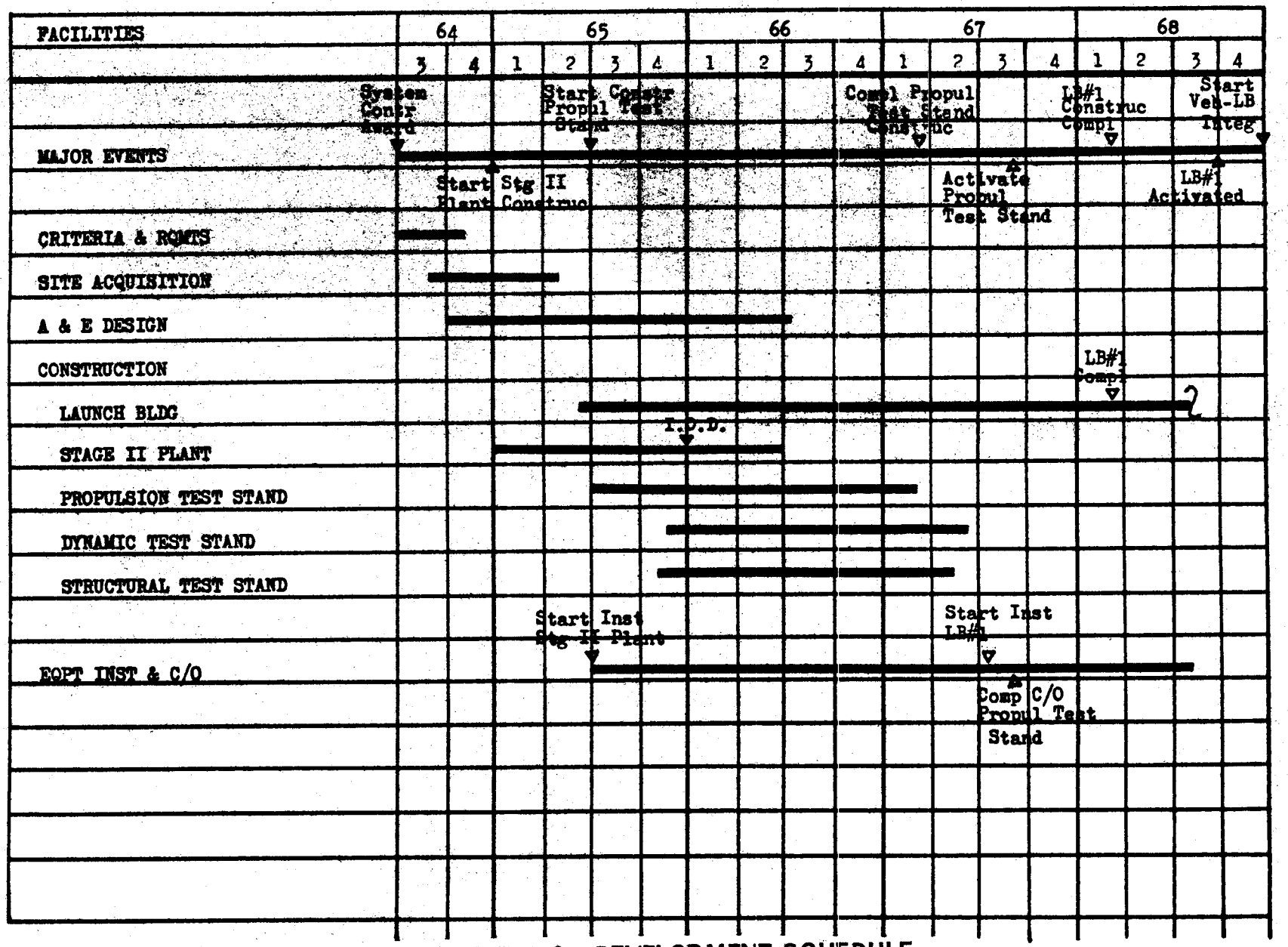



Figure 3.7.5-9 DEVELOPMENT SCHEDULE
Facilities

remains, however, before these tasks would become critical. With regard to facilities, the next most critical path is the launch building with a total of 19 weeks of slack time available before becoming critical.

3.7.5.5 Systems Test

Flight test operations are shown in Figure 3.7.5-10. The ground test vehicle (GTV) will consist of a complete vehicle, including transtage and payload, as is the case for dynamic test and structural test. One inert motor case is to be provided for the GTV; the other five will be empty, as will be those for the dynamic test vehicle (DTV) and structural test vehicle (STV). The GTV will be used for checkout of Launch Buildings 1 through 3 for the flight-test program and will then be used to check out the additional launch buildings required for the operational program. The first launch will be conducted with a dummy second stage (labeled 1 D on the summary schedule). Launch Building Number 2 will be used for the third launch; the first two flight tests will be conducted from Launch Building Number 1. The second launch is shown as a constraint in the PERT network only because it is the last event shown on the network.

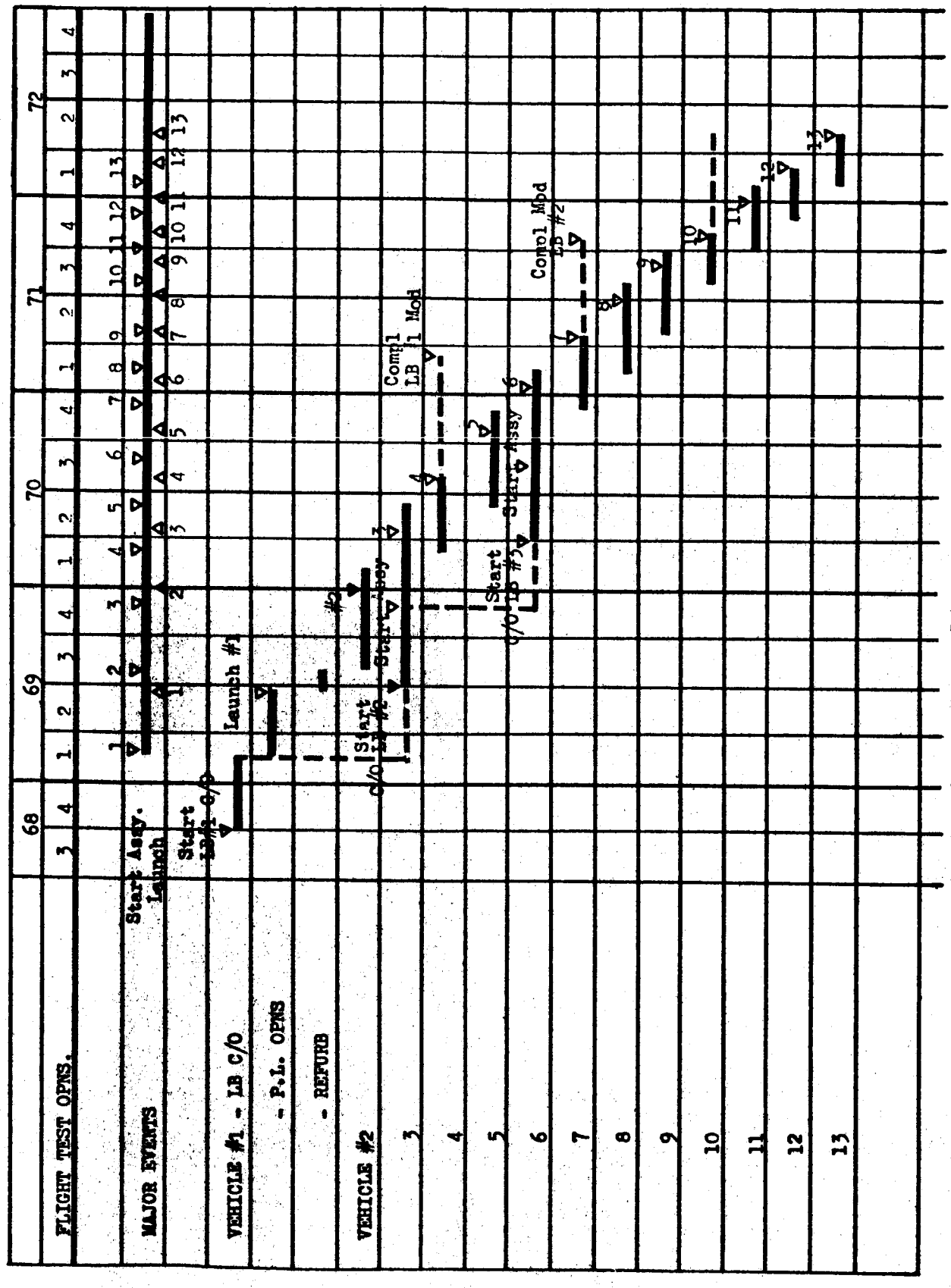



Figure 3.7.5-10 SCHEDULE
Flight Test Operations

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# 4.0 ADVANCED TECHNOLOGY

## 4.1 INTRODUCTION

In consideration of the reduction of NOVA-class mission costs, a study was made to determine the savings that might be realized through advancements in high-energy propulsion systems as applied to this mission. Should such savings prove significant, a possible delay in operational availability to incorporate these advances may be advisable. The preliminary findings associated with the subject work increment are set forth in this section.

## 4.2 SUMMARY

Three advanced-technology and one current-technology NOVA-class two-stage (solid/cryogenic) concepts were evaluated on the basis of comparative performance, development risk, development time, growth potential, development cost, and cost effectiveness.

The current-technology concept, T65, upon which the preliminary design portion of this study was based, is a tandem-staged vehicle using six solid first-stage motors and five M-1 second-stage engines.

APM-67 is a parallel-staged vehicle using six solid-booster motors and seven modified M-1 second-stage engines. Both the solid- and liquid-propulsion systems are ignited at launch and all units provide thrust vector control (TVC) by nozzle gimbaling. This design is predicated on the development of the stepped expansion ratio or altitude-compensating feature in the M-1 engines.

AT-41 is a tandem-staged vehicle using four solid fixed-nozzle first-stage motors and a single high-pressure, high-expansion-ratio, expansion-deflection (E-D) type second-stage engine. TVC on the first stage is obtained by secondary injection of combustion gases by direct chamber bleed. TVC on the second stage is obtained by flow modulation of opposing thrust-chamber segments (throttling), secondary injection, or a combination of both.

The APM-41 is a parallel-staged vehicle using four solid fixed-nozzle booster motors and a single E-D type sustainer engine with partial altitude compensation. As with APM-67, all units are ignited at launch. TVC is identical to that described for AT-41, above.

The advanced-technology vehicles were sized for maximum payload/launch weight ratio for a fixed-payload size. The principal variables are thrust level and staging velocity.

Launch weights and payload in 225-kilometer orbit for the baseline vehicle and the three advanced-technology vehicles are:

| Configuration | Launch Weight | Payload |
|---|---|---|
| T65 | 38,062,000 | 1,070,000 |
| APM-67 | 29,996,000 | 1,100,000 |
| AT-41 | 24,944,000 | 1,100,000 |
| APM-41 | 21,975,000 | 1,100,000 |

Two of the advanced-technology vehicles (APM-41 and AT-41) showed that significant gains can be made in all categories of comparison except development risk and time. APM-41 was best from the standpoints of cost effectiveness, performance, and growth potential. APM-67 showed some gains in these categories with less development risk and time. The baseline current-technology vehicle (T65) shows least development time and risk but rates substantially below APM-41 in the other categories.

For structural considerations, fixed-nozzle design reduces the first-stage inert weight; the shorter length of the parallel-staged concept reduces flight bending loads and permits lighter solid-motor cases because of the reduced static buckling loads.

Launch cone angles (from building) are 2.2 degrees for the AT-41, 5.0 degrees for APM-67, and 4.7 degrees for APM-41. Flight control requirements are 3.65 degrees equivalent gimbal angle for AT-41, 5.2 degrees for APM-67, and 5.5 degrees for APM-41. Stage separation occurs at a dynamic pressure of approximately 100 psf for APM-67 and 300 to 400 psf for AT-41 and APM-41. Staging is accomplished on APM-67 by sliding the spent solid cluster away from the liquid core on rails, with retrorocket assist; AT-41 incorporates dual-plane separation with retrorocket assist; APM-41 is staged by "peeling" the individual spent solid motors away from the core in a lateral outboard motion.

Reliability is expected to improve for the advanced-technology vehicles because of the additional time to develop common subsystems and the additional launch and operational experience gained with interim vehicles. Of the concepts studied, highest reliability is expected for APM-41 because of fewer propulsion units and the capability of hold-down for starting the liquid engine. AT-41 has the same number of propulsion units, but the reliability is lowered by the in-flight start requirement for the liquid engine. APM-67 reliability is slightly higher than T65 because of the hold-down feature, but less than AT-41 because of the greater number of propulsion units.

Manufacturing costs vary according to complexity, size, and rate, with AT-41 indicated as least costly followed by, in increasing order of cost, APM-41,

APM-67, and T65. Manufacturing facilities are quite similar to those required for the T65, with the exception that new facilities would be required to build the large E-D engine.

From ground support considerations, AT-41 is most desirable, followed by APM-41. T65 and APM-67 are comparable in this respect, but are less desirable than the other two vehicles.

The development test requirements for the various configurations are similar, differing mainly in the relative phasing of the various tasks. The configurations using the E-D engine would require a greater interval between start of development static test and start of acceptance static test. Flight test requirements are greater with the parallel-staged vehicles than with the tandem-staged vehicles.

The development program indicates initial operational capability (IOC) in mid-1973 for APM-67, early 1976 for AT-41, and early 1977 for APM-41.

## 4.3 SELECTION OF CANDIDATE CONFIGURATIONS

A number of advanced NOVA-class concepts were examined. These included the use of both conventional and unconventional chemical propellant stages and nuclear stages.

### 4.3.1 Liquid Fluorine-Liquid Hydrogen Propulsion

Performance estimates indicate that the use of fluorine-hydrogen propellants in altitude-compensating engines would provide single-stage-to-orbit capability with a good payload-to-launch-weight ratio. The exhaust products are, however, highly toxic and may contaminate the launch area and the air space used by commercial airlines operating in the vicinity of Cape Canaveral. This may be avoided by auxiliary boost with nontoxic propellants to an altitude where contamination is no longer a problem. In the case of auxiliary solid boost, the payload-to-launch-weight ratio decreases as the size of the solid stage increases; therefore, this stage should be the minimum required to avoid undue contamination. A detailed study of the dispersion of toxic effluents would be required before this system could be evaluated. Further consideration of fluorine as a propellant for this study was dropped upon direction of the MSFC project office.

### 4.3.2 Nuclear Propulsion

The application of nuclear propulsion to the NOVA mission was studied. To avoid the dangers of radiation at the launch site and contamination of the area in the vicinity of Cape Canaveral, a solid-propellant first stage was planned. Further consideration of nuclear propulsion for this study was also dropped upon direction of the MSFC project office.

### 4.3.3 Unconventional Solid-Propellant Motors

On the assumption that large time variations in thrust tailoff of solid propellant motors can appreciably affect vehicle control just prior to stage separation, two booster concepts were examined which would reduce or eliminate this problem.

#### 4.3.3.1 Annular Booster Concept

This concept, shown in Figure 4.3-1, embodies an annular, or ring-shaped, solid rocket motor with an end-burning grain. The six nozzles are connected to the common combustion chamber to minimize thrust variations between nozzles. Aluminum or other metallic wires are used to increase the burning rate to from 3 to 5 inches per second. This is necessary to produce the required thrust with a reasonable cross-sectional loading.

#### 4.3.3.2 Manifolded-Head Booster Concept

This concept, shown in Figure 4.3-2, uses a number of conventional internal-burning star-grain solid rocket motors attached to a common head-end manifold that also contains a star grain. The manifold equalizes the pressure to essentially eliminate variations in thrust between the nozzles.

Because certain manufacturing, logistic, and technical difficulties were indicated, these configurations were dropped from the evaluation.

### 4.3.4 Liquid Oxygen-Liquid Hydrogen Propulsion

A number of advanced-design engines could be considered for the second or sustainer stage of the subject vehicles. The selection, however, was made from the engines listed in NASA Memo M-P&VE-PA-29-63, dated January 15, 1963. From this group, the Rocketdyne L-9H Toroidal most nearly matched the concept requirements. Since this engine is in the technological study phase only, it was scaled up to match the individual concept requirements. This engine is a high-pressure unit having a nozzle expansion ratio of 150. TVC is obtained by throttling the thrust-chamber segments on one side while implementing the flow on the opposite side, by secondary fluid injection, or a combination of both.

The basic nozzle of the M-1 engine has an expansion ratio of 40. The nozzle could be modified to reduce this ratio to 20 at launch by the insertion of a jettisonable flow separator or a mechanical device to change the ratio to 40 at the appropriate altitude.

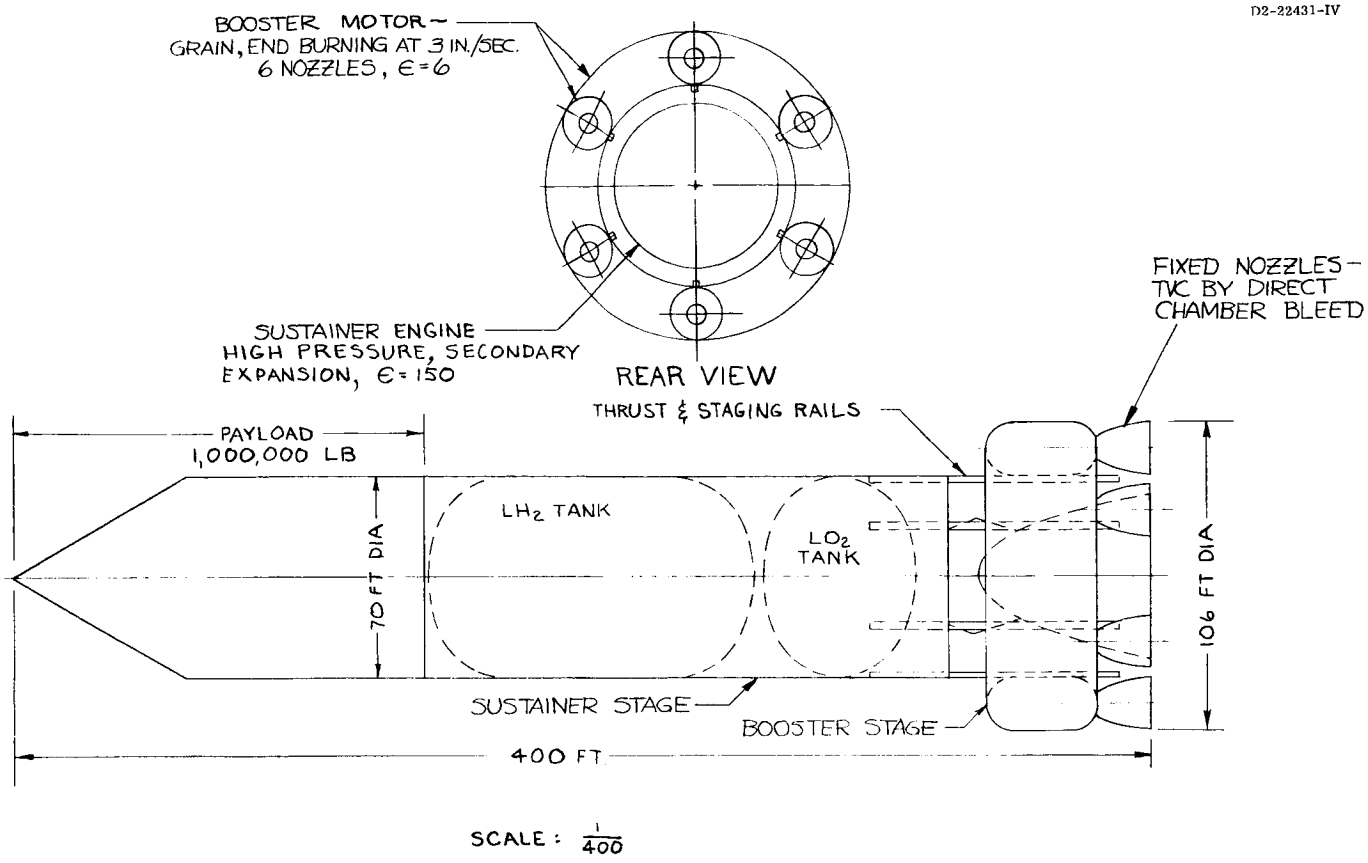


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Figure 4.3-1 ANNULAR BOOSTER CONCEPT

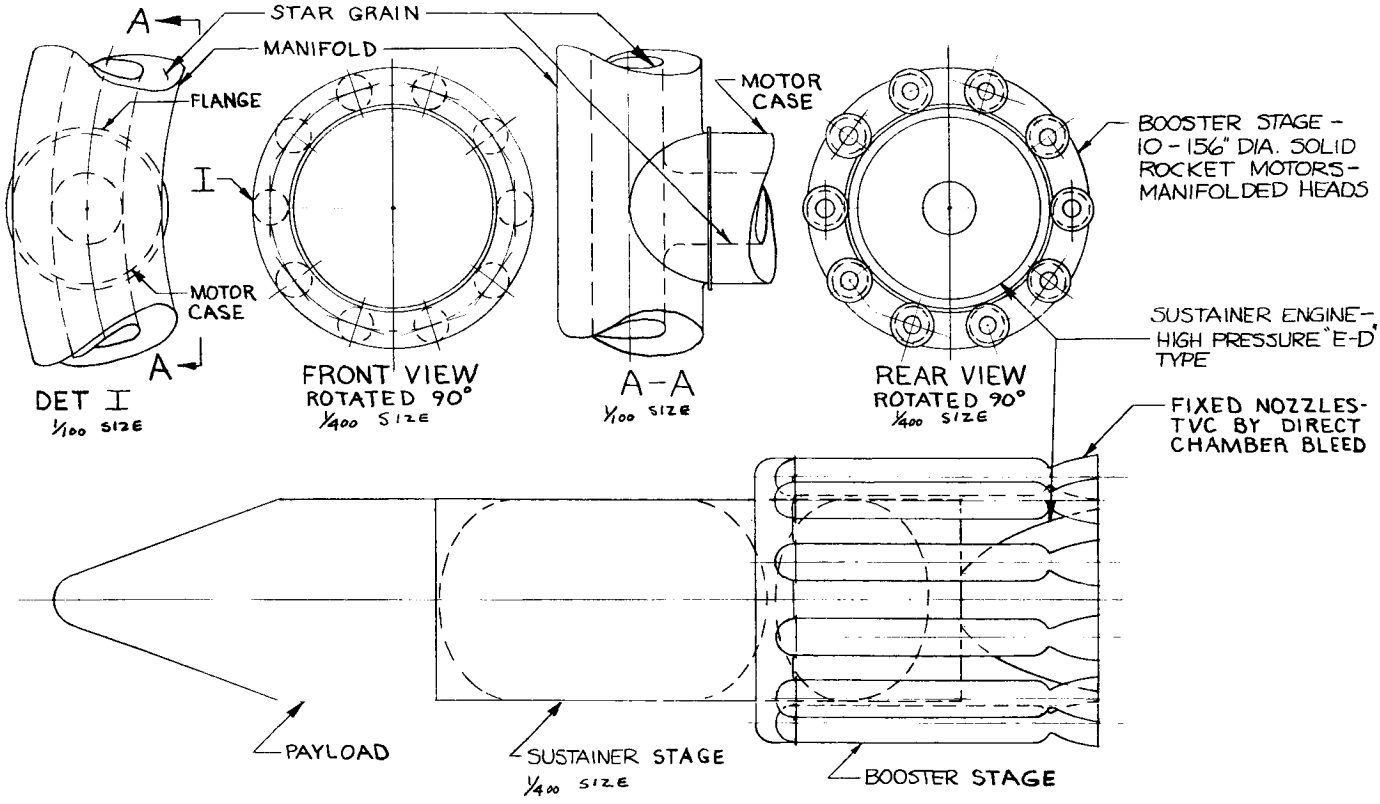


Figure 4.3-2 MANIFOLDED HEAD BOOSTER CONCEPT

### 4.3.5 Vehicle Concept Selection

A variety of advanced vehicle concepts to perform the NOVA missions is possible. The limited scope of this portion of the effort, however, required deferment of consideration of many of the less conventional types. Three of the major factors affecting vehicle configuration are precise payload definition, liquid-propellant tankage concept, and vehicle guidance and control limitations. To simplify the configuration and analysis of the advanced vehicles presented in this section, current-technology payload, tankage, and basic control concepts were used.

#### 4.3.5.1 Configuration APM-67

Configuration APM-67, shown in Figure 4.3-3, is a parallel-staged expendable launch vehicle using a cluster of six 260-inch-diameter solid-propellant booster motors and seven modified M-1 sustainer engines. Booster and sustainer propulsion units are ignited at launch. The booster motors are jettisoned at burnout. Thrust vector control (TVC) is obtained by nozzle gimbaling.

#### 4.3.5.2 Configuration AT-41

Configuration AT-41, shown in Figure 4.3-4, is a tandem-staged expendable launch vehicle using a cluster of four 260-inch-diameter solid-propellant first-stage motors and a single expansion-deflection (E-D) second-stage engine.

The first-stage motors have fixed nozzles. TVC is obtained by secondary injection of combustion gases by direct chamber bleed. Alternate methods of TVC have not been evaluated.

Dual-plane separation is used for staging because of the proximity of the large-diameter nozzle to the interstage, and the necessity for rapid start of the second-stage engine. Since staging occurs at a relatively high dynamic pressure, the uncontrolled coast period must be minimized. Separation adajcent to the nozzle exit plane permits the immediate start of the engine with a consequent early attainment of TVC. The remaining interstage is then jettisoned to reduce the second-stage inert weight.

An alternate configuration, AT-61, shown in Figure 4.3-5, uses a cluster of six 260-inch-diameter solid-propellant motors. For optimum design with the high-performance second-stage engine, the solid-propellant motors must have a relatively low burn time (less than 80 seconds) and high thrust level. As a result, the cross-sectional loading and mass fraction of the solid motor tend to be low. Reducing the thrust level of the individual motor by using a larger number of motors in the stage improves the cross-sectional loading. This apparent improvement in mass fraction, however, is offset by structure required to cluster a large number of units and by a decrease in reliability as the number of units increases.

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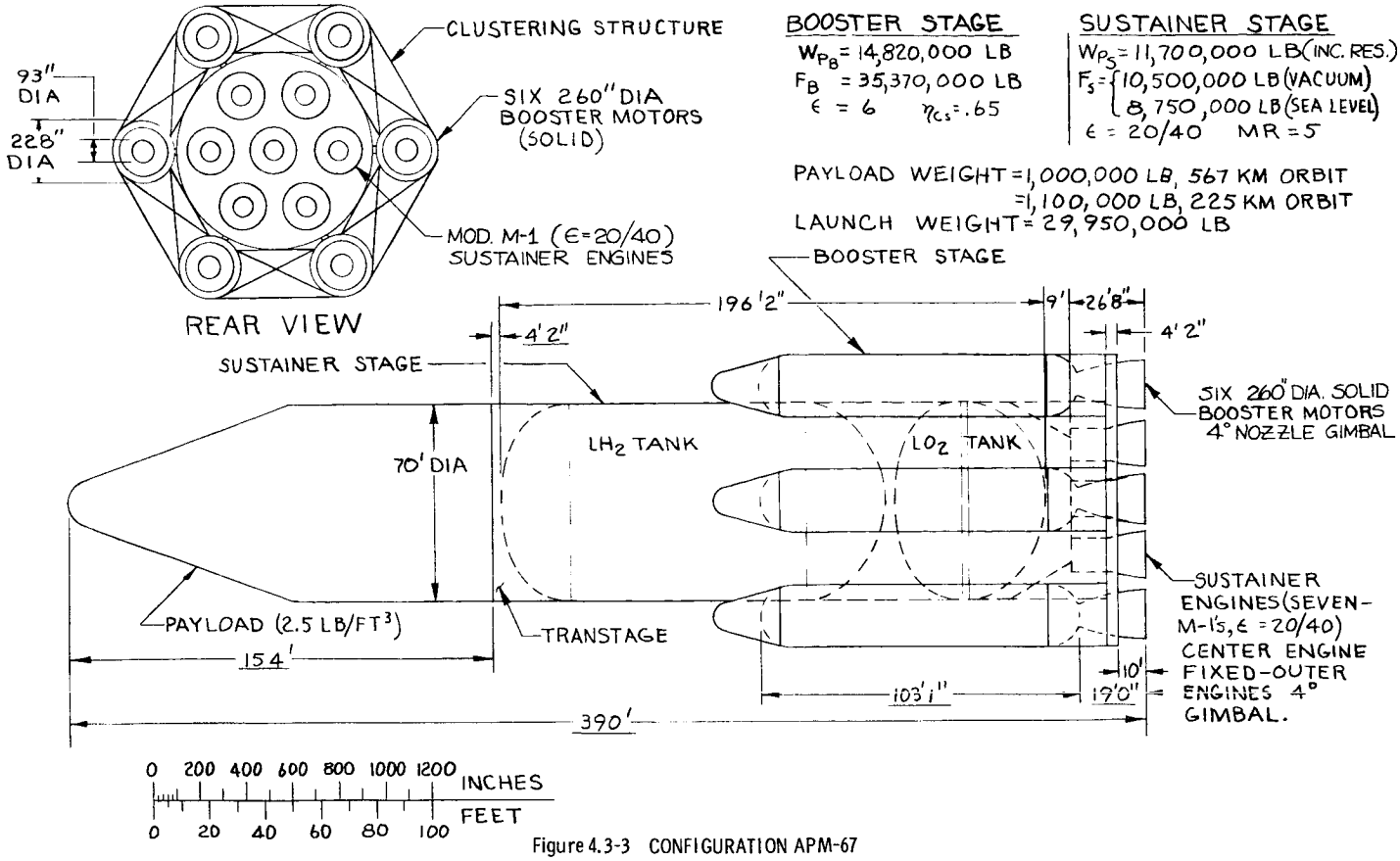


Figure 4.3-3 CONFIGURATION APM-67

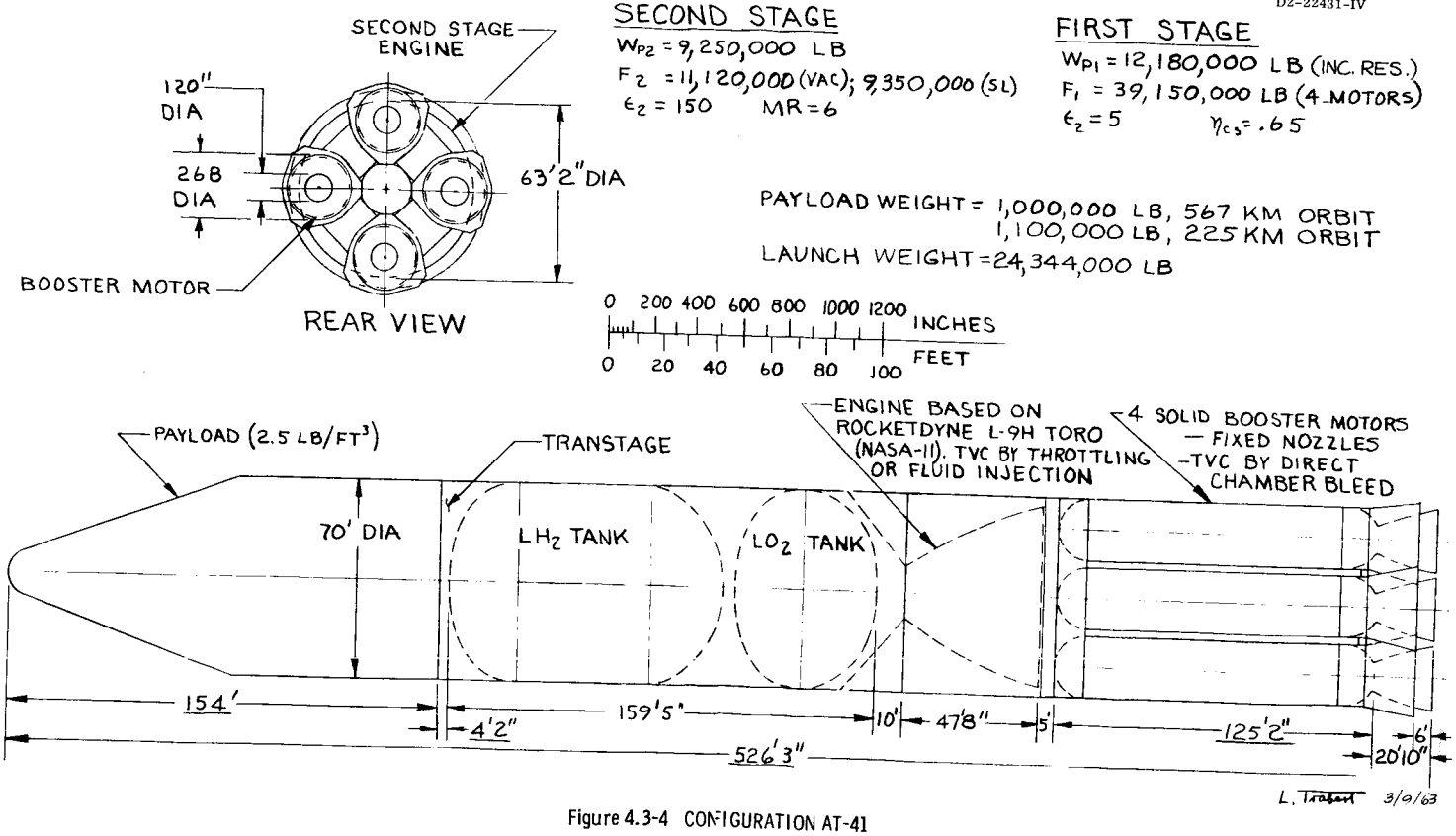


Figure 4.3-4 CONFIGURATION AT-41

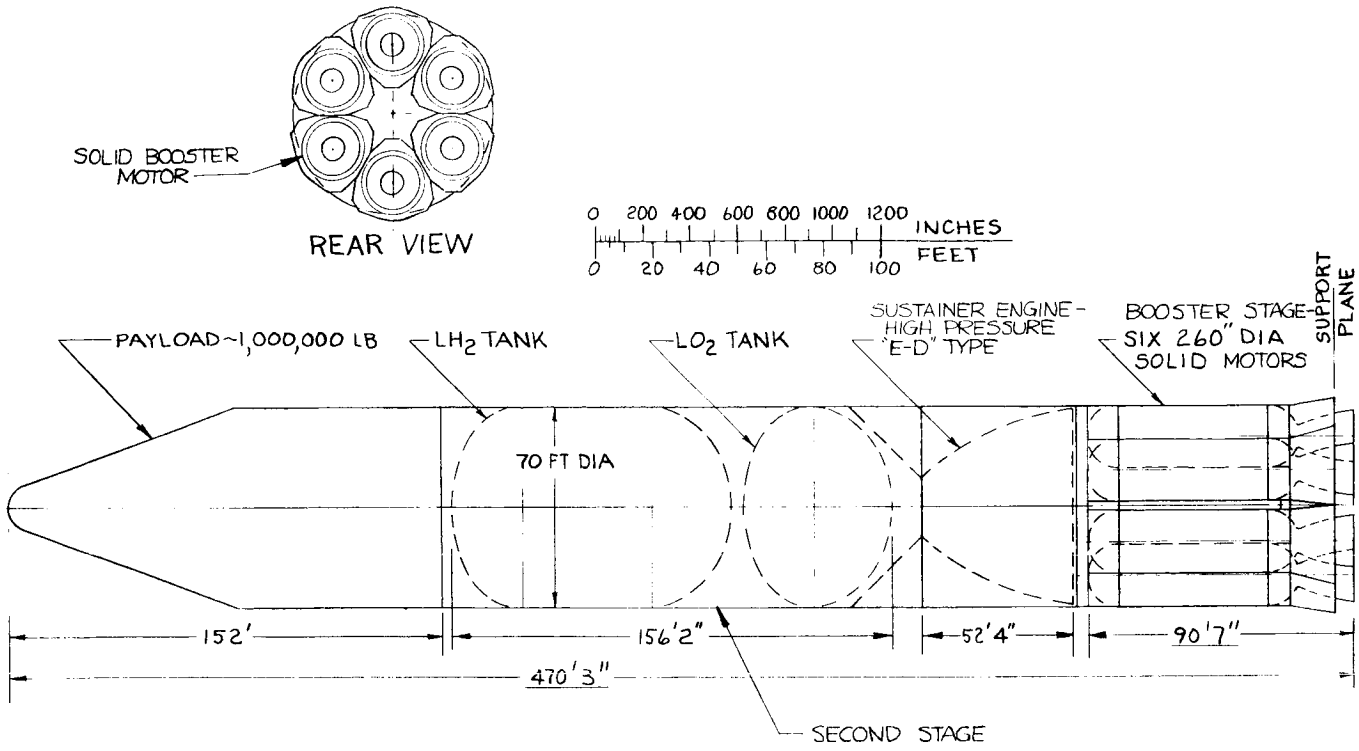


Figure 4.3-5 CONFIGURATION AT-61

4.3.5.3 Configuration APM-41

Configuration APM-41, shown in Figure 4.3-6, is a parallel-staged expendable launch vehicle using four 260-inch-diameter solid-propellant booster motors and a single E-D type sustainer engine. All booster units and the sustainer engine are ignited at launch; the boosters are jettisoned at burnout.

The booster motors have fixed nozzles. TVC is obtained by secondary injection of combustion gases through direct chamber bleed.

The sustainer engine was selected in the same manner as the second-stage engine for AT-41 and was scaled up to provide 9.5 million pounds of thrust. The nozzle has an expansion ratio of 150 and is capable of up to 95-percent altitude compensation for efficient operation from launch to orbit injection. TVC is obtained by throttling, secondary fluid injection, or a combination of both.

4.3.6 Performance Evaluation

Of the configurations examined during the study, three were selected for performance evaluation: APM-67, AT-41, and APM-41. Configuration APM-67 represents a small extension of current technology and was evaluated for comparative improvement in performance over the current-technology vehicle. Nominal performance gains were made in this concept by the use of a variable or stepped second-stage expansion ratio and, of course, further gains are obtainable by increasing M-1 engine thrust.

Configuration AT-41 and APM-41 indicated that significant gains in relative performance can be made through the use of the high-chamber-pressure, high-expansion-ratio expansion-deflection type engine. APM-41 shows the maximum payload-to-launch-weight ratio.

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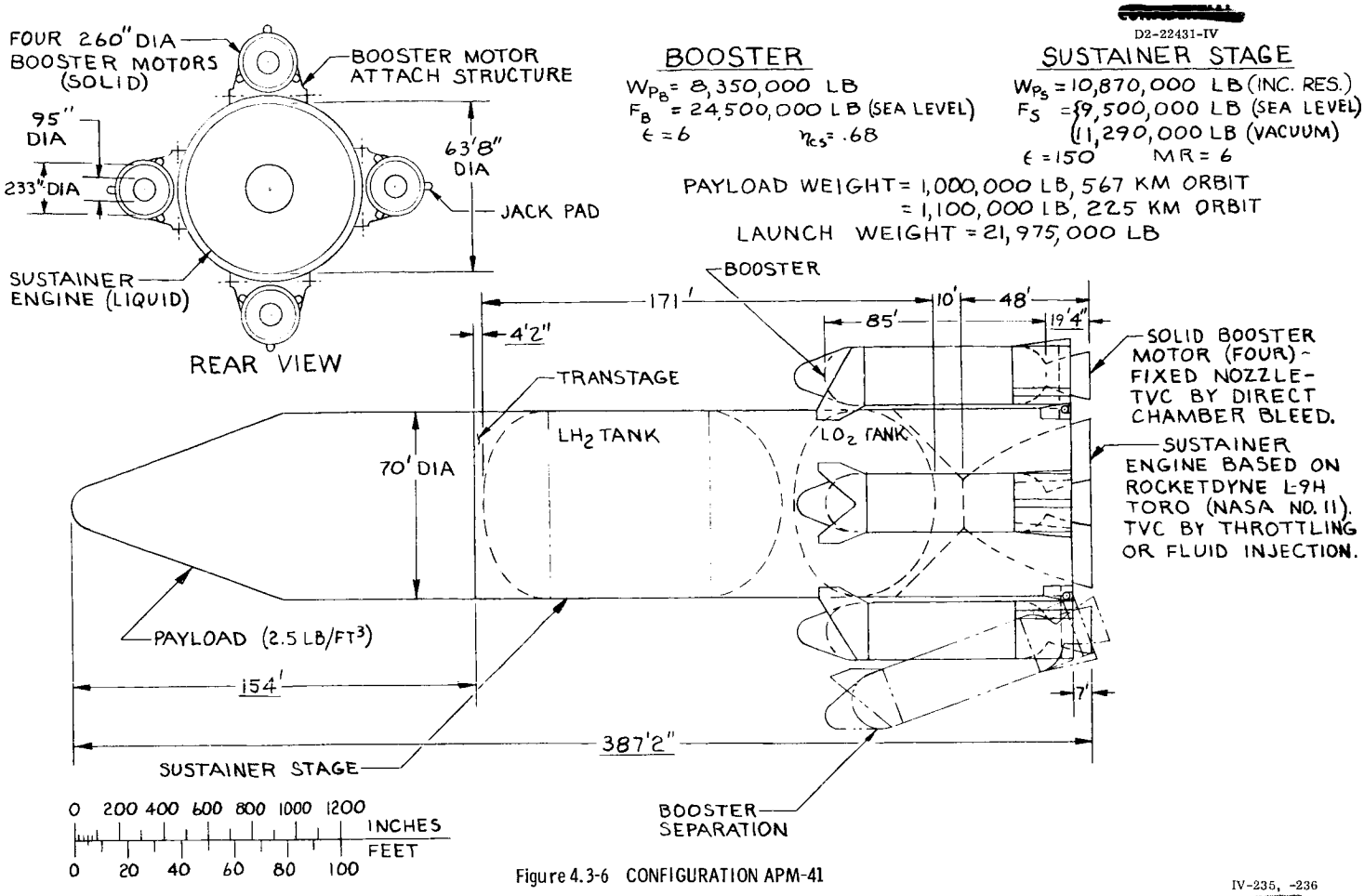



Figure 4.3-6 CONFIGURATION APM-41

## 4.4 SIZING AND STAGING

### 4.4.1 Mission

The three advanced-technology configurations were sized to place 1.1 million pounds into a 225-kilometer orbit. A typical transtage design using storable propellants will give these vehicles a payload capability of approximately 1-million pounds into a 567-kilometer orbit.

### 4.4.2 Tandem Configuration

The tandem configuration was parametrically sized to determine second-stage thrust-to-weight ratio giving minimum launch weight. For this sizing, a single high-pressure $LO_2/LH_2$ engine of undefined thrust level was assumed in the second stage. The vacuum specific impulse is 454 seconds. Sea-level specific impulse of the four first-stage solid motors is 233 seconds.

Minimum launch weight for this configuration is obtained with second-stage thrust-to-weight ratio equal to 1.0, as indicated in Figure 4.4-1. Tandem configuration AT-41 was designed with this thrust-to-weight ratio and is indicated by a circle on Figure 4.4-1. Staging velocity is 3050 feet per second.

### 4.4.3 Parallel-Modified Configurations

Two parallel-modified configurations were sized. A vehicle using four solid motors and one high-pressure liquid sustainer engine was sized for a range of sustainer thrust-to-weight ratios. This configuration uses the same motors and engine as the tandem configuration. Figure 4.4-1 indicates that launch weight decreases as second-stage thrust-to-weight ratio increases. However, the decrease in launch weight for a thrust-to-weight ratio greater than 1.0 is small, and this value was chosen as the design point for configuration APM-41. This configuration is indicated by a circle on Figure 4.4-1. APM-41 is staged at a velocity of 3300 feet per second. The APM-41 parallel-modified configuration has a launch weight approximately 12 percent less than the AT-41 tandem configuration.

The other parallel-modified vehicle has six solid motors and a sustainer with seven modified M-1 engines. Each M-1 engine has a sea-level thrust of 1.25 million pounds, sea-level specific impulse of 347 seconds for the $\epsilon = 20$ phase, vacuum thrust of 1.5 million pounds, and vacuum specific impulse of 428 seconds for the $\epsilon = 40$ phase. Launch weight is shown in Figure 4.4-2 for a range of staging velocities. Configuration APM-67B was designed at the staging ratio for minimum launch weight. This configuration is indicated by a circle in Figure 4.4-2. Its staging velocity is 4630 feet per second.

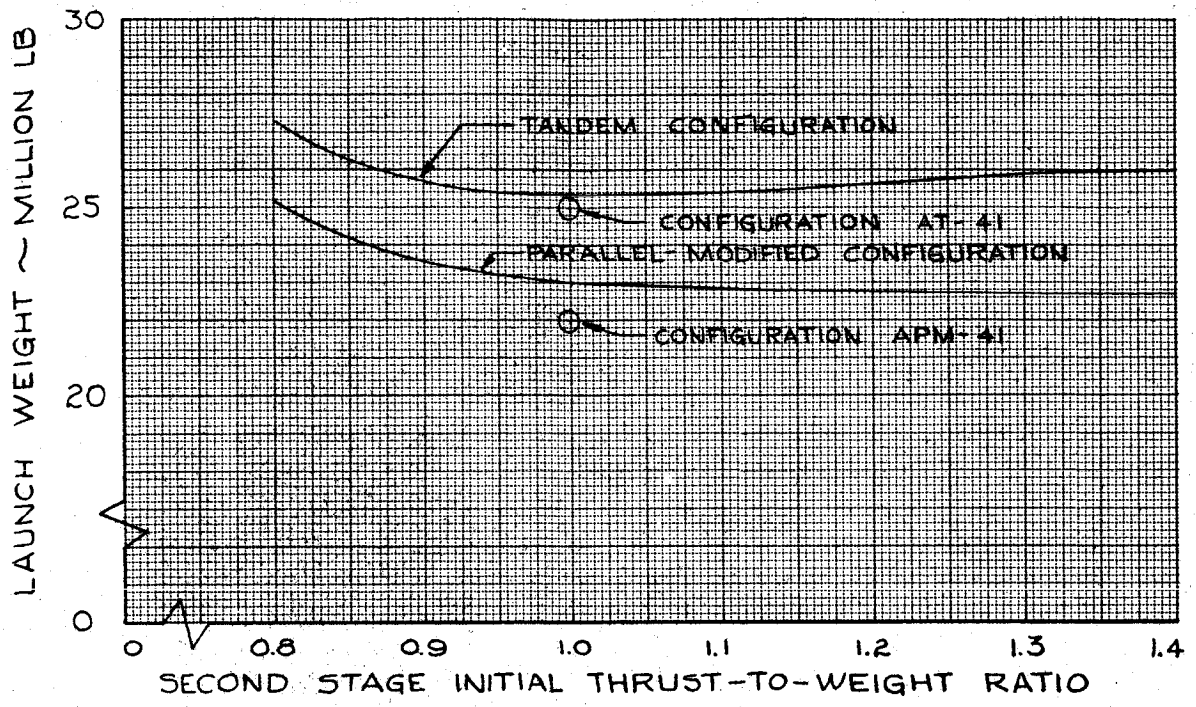



**Figure 4.4-1 VEHICLE SIZING**
**Advanced Configurations**

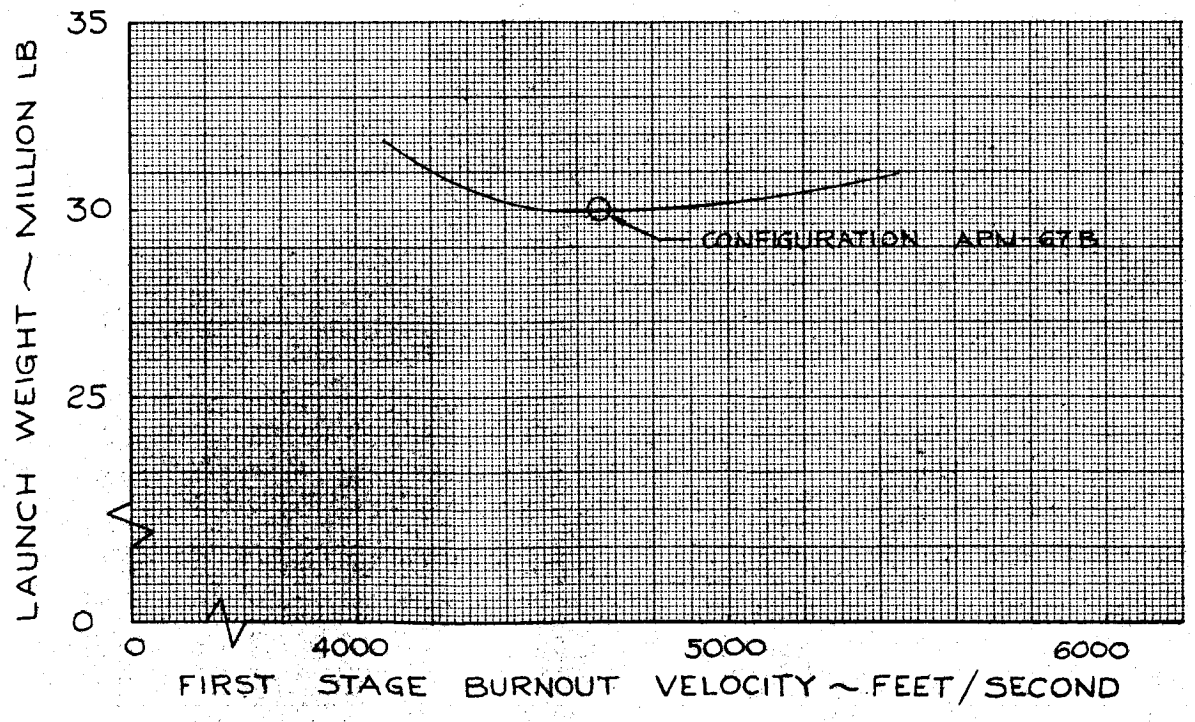



**Figure 4.4-2 VEHICLE SIZING**
**Advanced Configurations**

### 4.4.4 Vehicle Comparisons

Each of the advanced configurations has a launch weight considerably less than the baseline configuration (T65D). The APM-67B weighs about 21 percent less, the AT-41 about 34 percent less, and the APM-41 about 42 percent less.

## 4.5 STRUCTURAL CONSIDERATIONS

### 4.5.1 AT-41 Configuration

The fixed-nozzle design of this configuration would permit a lighter skirt design because the skirt reaction points could be moved closer to the centerline of the motor shell. This would be an advantage over the present-technology vehicle as well as the APM-67B configuration.

The AT-41 configuration would be more critical for launch-pad motor-case buckling than the current-technology vehicle because of higher loading per motor case. This would require additional case thickness.

The structural aspects of separation for this vehicle would be simpler than those of the other advanced-technology concepts.

Relative to the other advanced concepts, this vehicle would have greater flight loads because of its increased length.

The clustering arrangement is a problem because of the large spacing between motors. This effect would significantly reduce the 1.6-cps first-mode-frequency prediction for a rigid-cluster-structure vehicle. The relative weight of the cluster structure.

### 4.5.2 APM-41 Configuration

This configuration has fixed nozzles that give it the same advantages in skirt design as the AT-41 configuration.

The lighter weight of this concept and the fact that second-stage weight does not pass through the motor cases will eliminate the motor-case buckling problem.

The low thrust-to-weight ratio at burnout will reduce the fluid-head effects, and the proof-test penalty will be less than for the other concepts.

The shorter length of this vehicle will reduce flight bending loads.

The forward attachment of the motor cases to the second stage can be accomplished in a dry-bay area, thereby avoiding concentrated loads in the propellant tanks.

The separation scheme for this concept is considered to be a structural problem area. At a separation dynamic pressure of 400 psf with the vehicle oriented such that the lift forces arising from an angle of attack act perpendicular to the rotational plane of separation, large reaction loads will develop in the hinge structure. This effect, coupled with the dynamic aspects of the situation, warrant much additional investigation.

The first-mode frequency for this vehicle is estimated to be 2.9 cps.

### 4.5.3 APM-67B Configuration

The reduced length of this vehicle will result in reduced flight bending loads.

Motor-case buckling will not be critical for this vehicle because the second-stage weight does not pass through the motor cases.

The gimbaled nozzles of this configuration make it less desirable than the other advanced-technology concepts because of skirt design considerations.

The forward attachment of the motor cases must be in the hydrogen tank; this produces localized loads and thermal stress problems.

The parallel-staging concept using rails to slide the first stage rearward is subject to binding loads and introduces concentrated loads to the propellant tanks.

The first-mode frequency for this vehicle is estimated to be 2.3 cps.

## 4.6 WEIGHTS

### 4.6.1 Introduction

Research objectives are to establish a broad NOVA plan. Three systems were investigated as part of this study. They have been designated AT-41, APM-41, and APM-67B, and are discussed in Section 4.6.3.

Preliminary first-stage data were extrapolated from a previous study. Second-stage preliminary mass-fraction data were based on information generated as part of this study (see Section 4.6.2).

### 4.6.2 Preliminary Second-Stage Mass-Fraction Data

The preliminary second-stage mass-fraction data (Figure 4.6-1) were based on the initial estimated performance requirements summarized in Figure 4.6-2. The initial configuration was assumed to be an $LO_2/LH_2$ vehicle with an expansion-deflection (E-D) engine. The tankage arrangement was similar to that shown in Figure 4.6-3. Later work was based on the second-stage tankage configuration shown in Figure 4.6-4. The change in configuration did not significantly

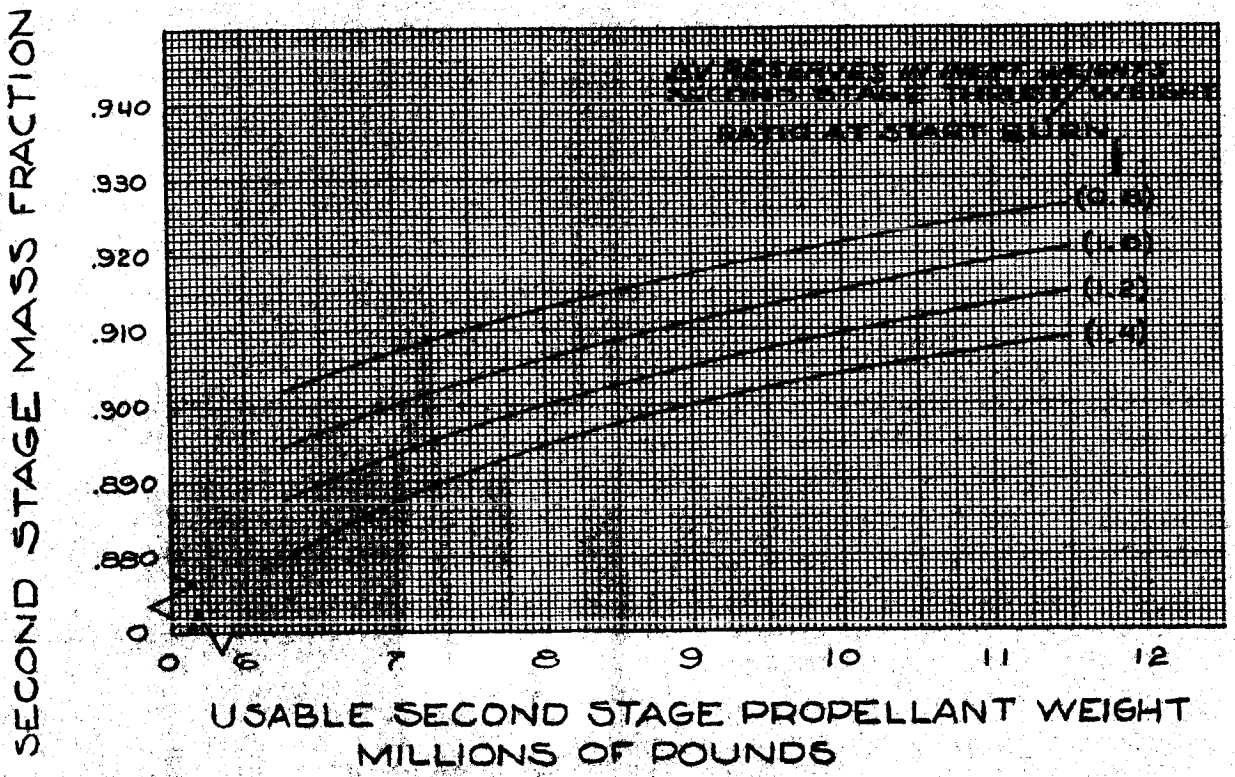



**Figure 4.6-1 PRELIMINARY SECOND STAGE MASS FRACTION DATA**

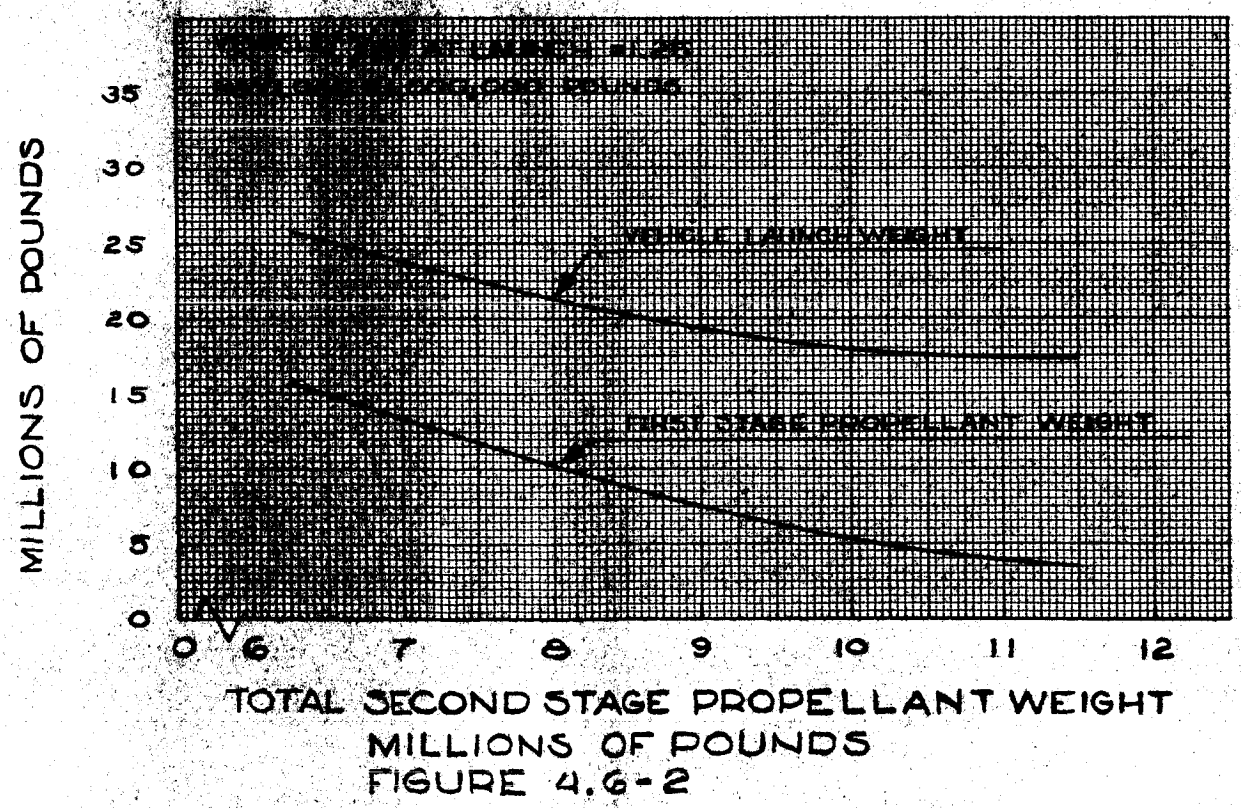



**Figure 4.6-2 INITIAL WEIGHT ASSUMPTIONS**

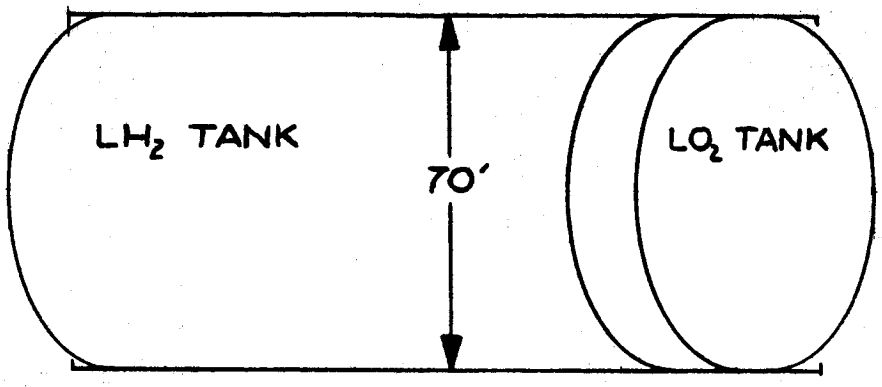



Figure 4.6-3 PRELIMINARY SECOND STAGE CONFIGURATION

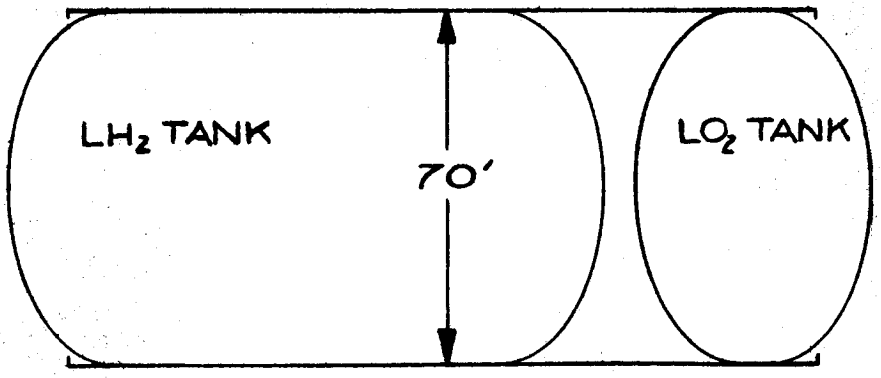



Figure 4.6-4 FINAL SECOND STAGE CONFIGURATION

affect the validity of the data for preliminary estimates of second-stage mass fractions. Criteria and assumptions for these data are listed in Table 4.6-8.

### 4.6.3 Vehicle Summation

The mission of the three vehicles considered is to inject 1.1 million pounds of payload and an orbital transfer stage into a 225-kilometer orbit. These vehicles are shown in Figure 4.6-5.

Following are brief discussions of AT-41, APM-41, and APM-67B. Mass-fraction definitions, separation procedures, stage propellant weights, and stage thrust levels are covered. (For more detailed information, see Tables 4.6-1 through 4.6-9, and Figures 4.6-1 through 4.6-8.) Table 4.6-1 is a brief outline of the weight notation used for vehicle components. It is based on the NASA weight code, but is modified in places for the parallel-modified vehicles.

#### 4.6.3.1 AT-41 Configuration

AT-41 is a tandem-staged vehicle using a solid-propellant first stage with an $LO_2/LH_2$ second stage. The second stage is ignited coincident to separation. Separation is similar to that used in other tandem-staged configurations. The interstage separating the first and second stages cannot be separated with the first stage because of the geometry of the E-D engine. Instead, it is jettisoned separately at second-stage ignition in a dual-plane procedure. First-stage propellant weight consists of 12.18 million pounds of solid propellant in four 260-inch-diameter motor cases. First-stage thrust is 39.15 million pounds at launch. Total second-stage propellant weight available is 9.25 million pounds. Second-stage thrust at burnout is 11.122 million pounds. A single E-D engine is used. $\Delta V$ reserve propellant is 122,000 pounds.

First-stage mass fraction is defined as the ratio of total solid-propellant weight used and the sum of this propellant weight plus the total inert weight jettisoned at staging. Second-stage mass fraction is defined as the ratio of stage-propellant weight used from ignition to burnout and the sum of this propellant weight plus stage inert weight. Second-stage inert weight includes $\Delta V$ reserve weight.

Weight statements are provided in Tables 4.6-2 and 4.6-3. Weight, center of gravity, and moment of inertia data are graphically presented in Figure 4.6-6. A sketch at AT-41 is shown in Figure 4.6-5.

#### 4.6.3.2 APM-41 Configuration

APM-41 is a modified parallel-staged vehicle. Both stages are ignited at launch with the booster stage jettisoned after it has burned out. Sustainer operation is continuous from launch. Separation is achieved by allowing the burned-out

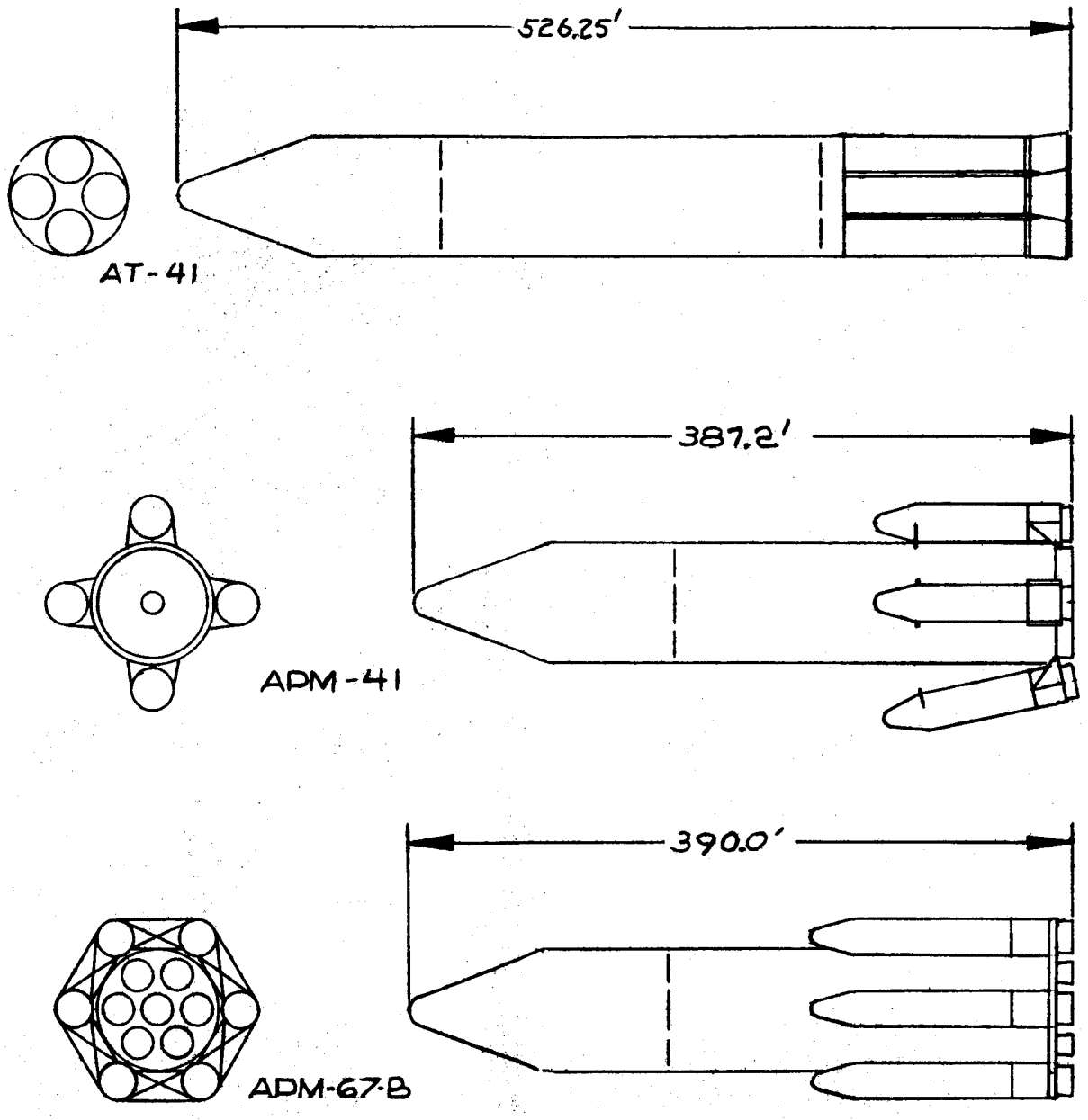



Figure 4.6-5 ADVANCED-TECHNOLOGY CONFIGURATIONS

WEIGHT CODING — BASED ON NASA WEIGHT CODE
FOR LIQUID AND SOLID STAGES

| | |
|---|---|
| $W_3$ | Structure |
| $W_4$ | Propulsion System and Accessories |
| $W_5$ | Recovery and Re-entry Equipment |
| $W_6$ | Equipment and Instrumentation |
| $W_7$ | Residual and Reserve Propellants and Service Items |
| $W_8$ | Standard Propellant and Service Item Consumption |
| $W_9$ | Other Weight Items |
| $W_{ag}$ | Stage at Ground Ignition |
| $W_{ai}$ | Stage at Ignition |
| $W_{ac}$ | Stage at Cutoff |
| $W_{as}$ | Stage at Separation |
| $W_{aL}$ | Stage at Liftoff |
| $W_{af}$ | Stage Mass Fraction |

| | | |
|---|---|---|
| Subscripts - | Booster Stage | M |
| | Sustainer Stage | N |
| | Liquid | O |
| | Solid | P |

$W_{aK}$ Vehicle Launch Weight

Table 4.6-1

VEHICLE WEIGHT STATEMENT

AT-41

| | | Pounds |
|---|---|---|
| Payload plus Orbital Transfer Stage (225-kilometer orbit) | | ( 1,100,000) |
| Ws 2c Second-Stage Weight at Cutoff | | ( 887,030) |
| Ws 2d | Dry Weight | 585,695 |
| W7* | Trapped Propellants and Gas Residuals | 134,010 |
| 7.2.6 | $\Delta$V Reserves | 122,000 |
| 7.11 | P. U. Residual | 45,325 |
| | Vehicle Weight at Second-Stage Cutoff | ( 1,987,030) |
| W8 Second-Stage Propellant | | ( 9,128,000) |
| | Vehicle Weight at Second-Stage Ignition | (11,115,030) |
| 3.6.1.2 Interstage Weight | | ( 110,105) |
| | **Vehicle Weight after First-Stage Separation | (11,225,135) |
| Ws 1c First-Stage Weight at Burnout | | ( 1,648,620) |
| Ws 1d | Dry Weight | 1,470,090 |
| W7 | Residual Propellant and Service Items | 178,530 |
| | Vehicle Weight at First-Stage Burnout | (12,763,650) |
| W8 First-Stage Propellant Weight | | (12,180,000) |
| | Vehicle Weight at Liftoff | (24,943,650) |

*W7 less 7.11 and 7.2,6

**Interstage is jettisoned from second stage at second-stage ignition.

Table 4.6-2

## WEIGHT STATEMENT — AT-41 CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

| | | | | Pounds |
|---|---|---|---|---|
| Payload and Orbital Transfer Stage | | | | ( 1,100,000) |
| | | Second Stage | | |
| W3 | Structure | | | ( 439,560) |
| | 3.1 | $LH_2$ Container | | ( 121,460) |
| | | 3.1.1,2 | Skin, Including Stiffening | 52,800 |
| | | 3.1.4 | Forward Bulkhead | 12,025 |
| | | 3.1.5 | Aft Bulkhead | 15,600 |
| | | 3.1.10 | Container, Wall Insulation, Outer | 11,595 |
| | | 3.1.12 | Forward Bulkhead Insulation, Outer | 7,000 |
| | | 3.1.14 | Aft Bulkhead Insulation, Outer | 7,630 |
| | | 3.1.15 | Antislosh Devices | 5,850 |
| | | 3.1.26 | Miscellaneous | 8,960 |
| | 3.2 | $LO_2$ Container | | ( 58,330) |
| | | 3.2.4 | Forward Bulkhead | 15,145 |
| | | 3.2.5 | Aft Bulkhead | 37,735 |
| | | 3.2.15 | Antislosh Devices | 2,150 |
| | | 3.2.26 | Miscellaneous | 3,300 |
| | 3.6 | Structure Forward of Tanks | | 24,600 |
| | 3.7 | Structure Between Tanks | | 84,960 |
| | 3.8 | Structure Aft of Tanks | | 87,710 |
| | 3.9 | Thrust Structure | | 55,000 |
| | 3.14 | Base Heat Protection | | 7,500 |
| W4 | Propulsion System and Accessories | | | ( 131,460) |
| | 4.1 | Engines and Accessories | | 88,510 |
| | 4.7 | Fuel System | | 23,120 |
| | | 4.7.3,4,7 | Fill and Drain, Distribution, and Vent System | 14,015 |
| | | 4.7.8 | Tank Pressurization System | 3,325 |
| | | 4.7.10 | Antivortex Devices | 500 |
| | | 4.7.26 | Miscellaneous | 5,280 |

Table 4.6-3

WEIGHT STATEMENT — AT-41 CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

| | | | Pounds |
|---|---|---|---|
| | 4.8 | Oxidizer System | 8,830 |
| | 4.8.3,4,7 | Fill and Drain, Distribution, and Vent System | 5,160 |
| | 4.8.8 | Tank Pressurization System | 1,225 |
| | 4.8.10 | Antivortex Devices | 500 |
| | 4.8.26 | Miscellaneous | 1,945 |
| | 4.10 | Control System Hardware | 11,000 |
| | 4.10.1 | Thrust-Vector-Control Hardware | 11,000 |
| W6 | Equipment and Instrumentation | | ( 24,245) |
| | 6.2-12 | Electrical, Telemetry, etc. | 4,800 |
| | 6.17 | Separation System | 14,735 |
| | 6.17.1,2 | Installed Retro Hardware | 6,735 |
| | 6.17.5 | Explosive Separation Devices | 8,000 |
| | 6.18 | Ullage System | 4,710 |
| Ws 2d | Dry Stage | | ( 595,265) |
| W7 | Residual and Reserve Propellants | | ( 291,765) |
| | 7.1 | $LH_2$ Pressurants | 11,585 |
| | 7.2,6 | $\Delta V$ Reserve Propellants | 122,000 |
| | 7.3,7 | Thrust Decay Residuals | 20,180 |
| | 7.4,8 | Propellant Trapped in Engines and Lines | 33,620 |
| | 7.5 | $LO_2$ Pressurants | 41,535 |
| | 7.9 | Retrorocket Propellants | 8,980 |
| | 7.11 | Maximum Propellant Utilization Residual ($LO_2$) | 45,325 |
| | 7.26 | Miscellaneous | 8,540 |
| Ws 2c | Stage Weight at Cutoff | | ( 887,030) |
| W8 | Usable Propellant | | ( 9,128,000) |
| | 8.1,2 | $LO_2/LH_2$ Propellant Consumed | 9,128,000 |
| Ws 2i | Stage Weight at Ignition | | (10,015,030) |
| Ws 2f | Stage Mass Fraction* | (0.911) | |

$$*Ws\ 2f = \frac{8.1,2}{Ws\ 2c + 8.1,2}$$

Table 4.6-3 (Cont.)

## WEIGHT STATEMENT — AT-41 CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

### First Stage

| | | | Pounds |
|---|---|---|---|
| W3 | Structure | | ( 1,176,125) |
| | 3.4 | Solid Propellant Container | 851,665 |
| | | 3.4.1,4,6,15,18 Case | 728,120 |
| | | 3.4.8 Container Wall Liner | 82,800 |
| | | 3.4.8.1 Bonding Material | 51,200 |
| | | 3.4.8.2 Tailoff Insulation | 31,600 |
| | | 3.4.9 Forward Bulkhead Insulation | 2,140 |
| | | 3.4.16 Aft Bulkhead Insulation | 15,205 |
| | | 3.4.26 Miscellaneous | 23,400 |
| | 3.6 | Structure Forward of Propellant Containers | 282,775 |
| | | 3.6.1 Forward Interstage | 143,795 |
| | | 3.6.1.1 Structure Separating with Stage | 33,690 |
| | | 3.6.1.2 Structure Undergoing Dual Plane Separation* | 110,105 |
| | | 3.6.11 Cluster Structure | 138,980 |
| | 3.8 | Structure Aft of Propellant Containers | 23,955 |
| | | 3.8.11 Aft Support Structure | 17,875 |
| | | 3.8.12 Aft Aerodynamic Fairing | 6,080 |
| | 3.14 | Base Heat Protection | 7,500 |
| | 3.26 | Miscellaneous | 10,230 |
| W4 | Propulsion System | | ( 260,735) |
| | 4.2 | Nozzles | 246,235 |
| | 4.10 | Stage Control System Hardware | 14,500 |
| | | 4.10.1 Thrust-Vector-Control Hardware | 14,500 |
| W6 | Equipment and Instrumentation | | ( 33,230) |
| | 6.2-12 | Electrical, Telemetry, etc. | 4,000 |
| | 6.17 | Separation Systems | 29,230 |
| Ws 1d | Dry Stage | | 1,470,090 |

*Interstage is jettisoned from second stage at second-stage ignition.

Table 4.6-3 (Cont.)

WEIGHT STATEMENT — AT-41 CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

| | | | Pounds |
|---|---|---|---|
| W7 | Residual Propellant and Service Items | | ( 178,530) |
| | 7.9 Service Items, Trapped and Reserves | | 114,940 |
| | 7.9.13 Separation System Propellants | | 114,940 |
| | 7.11 Solid Propellant Slivers (Inert) | | 63,590 |
| Ws 1c | Stage Weight at Cutoff | | ( 1,648,620) |
| W8 | Usable Propellant | | (12,180,000) |
| | 8.5 Solid Propellant Consumed | | 12,180,000 |
| Ws 1i | Stage Weight at Ignition | | (13,828,620) |
| Ws 1f | Stage Mass Fraction* | (0.881) | |
| Wv 1L | Vehicle Launch Weight | | (24,943,650) |

*$Ws\ 1f = \frac{8.5}{Ws\ 1c + 8.5}$

Table 4.6-3 (Cont.)

# VEHICLE WEIGHT STATEMENT

## APM-41

| | | Pounds |
|---|---|---|
| Payload plus Orbital Transfer Stage (225-kilometer orbit) | | ( 1,100,000) |
| Ws 2c Sustainer-Stage Weight at Cutoff | | ( 920,800) |
| Ws 2d | Dry Weight | 610,195 |
| W7* | Trapped Propellants and Gas Residuals | 132,345 |
| 7.2,6 | ΔV Reserves | 125,000 |
| 7.11 | P.U. Residuals | 53,260 |
| | Vehicle Weight at Sustainer Cutoff | ( 2,020,800) |
| W8 Sustainer Propellant | | ( 8,875,000) |
| | Vehicle Weight After Booster Dropoff | 10,895,800 |
| Ws 1c Booster Weight at Burnout | | ( 858,595) |
| Ws 1d | Dry Weight | 817,355 |
| W7 | Residual Propellant and Service Items | 41,240 |
| | Vehicle Weight at Booster Burnout | (11,754,395) |
| W8 Booster Propellant Weight | | (10,220,000) |
| 8.1,2 | Liquid Propellant | 1,870,000 |
| 8.5 | Solid Propellant | 8,350,000 |
| | Vehicle Weight at Liftoff | (21,974,395) |

*W7 less 7.2, 6 and 7.11

Table 4.6-4

WEIGHT STATEMENT — APM-41 CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

| | | | | Pounds |
|---|---|---|---|---|
| Payload and Orbital Transfer Stage | | | | (1,100,000) |
| | | Sustainer Stage | | |
| W3 | Structure | | | ( 437,505) |
| | 3.1 | $LH_2$ Container | | ( 126,310) |
| | | 3.1.1,2 | Skin Including Stiffening | 57,825 |
| | | 3.1.4 | Forward Bulkhead | 12,025 |
| | | 3.1.5 | Aft Bulkhead | 14,700 |
| | | 3.1.10 | Container, Wall Insulation, Outer | 11,070 |
| | | 3.1.12 | Forward Bulkhead Insulation, Outer | 7,000 |
| | | 3.1.14 | Aft Bulkhead Insulation, Outer | 7,630 |
| | | 3.1.15 | Antislosh Devices | 6,160 |
| | | 3.1.26 | Miscellaneous | 9,900 |
| | 3.2 | $LO_2$ Container | | ( 48,615) |
| | | 3.2.4 | Forward Bulkhead | 15,145 |
| | | 3.2.5 | Aft Bulkhead | 27,560 |
| | | 3.2.15 | Antislosh Devices | 2,270 |
| | | 3.2.26 | Miscellaneous | 3,640 |
| | 3.6 | Structure Forward of Tanks | | 25,070 |
| | 3.7 | Structure Between Tanks | | 86,430 |
| | 3.8 | Structure Aft of Tanks | | 87,580 |
| | 3.9 | Thrust Structure | | 56,000 |
| | 3.14 | Base Heat Protection | | 7,500 |
| W4 | Propulsion System and Accessories | | | ( 134,580 |
| | 4.1 | Engines and Accessories | | 93,400 |
| | 4.7 | Fuel Systems | | 22,750 |
| | | 4.7.3,4,7 | Fill and Drain, Distribution, and Vent System | 13,600 |
| | | 4.7.8 | Tank Pressurization System | 3,400 |
| | | 4.7.10 | Antivortex Devices | 500 |
| | | 4.7.26 | Miscellaneous | 5,250 |

Table 4.6-5

WEIGHT STATEMENT — APM-41 CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

| | | | Pounds |
|---|---|---|---|
| | 4.8 | Oxidizer System | 8,680 |
| | 4.8.3,4,7 | Fill and Drain, Distribution, and Vent System | 5,000 |
| | 4.8.8 | Tank Pressurization System | 1,250 |
| | 4.8.10 | Antivortex Devices | 500 |
| | 4.8.26 | Miscellaneous | 1,930 |
| | 4.10 | Control System Hardware | 9,750 |
| | 4.10.1 | Thrust-Vector-Control Hardware | 9,750 |
| W6 | Equipment and Instrumentation | | ( 38,110) |
| | 6.2-12 | Electrical, Telemetry, etc. | 4,800 |
| | 6.17 | Separation System | 33,310 |
| | 6.17.1,2 | Installed Retro Hardware | 7,010 |
| | 6.17.9 | Staging Structure | 23,900 |
| | 6.17.10 | Mechanical Separation Devices | 2,400 |
| | 6.18 | Ullage System | None |
| Ws 2d | Dry Stage | | ( 610,195) |
| W7 | Residual and Reserve Propellants | | ( 310,605) |
| | 7.1 | $LH_2$ Pressurants | 13,380 |
| | 7.2,6 | $\Delta V$ Reserve Propellants | 125,000 |
| | 7.3,7 | Thrust Decay Residuals | 19,500 |
| | 7.4,8 | Propellant Trapped in Engines and Lines | 33,600 |
| | 7.5 | $LO_2$ Pressurants | 48,125 |
| | 7.9 | Retrorocket Propellants | 9,345 |
| | 7.11 | Maximum Propellant Utilization Residual ($LO_2$) | 53,260 |
| | 7.26 | Miscellaneous | 8,395 |
| Ws 2c | Stage Weight at Cutoff | | ( 920,800) |
| W8 | Usable Propellant | | (8,875,800) |
| | 8.1,2 | $LO_2/LH_2$ Propellant Consumed | 8,875,800 |
| Ws 2i | Stage Weight at Booster Dropoff | | (9,795,800) |
| Ws 2f | Stage Mass Fraction* | (0.906) | |

$$* \; Ws\ 2f = \frac{8.1,2}{Ws\ 2c + 8.1,2}$$

Table 4.6-5 (Cont.)

WEIGHT STATEMENT — APM-41 CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

Booster Stage

| | | | Pounds |
|---|---|---|---|
| W3 | Structure | | ( 647,145) |
| | 3.4 | Solid-Propellant Container | 583,345 |
| | | 3.4.1, 4, 6, 15, 18 Case | 493,710 |
| | | 3.4.8 Container Wall Liner | 50,900 |
| | | 3.4.8.1 Bonding Material | 33,000 |
| | | 3.4.8.2 Tailoff Insulation | 17,900 |
| | | 3.4.9 Forward Bulkhead Insulation | 2,140 |
| | | 3.4.16 Aft Bulkhead Insulation | 22,685 |
| | | 3.4.26 Miscellaneous | 13,910 |
| | 3.8 | Structure Aft of Propellant Containers | 39,900 |
| | | 3.8.11 Aft Support Structure | 39,900 |
| | | 3.8.12 Aft Aerodynamic Fairing | None |
| | 3.10 | Other Fairings and Associated Structure | 6,440 |
| | | 3.10.1 Nose Fairings | 6,440 |
| | 3.14 | Base Heat Protection | 13,000 |
| | 3.26 | Miscellaneous | 4,460 |
| W4 | Propulsion System | | ( 137,520) |
| | 4.2 | Nozzles | 126,120 |
| | 4.10 | Stage Control System Hardware | 11,400 |
| | | 4.10.1 Thrust-Vector-Control Hardware | 11,400 |
| W6 | Equipment and Instrumentation | | ( 32,690) |
| | 6.2-12 | Electrical, Telemetry, etc. | 2,950 |
| | 6.17 | Separation Systems | 29,740 |
| Ws 1d | Dry Stage | | ( 818,800) |
| W7 | Residual Propellant and Service Items | | ( 41,240) |
| | 7.9 | Service Items, Trapped and Reserves | |
| | | 7.9.13 Separation System Propellants | |
| | 7.11 | Solid-Propellant Slivers (Inert) | 41,240 |

Table 4.6-5 (Cont.)

## WEIGHT STATEMENT — APM-41 CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

| | | | Pounds |
|---|---|---|---|
| Ws 1c | Stage Weight at Cutoff | | ( 858,595) |
| W8 | Usable Propellant | | (10,220,000) |
| | 8.1,2 $LO_2/LH_2$ Propellant Consumed | | 1,870,000 |
| | 8.5 Solid Propellant Consumed | | 8,350,000 |
| Ws 1i | Booster Weight at Ignition | | ( 9,208,595) |
| Ws 1g | Stage Weight at Ignition | | (11,078,595) |
| Ws 1b | Booster Mass Fraction* | (0.907) | |
| Ws 1f | Stage Mass Fraction** | (0.922) | |
| Wv 1L | Vehicle Launch Weight | | (21,974,395) |

---

* $Ws\ 2b = \dfrac{8.5}{Ws\ 1c + 8.5}$

** $Ws\ 1f = \dfrac{8.1,2 + 8.5}{Ws\ 1c + 8.1,2 + 8.5}$

Table 4.6-5 (Cont.)

VEHICLE WEIGHT STATEMENT

APM-67B

| | | Pounds |
|---|---|---|
| Payload plus Orbital Transfer Stage (225-kilometer orbit) | | ( 1,100,000) |
| Ws 2c Sustainer Stage Weight at Cutoff | | ( 1,129,700) |
| Ws 2d | Dry Weight | 773,670 |
| W7* | Trapped Propellants and Gas Residuals | 151,700 |
| 7.2,6 | ΔV Reserves | 147,000 |
| 7.11 | P.U. Residuals | 57,330 |
| | Vehicle Weight at Sustainer Cutoff | ( 2,229,700) |
| W8 | Sustainer Propellant | ( 9,103,000) |
| | Vehicle Weight After Booster Dropoff | (11,332,700) |
| Ws 1c Booster Weight at Burnout | | ( 1,392,620) |
| Ws 1d Dry Weight | | 1,299,730 |
| W7 | Residual Propellant and Service Items | 92,890 |
| | Vehicle Weight at Booster Burnout | (12,725,320) |
| W8 | Booster Propellant Weight | (17,270,000) |
| 8.1,2 | Liquid Propellant | 2,450,000 |
| 8.5 | Solid Propellant | 14,270,000 |
| | Vehicle Weight at Liftoff | (29,995,320) |

*Less 7.2, 7.6, and 7.11

Table 4.6-6

WEIGHT STATEMENT — APM-67B CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

| | | | | Pounds |
|---|---|---|---|---|
| Payload and Orbital Transfer Stage | | | | ( 1,100,000) |
| | | Sustainer Stage | | |
| W3 | Structure | | | ( 576,310) |
| | 3.1 | $LH_2$ Container | | 163,885 |
| | | 3.1.1,2 | Skin, Including Stiffening | 84,110 |
| | | 3.1.4 | Forward Bulkhead | 17,490 |
| | | 3.1.5 | Aft Bulkhead | 22,680 |
| | | 3.1.10 | Container, Wall Insulation, Outer | 9,085 |
| | | 3.1.12 | Forward Bulkhead Insulation, Outer | 3,605 |
| | | 3.1.14 | Aft Bulkhead Insulation, Outer | 3,935 |
| | | 3.1.15 | Antislosh Devices | 7,360 |
| | | 3.1.26 | Miscellaneous | 15,620 |
| | 3.2 | $LO_2$ Container | | 68,175 |
| | | 3.2.1,2 | Skin, Including Stiffening | 3,190 |
| | | 3.2.4 | Forward Bulkhead | 14,730 |
| | | 3.2.5 | Aft Bulkhead | 40,790 |
| | | 3.2.15 | Antislosh Devices | 2,260 |
| | | 3.2.26 | Miscellaneous | 7,205 |
| | 3.6 | Structure Forward of Tanks | | 37,980 |
| | 3.7 | Structure Between Tanks | | 88,370 |
| | 3.8 | Structure Aft of Tanks | | 104,400 |
| | 3.9 | Thrust Structure | | 104,000 |
| | 3.14 | Base Heat Protection | | 9,500 |
| W4 | Propulsion System and Accessories | | | ( 164,415) |
| | 4.1 | Engines and Accessories | | 122,000 |
| | 4.7 | Fuel System | | 25,300 |
| | | 4.7.3,4.7 | Fill and Drain, Distribution, and Vent System | 14,535 |
| | | 4.7.8 | Tank Pressurization System | 3,520 |
| | | 4.7.10 | Antivortex Devices | 500 |
| | | 4.7.26 | Miscellaneous | 6,745 |

Table 4.6-7

WEIGHT STATEMENT — APM-67B CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

| | | | | Pounds |
|---|---|---|---|---|
| | 4.8 | Oxidizer System | | 8,115 |
| | | 4.8.3, 4, 7 | Fill and Drain, Distribution, and Vent System | 4,465 |
| | | 4.8.8 | Tank Pressurization System | 1,080 |
| | | 4.8.10 | Antivortex Devices | 500 |
| | | 4.8.26 | Miscellaneous | 2,070 |
| | 4.10 | Control System Hardware | | 9,000 |
| | | 4.10.1 | Thrust-Vector-Control Hardware | 9,000 |
| W6 | Equipment and Instrumentation | | | ( 32,945) |
| | 6.2-12 | Electrical, Telemetry, etc. | | 8,200 |
| | 6.17 | Separation Systems | | 32,945 |
| | | 6.17.1, 2 | Installed Retro Hardware | 8,645 |
| | | 6.17.5 | Explosive Separation Devices | 300 |
| | | 6.17.8 | Separation Rails | 24,000 |
| Ws 2d | Dry Stage | | | ( 773,670) |
| W7 | Residual and Reserve Propellants | | | ( 356,030) |
| | 7.1 | $LH_2$ Pressurants | | 26,270 |
| | 7.2, 6 | $\Delta V$ Reserve Propellants | | 147,000 |
| | 7.3, 7 | Thrust Decay Residuals | | 17,500 |
| | 7.4, 8 | Propellant Trapped in Engines and Lines | | 38,100 |
| | 7.5 | $LO_2$ Pressurants | | 52,715 |
| | 7.9 | Retrorocket Propellants | | 11,530 |
| | 7.11 | Maximum Propellant Utilization Residual ($LO_2$) | | 57,330 |
| | 7.26 | Miscellaneous | | 5,585 |
| Ws 2c | Stage Weight at Cutoff | | | ( 1,129,700) |
| W8 | Usable Propellant | | | ( 9,103,000) |
| | 8.1, 2 | $LO_2/LH_2$ Propellant Consumed | | 9,103,000 |
| Ws 2i | Stage Weight at Booster Dropoff | | | (10,232,700) |
| Ws 2f | Stage Mass Fraction* | | (0.890) | |

$$* \ Ws\ 2f = \frac{8.1,2}{Ws\ 2c + 8.1,2}$$

Table 4.6-7 (Cont.)

WEIGHT STATEMENT — APM-67B CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

Booster Stage

| | | | Pounds |
|---|---|---|---|
| W3 | Structure | | ( 1,067,080) |
| | 3.4 | Solid-Propellant Container | 997,370 |
| | | 3.4.1, 4, 6, 15, 18 Case | 843,815 |
| | | 3.4.8 Container Wall Liner | 92,480 |
| | | 3.4.8.1 Bonding Material | 60,000 |
| | | 3.4.8.2 Tailoff Insulation | 32,480 |
| | | 3.4.9 Forward Bulkhead Insulation | 3,210 |
| | | 3.4.16 Aft Bulkhead Insulation | 32,040 |
| | | 3.4.26 Miscellaneous | 25,825 |
| | 3.8 | Structure Aft of Propellant Containers | 42,750 |
| | | 3.8.11 Aft Support Structure | 42,750 |
| | | 3.8.12 Aft Aerodynamic Fairing | |
| | 3.10 | Other Fairings and Associated Structure | 9,660 |
| | | 3.10.1 Nose Fairings | 9,660 |
| | 3.14 | Base Heat Protection | 13,500 |
| | 3.26 | Miscellaneous | 3,800 |
| W4 | Propulsion System | | ( 212,965) |
| | 4.2 | Nozzles | 195,840 |
| | 4.10 | Stage Control System Hardware | 17,125 |
| | | 4.10.1 Thrust-Vector-Control Hardware | 17,125 |
| W6 | Equipment and Instrumentation | | ( 19,685) |
| | 6.2-12 | Electrical, Telemetry, etc. | 5,125 |
| | 6.17 | Separation Systems | 14,560 |
| Ws 1d | Dry Stage | | ( 1,299,730) |
| W7 | Residual Propellant and Service Items | | 92,890 |
| | 7.9 | Service Items, Trapped and Reserves | 18,230 |
| | | 7.9.13 Separation System Propellants | 18,230 |
| | 7.11 | Solid-Propellant Slivers (Inert) | 74,660 |
| Ws 1c | Stage Weight at Cutoff | | ( 1,392,620) |

Table 4.6-7 (Cont.)

[redacted]



WEIGHT STATEMENT — APM-67B CONFIGURATION — FINAL ITERATION

Solid NOVA Advanced-Technology Study

| | | | Pounds |
|---|---|---|---|
| W8 | Usable Propellant | | (17,270,000) |
| | 8.1,2 $LO_2/LH_2$ Propellant Consumed | | 2,450,000 |
| | 8.5 Solid Propellant Consumed | | 14,820,000 |
| Ws 1i | Booster Weight at Ignition | | (16,212,620) |
| Ws 1g | Stage Weight at Ignition | | (18,662,620) |
| Ws 1b | Booster Mass Fraction* | (0.914) | |
| Ws 1f | Stage Mass Fraction** | (0.925) | |
| Wv 1L | Vehicle Launch Weight | | (29,995,320) |

---

* $Ws\ 1b = \dfrac{8.5}{Ws\ 2c + 8.1,2}$

** $Ws\ 1f = \dfrac{8.1,2 + 8.5}{Ws\ 1c + 8.1,2 + 8.5}$

Table 4.6-7 (Cont.)

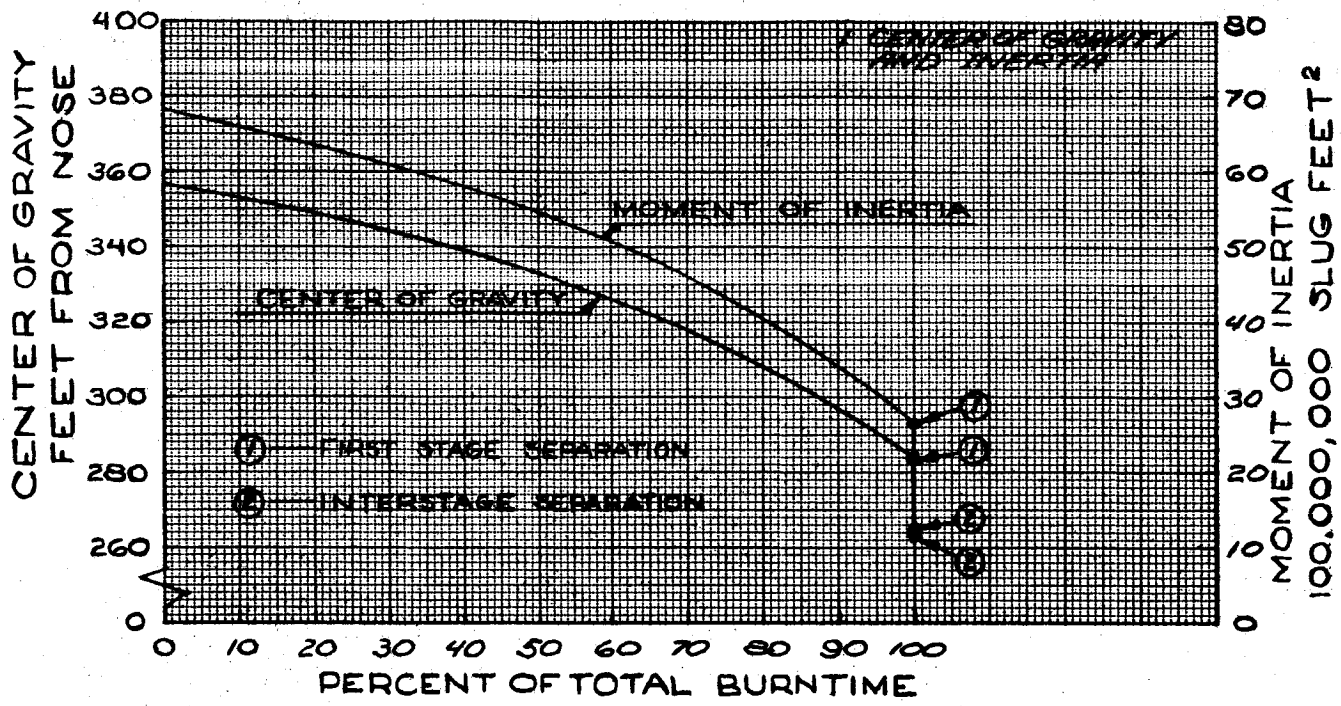


[redacted]

DESIGN CRITERIA FOR $LO_2/LH_2$ STAGES

| | AT-41 | APM-41 | APM-67B |
|---|---|---|---|
| Propulsion | | | |
| Boost Pumps | No | No | No |
| Thrust Per Engine | | | |
| Sea Level | 9.3 | 9.5 | 8.75 |
| Vacuum | 11.1 | 11.3 | 10.5 |
| Mixture Ratio O/F Nominal | 6 | 6 | 5 |
| Engine-Out Design | No | No | No |
| Engine Type | E-D | E-D | Mod M-1 |
| Number of Engines | 1 | 1 | 7 |
| Expansion Ratio | 150 | 150 | 20/40 |
| Ullage Rockets | Yes | No | No |
| Pressurization | | | |
| Fuel Tank Pressurization Concept | (He SLUG — $GH_2$ on $LH_2$) | | |
| Fuel Tank Mean Gas Temp. at BO (°R) | 160 | 160 | 160 |
| Fuel Tank Pressure at BO (psia) | 32 | 32 | 39 |
| Oxidizer Tank Pressurization Concept | (He SLUG — $GO_2$ on $LO_2$) | | |
| Oxidizer Tank Mean Gas Temp. at BO (°R) | 270 | 270 | 270 |
| Oxidizer Tank Pressurization at BO (psia) | 34 | 34 | 29 |
| Helium Slug Mean Gas Temp. at Start (°R) | 530 | 530 | 530 |
| Structure | | | |
| Ultimate Factor of Safety | 1.4 | 1.4 | 1.4 |
| Yield Factor of Safety | 1.1 | 1.1 | 1.1 |
| Tank Diameter (feet) | 70 | 70 | 70 |
| Tank Material | (Aluminum Advanced Technology) | | |
| Tank Construction | (Waffle Stiffened Skin) | | |
| Tank Ultimate Tensile Strength (Ksi) | 71.7 at R.T. | 84.0 at $LO_2T$ | 100.8 at $LH_2T$ |
| Tank Yield Tensile Strength (Ksi) | 56.0 at R.T. | 65.0 at $LO_2T$ | 71.12 at $LH_2T$ |
| Common Bulkhead | No | No | No |
| Separate Bulkheads | Yes | Yes | Yes |
| Bulkhead Ellipse Ratio | (0.7 Forward — 0.8 Aft) | | |
| Oxidizer Tank Location | Aft | Aft | Aft |
| Design Limit Ground Wind | (NASA 99% Prelaunch Ground Wind) | | |
| PAYLOAD (millions of pounds) | 1.1 | 1.1 | 1.1 |

Table 4.6-8



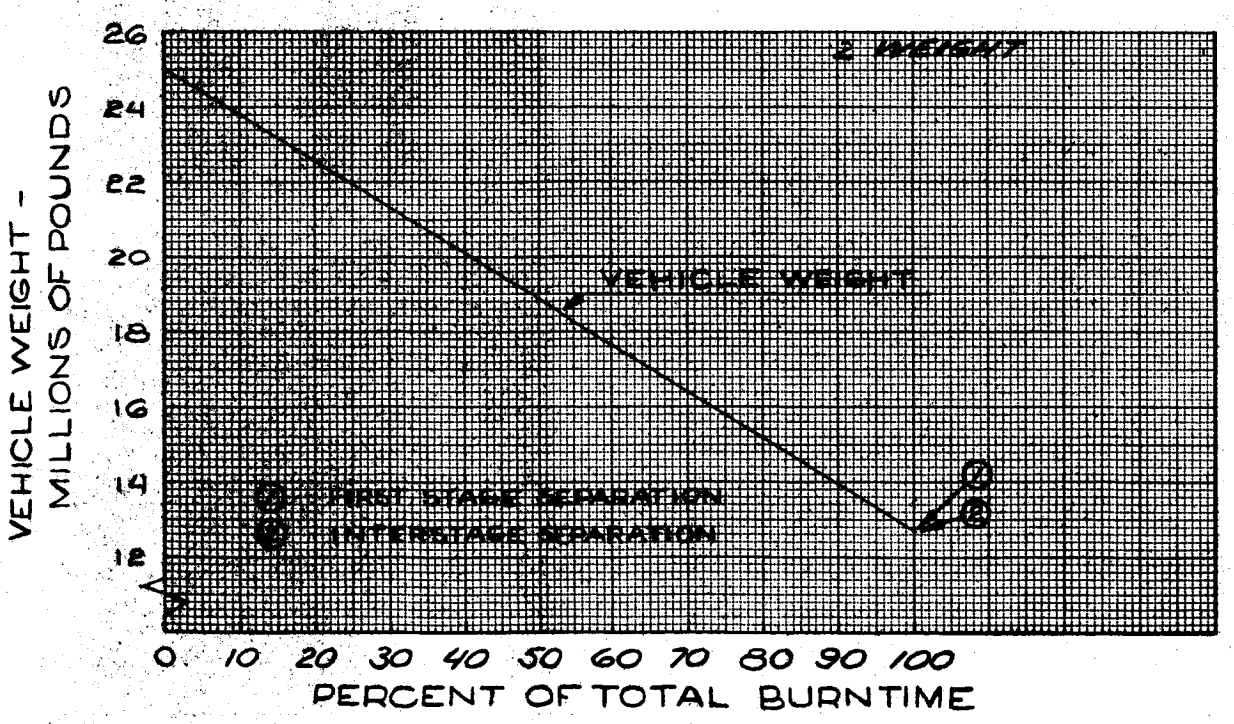
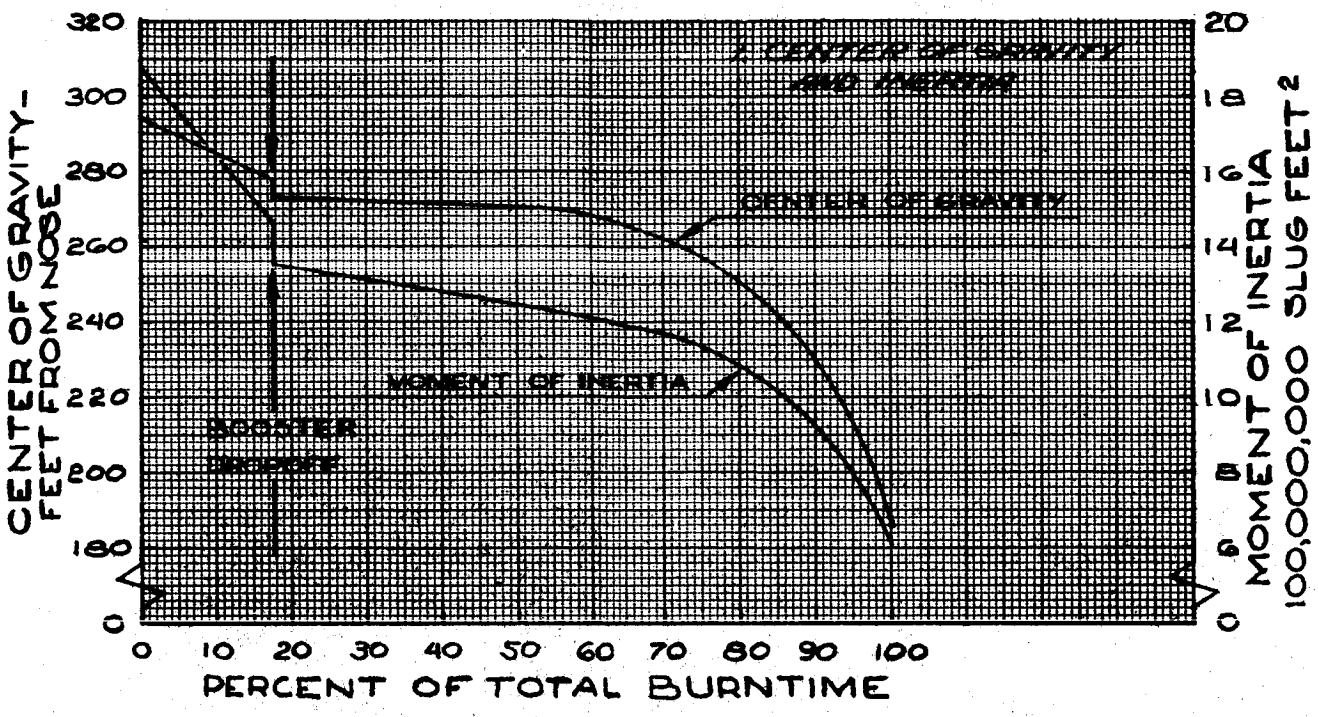




**Figure 4.6-6 CENTER OF GRAVITY, MOMENT OF INERTIA, AND WEIGHT Configuration AT-41**



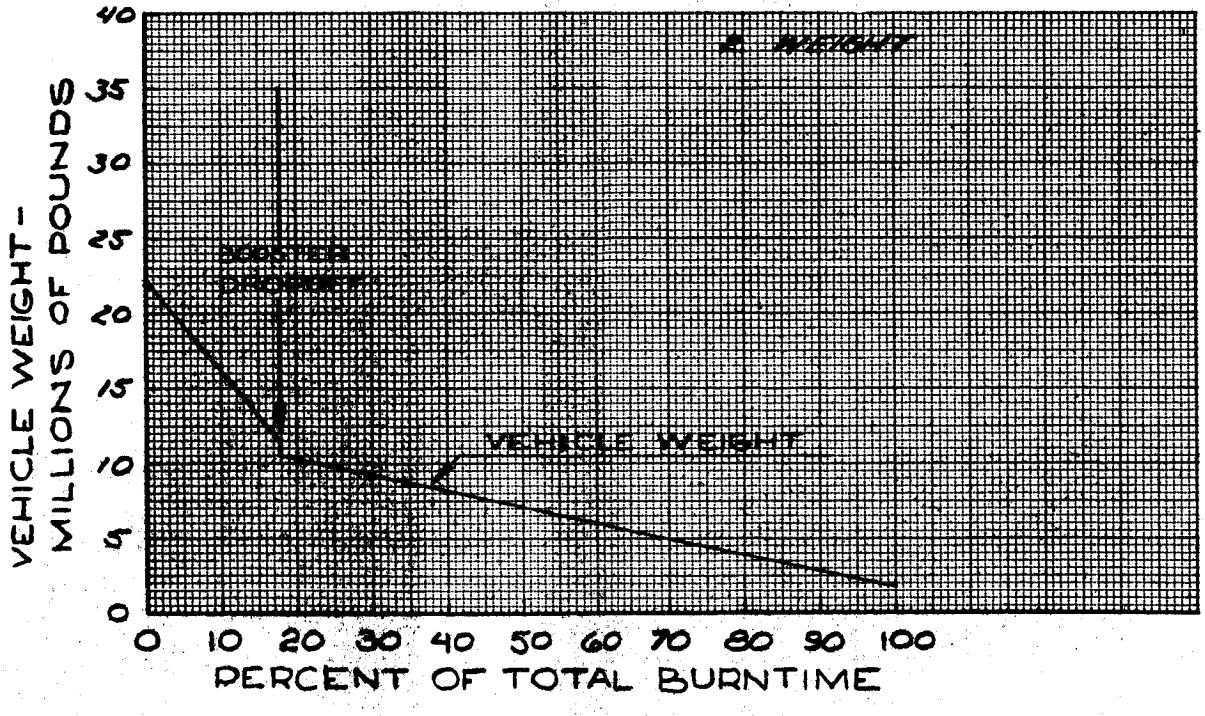
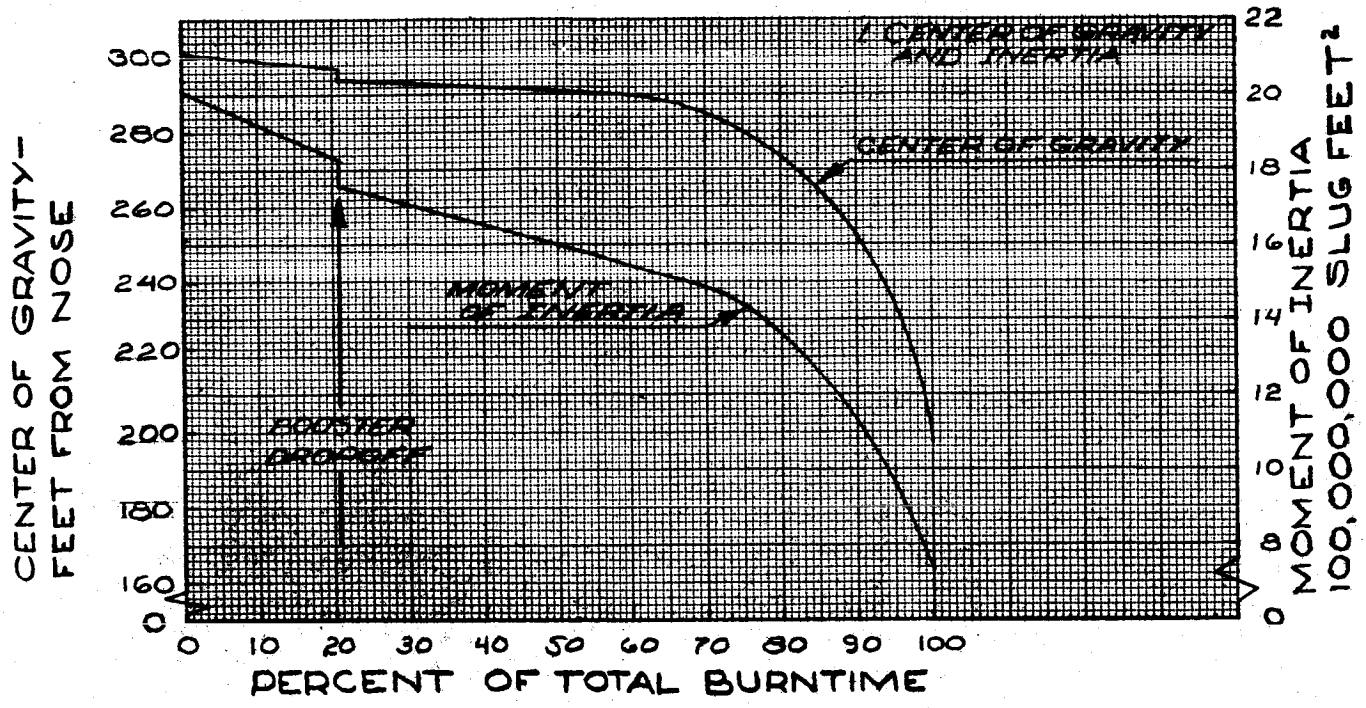




Figure 4.6-7 CENTER OF GRAVITY, MOMENT OF INERTIA, AND WEIGHT
Configuration APM-41



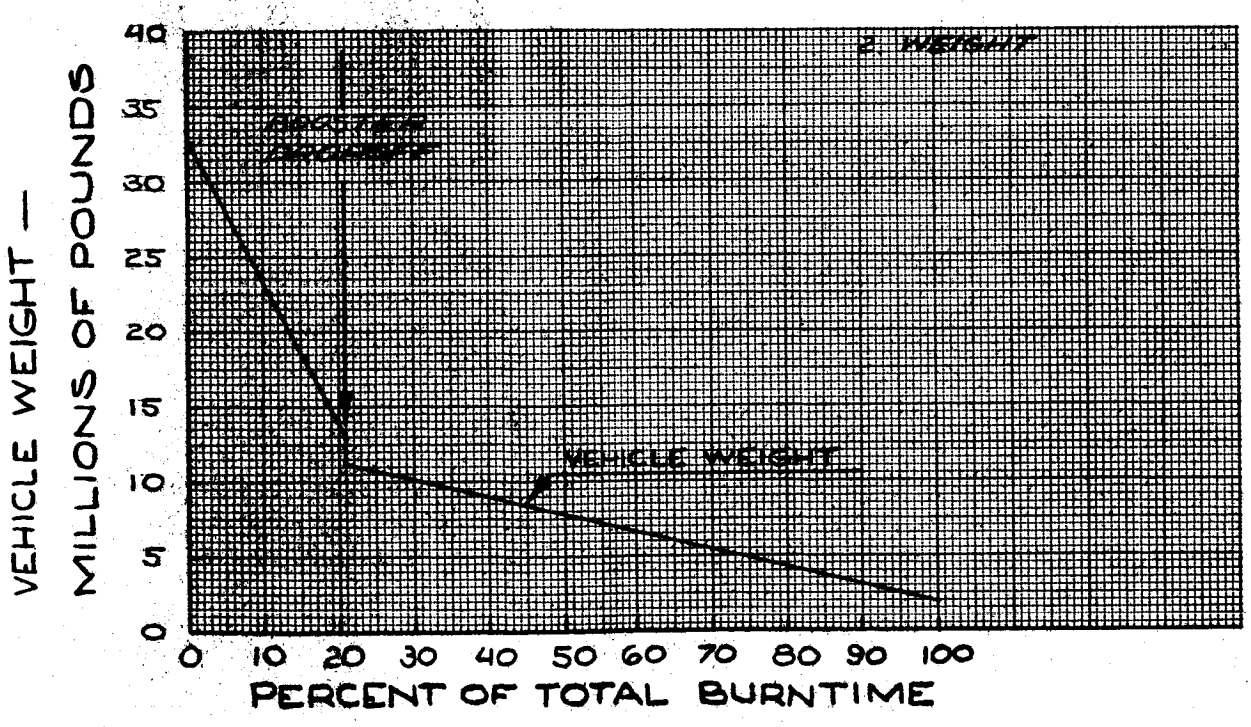




**Figure 4.6-8 CENTER OF GRAVITY, MOMENT OF INERTIA, AND WEIGHT Configuration APM-67B**

DESIGN CRITERIA FOR SOLID PROPELLANT STAGES

| | AT-41 | APM-41 | APM-67B |
|---|---|---|---|
| Basic Motor | | | |
| Diameter (inches) | 260 | 260 | 260 |
| Material | Maraged Steel | Maraged Steel | Maraged Steel |
| Ultimate Tensile Strength (psi) | 300,000 | 300,000 | 300,000 |
| Number Required | 4 | 4 | 6 |
| Thrust per Motor (millions of pounds) | 9.7875 | 6.125 | 5.895 |
| Ultimate Factor of Safety | 1.4 | 1.4 | 1.4 |
| Yield Factor of Safety | 1.1 | 1.1 | 1.1 |
| Expansion Ratio | 5 | 5 | 6 |
| Cross-Section Loading Efficiency | 0.68 | 0.70 | 0.70 |
| Thrust Vector Control | Direct Chamber Bleed | Direct Chamber Bleed | Gimbal |
| Separation Rockets Required | Yes | No | Yes |
| Separation Procedure | Dual-Plane Separation | Individual Case Jettison | Rail-Guided Separation |

Table 4.6-9

case to first rotate about a hinge at its base, thus disengaging from the sustainer stage. An $LO_2/LH_2$ sustainer stage is used. Total sustainer propellant weight available is 10,870,000 pounds, of which 1,870,000 pounds are used during booster assist, leaving 9,000,000 pounds to be used by the sustainer alone. Sustainer thrust is 9,500,000 pounds at launch and approximately 11,300,000 pounds at burnout. A single E-D engine is used. $\Delta V$ reserve propellant is 125,000 pounds. The engine operates on an oxidizer-to-fuel mixture ratio of 6.0. Booster propellant weight consists of 8,350,000 pounds of solid propellant in four 260-inch-diameter cases, and 1,870,000 pounds of liquid propellant. Boost thrust is 24,500,000 pounds delivered by the solid-propellant motors and 9,500,000 pounds delivered by the sustainer engine, giving a total launch thrust of 34,000,000 pounds.

Sustainer mass fraction is defined as the ratio of sustainer propellant weight used from booster dropoff to burnout and the sum of this propellant weight plus the sustainer inert weight. Sustainer inert weight includes $\Delta V$ reserve weight. Booster mass fraction is defined as the ratio of booster (solid) propellant weight used during booster assist, and the sum of booster propellant weight used plus the total inert weight jettisoned at staging. Stage mass fraction is defined as the ratio of total propellant weight used during booster assist (solid and liquid propellants) and the sum of the propellant weight used plus the total inert weight jettisoned at staging.

Weight statements are provided in Tables 4.6-4 and 4.6-5. Weight, center of gravity, and moment of inertia data are graphically presented in Figure 4.6-7. A sketch of APM-41 is shown in Figure 4.6-5.

#### 4.6.3.3 APM-67B Configuration

APM-67B is a parallel-staged vehicle. Both stages are ignited at launch with the booster stage jettisoned after it has burned out. $LO_2/LH_2$ sustainer operation is continuous from launch. Separation is achieved by allowing the burned-out cluster of cases to travel aft under the influence of a system of retrorockets. The cluster is guided by a set of rails mounted on the sustainer. Total sustainer propellant weight available is 11.7 million pounds, of which 2.45 million pounds are used during boost assist, leaving 9.25 million pounds to be used by the sustainer alone. Sustainer thrust is 8.75 million pounds at launch for seven engines, and 10.5 million pounds at burnout. The engines operate on an oxidizer-to-fuel mixture ratio of 5.0. $\Delta V$ reserve propellant is 147,000 pounds. Booster propellant weight consists of 14.82 million pounds of solid propellant in six 260-inch-diameter cases, and 2.45 million pounds of liquid propellant. Booster thrust is 35.37 million pounds delivered by six solid motors with 8.75 million pounds of thrust delivered by seven modified M-1 sustainer engines for a total launch thrust of 44.12 million pounds.

Sustainer mass fraction is defined as the ratio of sustainer propellant weight used from booster drop-off to burnout, and the sum of this propellant weight plus the sustainer inert weight. Sustainer inert weight includes $\Delta V$ reserve weight. Booster mass fraction is defined as the ratio of booster (solid only) propellant weight used during booster assist, and the sum of booster propellant weight used plus the total inert weight jettisoned at staging. Stage mass fraction is defined as the ratio of total (solid and liquid) propellant weight used during booster assist, and the sum of the propellant weight used plus the total inert weight jettisoned at staging.

Weight statements are provided in Tables 4.6-6 and 4.6-7. Weight, center of gravity, and moment of inertia data are graphically presented in Figure 4.6-8. A sketch of APM-67B is shown in Figure 4.6-5.

### 4.6.4 Vehicle Design Criteria

Tables 4.6-8 and 4.6-9 describe the design criteria used in the design of vehicles AT-41, APM-41, and APM-67B for purposes of weight estimation. Criteria and assumptions for the preliminary second-stage mass-fraction data are described in Section 4.6.2 and are included in Table 4.6-8.

### 4.6.5 Weight, Center of Gravity, and Moment of Inertia Data

Center of gravity, weight, and mass moment of inertia data for configurations AT-41, APM-41, and APM-67B are shown in Figures 4.6-6, 4.6-7, and 4.6-8. The abscissa of each plot is labeled "Percent of Total Burntime." This is based on the assumption that the mass flow rate for each propellant is constant.

The data for APM-41 and APM-67B include the entire thrust history from launch to sustainer burnout, including booster burnout.

The data for AT-41 include the thrust history of the first stage only, from launch to second-stage ignition.

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## 4.7 PROPULSION SYSTEM FEASIBILITY

### 4.7.1 Introduction

Preliminary designs are shown for 260-inch solid-propellant motors meeting specified thrust levels with given propellant weights. A variety of grain designs are used. Except for the chamber-bleed TVC system assumed, no advance in technology is required compared to the T65 first-stage motors.

Liquid-oxygen/liquid-hydrogen propellants are used, delivered under pressure of vaporized propellants, to modified M-1 and advanced high-pressure expansion-deflection (E-D) engines. Performance of the parallel-staged vehicle using the E-D engine is significantly improved over the baseline vehicle.

### 4.7.2 First Stages and Booster Stages

#### 4.7.2.1 Configuration APM-41

The booster stage of this parallel-staged vehicle consists of four 260-inch motors mounted symmetrically around the $LO_2/LH_2$ sustainer stage. Peel-off separation of the spent solid motors is assumed.

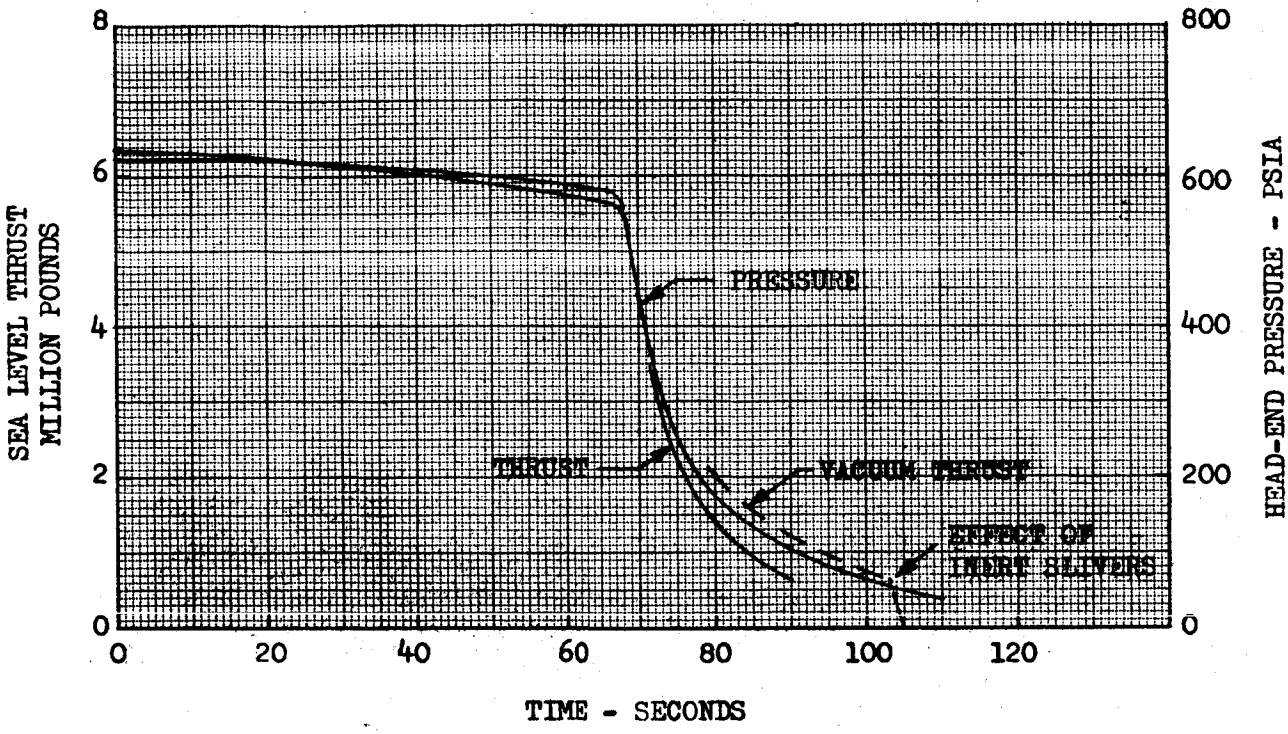
Design requirements established on vehicle performance considerations were met readily by a conventional internal-burning star grain. Motor characteristics are summarized in Figure 4.7-1. The slightly regressive thrust trace and rather long tailoff do not compromise the parallel-staged vehicle as they do a tandem configuration. Design and operation of these motors indicate no more development risk than the T65 motor except for one factor — the assumption of a direct-chamber-bleed thrust-vector-control system. Substantial progress has been made in the past year in hot gas valving, however, and the assumption does not seem inconsistent with the development timing assumed for this vehicle. If development problems should be encountered in aft-end ignition systems for very large solid-propellant motors, this configuration lends itself to convenient installation of conventional igniters.

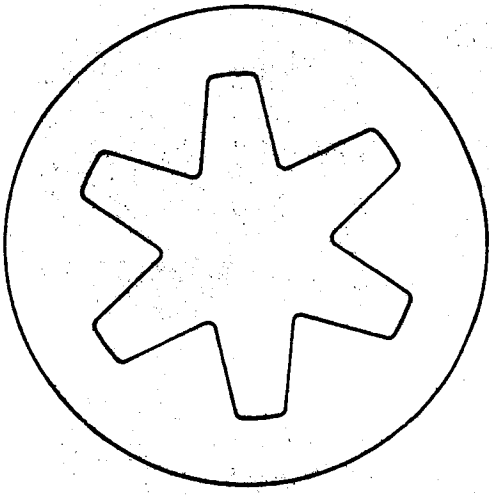
#### 4.7.2.2 Configuration APM-67B

Characteristics of the booster-stage motors for this configuration are shown in Figure 4.7-2. With the somewhat less demanding gimbaled-nozzle TVC system, these motors represent the same technology and, therefore, no higher development risk than the T65 baseline vehicle first-stage motors.

#### 4.7.2.3 Configuration AT-41

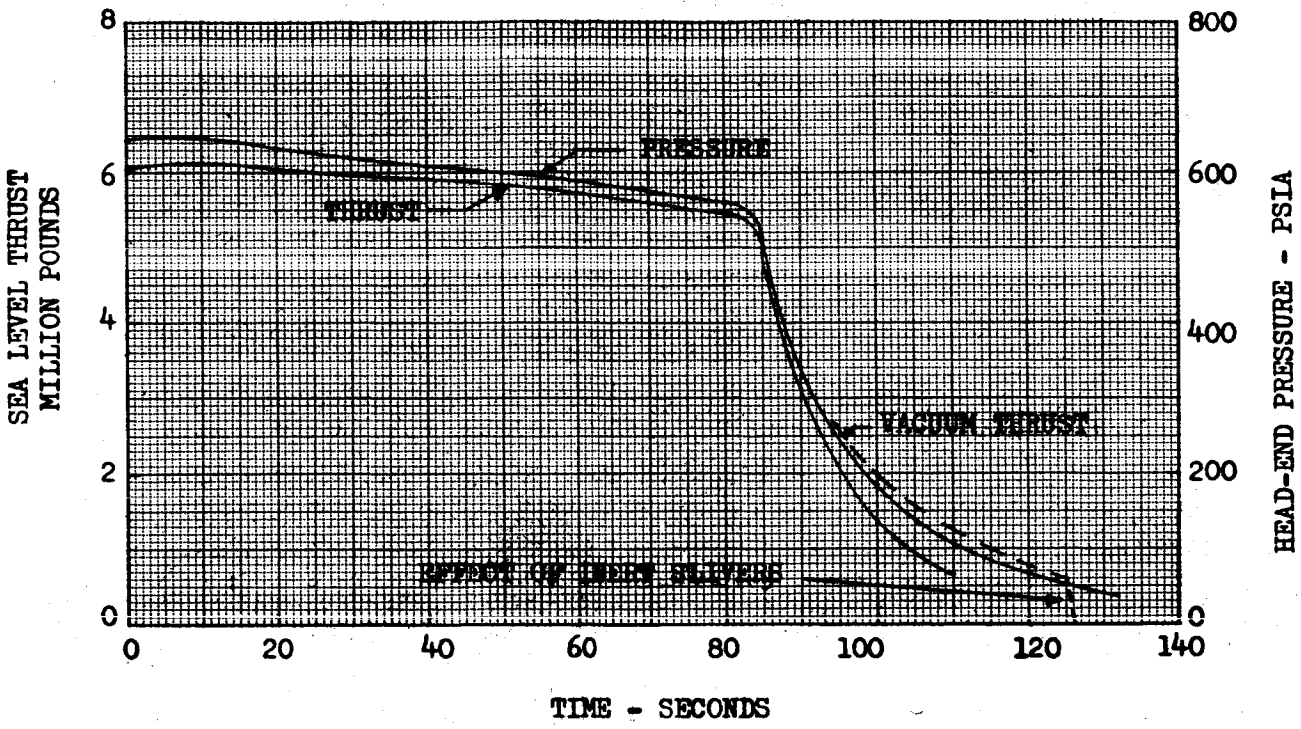
A summary description of the first-stage motors for this vehicle is given in Figure 4.7-3. With the direct-chamber-bleed TVC system, development problems are expected to be the same as for the APM-41 vehicle.

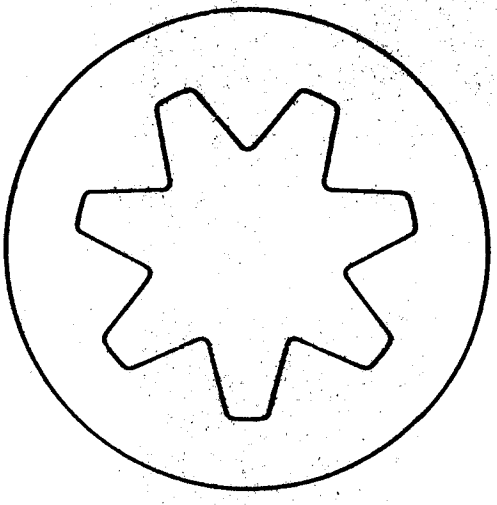


| | |
|---|---|
| Outside diameter, in. | 260 |
| Motor case length, in. | 1089 |
| Grain type | Six-point star |
| web thickness, in. | 35.25 |
| cylindrical cross section loading | .68 |
| port to throat area ratio | 2.42 |
| Thrust, initial S.L., lb | $6.239 \times 10^6$ |
| web time mean S.L., lb | $6.094 \times 10^6$ |
| Web burn time, sec | 68 |
| Action time, sec | 102 |
| Chamber pressure | |
| head end max, psia | 640 |
| nozzle entrance total, web time mean | 598 |
| Throat area, in.$^2$ | 7150 |
| Nozzle expansion ratio | 5.93 |
| Delivered specific impulse S.L. web time mean, sec | 233.3 |
| Propellant weight, lb | $2.0875 \times 10^6$ |

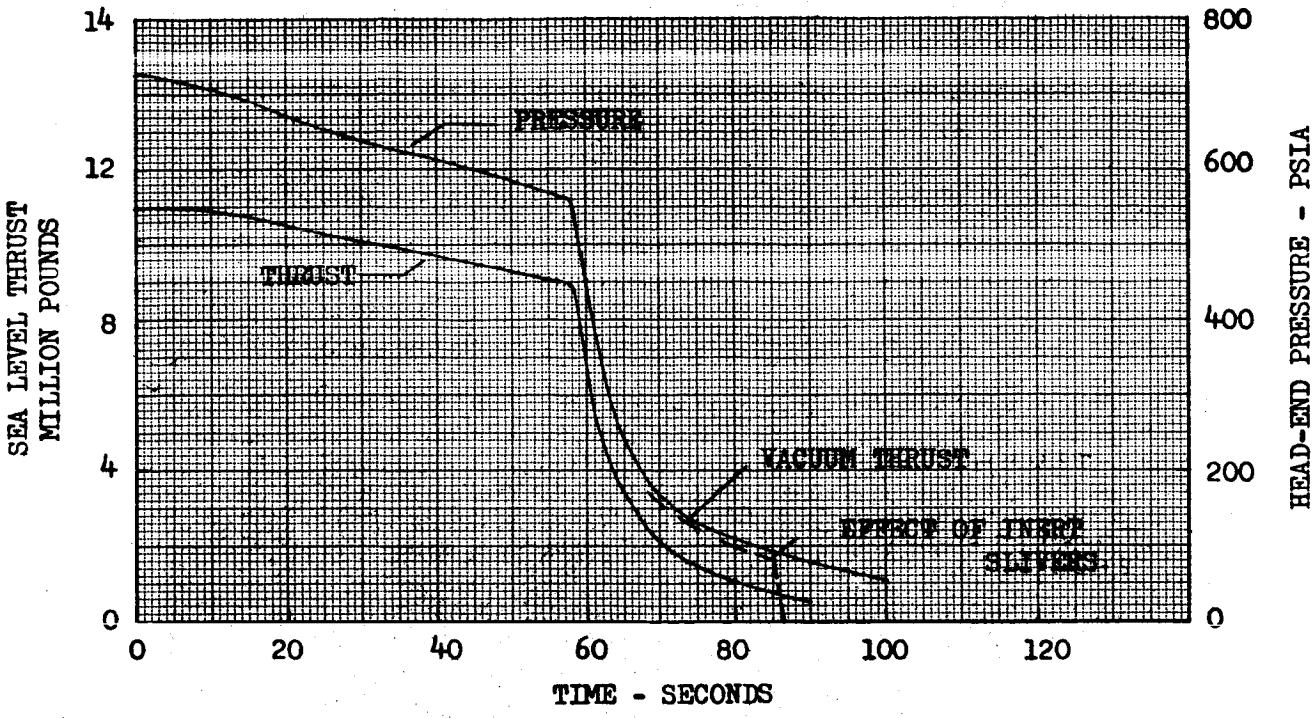
Figure 4.7-1 SUMMARY DESCRIPTION OF FIRST STAGE MOTORS
Configuration APM-41

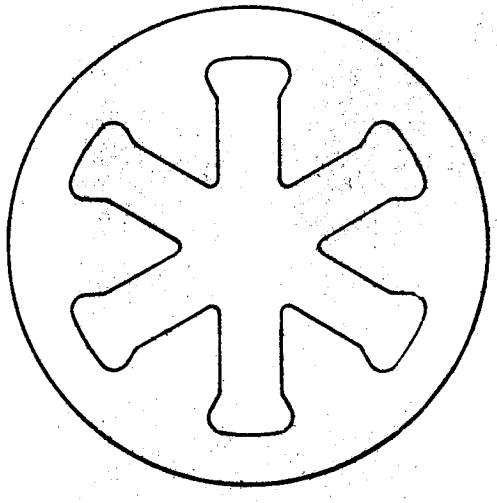


| | |
|---|---|
| Outside diameter, in. | 260 |
| Motor case length, in. | 1192 |
| Grain type | Seven-point star |
| web thickness, in. | 37.4 |
| cylindrical cross section loading | 0.65 |
| port to throat area ratio | 2.73 |
| Thrust, initial S.L., lb | $6.0465 \times 10^6$ |
| web time mean S.L., lb | $5.8500 \times 10^6$ |
| Web burn time, sec | 84 |
| Action time, sec | 123 |
| Chamber pressure | |
| head end maximum, psia | 648 |
| nozzle entrance total, web time mean | 598 |
| Throat area, in.$^2$ | 6868 |
| Nozzle expanstion ratio | 5.96 |
| Delivered specific impulse S.L. web time mean, sec | 233.4 |
| Propellant weight, lb | $2.470 \times 10^6$ |

Figure 4.7-2 SUMMARY DESCRIPTION OF FIRST STAGE MOTORS
Configuration APM-67B



| | |
|---|---|
| Outside diameter, in. | 260 |
| Motor case length, in. | 1535 |
| Grain type | Six-point wagon wheel |
| web thickness, in. | 26.44 |
| cylindrical cross section loading | .65 |
| port to throat area ratio | 1.652 |
| Thrust, initial S.L., lb | $10.975 \times 10^6$ |
| web time mean S.L., lb | $10.036 \times 10^6$ |
| Web burn time, sec | 59 |
| Action time, sec | 96 |
| Chamber pressure, psia | |
| head end maximum | 729 |
| nozzle entrance total, web time mean | 622 |
| Throat area, in.$^2$ | 11302 |
| Nozzle expansion ratio | 4.99 |
| Delivered specific impulse S.L. web time mean, sec | 233.5 |
| Propellant weight, lb | $3.0385 \times 10^6$ |

Figure 4.7-3 SUMMARY DESCRIPTION OF FIRST STAGE MOTORS
Configuration AT-41

In none of these configurations is there a demand for unique grain design, high burning rates, or exceptional physical properties. Tailoff duration of all motors is limited by the use of inert slivers. Other grain designs could be developed to meet variations in the design requirements assumed for these vehicles.

### 4.7.3 Second Stages and Sustainer Stages

#### 4.7.3.1 Configurations APM-41 and AT-41

The pacing propulsion component among the advanced-technology vehicles is the high-pressure, high-expansion ratio, altitude-compensating E-D engine concept. This engine represents the greatest area of technical risk for the advanced-technology vehicles. The considerable vehicle performance payoff associated with this engine concept, especially in the parallel-staged configuration, should encourage an early effort to demonstrate full operational feasibility for this or a similar engine design. The propellant tankage and feed system for these vehicles is straightforward.

#### 4.7.3.2 Configuration APM-67B

This vehicle represents an application of M-1 engines modified for sea-level and vacuum operation. The modification would consist of additional flow separators in the nozzle to induce near-optimum expansion at one or more altitudes during boost. They could take the form of physical wedges or secondary injection. The problems this might introduce in local description of the nozzle cooling have not been determined.

## 4.8 FLIGHT CONTROL

### 4.8.1 Control Requirements

The control requirements of the advanced-technology vehicles are presented in Table 4.8-1. The thrust deflection required to trim 8 degrees of angle-of-attack is an approximation of the dynamic deflection that would be required if the vehicles were subjected to a 99-percent wind profile during boost. This has been found to be a good approximation to use when a continuous boost simulation is not made. The static (misalignment) thrust deflection is based on three-sigma probability misalignments due to thrust-level variation, thrust-line variation, and vehicle center-of-gravity variation. An allowance of 1 degree of deflection is included in the design thrust deflection to compensate for hardware compliance. The total design deflection is greater than 5 degrees for the parallel vehicles and less than 4 degrees for the tandem vehicle.

The requirements of the two parallel vehicles are similar in magnitude since the vehicles are similar in size and shape. The requirements of the tandem vehicle are typically less than those of the parallel vehicles because the higher moment of inertia of the tandem configuration makes the vehicle less sensitive to flight-path disturbances.

CONTROL REQUIREMENTS SUMMARY

| Configuration | AT-41 | APM-67B | APM-41 |
|---|---|---|---|
| Maximum Aerodynamic Angular Divergence $\left(\frac{M\alpha}{I}\right)_{max}$ | 0.44 | 0.98 | 1.02 |
| Control Authority at Maximum Dynamic Pressure $\left(\frac{M\delta}{I}\right)$ | 3.1 | 1.7 | 1.6 |
| Thrust Deflection Required to Trim 8-Degree Angle-of-Attack (degrees) | 2.6 | 4.1 | 4.4 |
| Root-Sum-Square Static-Thrust Deflection (degrees) | 0.5 | 1.0 | 1.0 |
| Root-Sum-Square Total Thrust Deflection Required (degrees) | 2.65 | 4.21 | 4.51 |
| Design Thrust Deflection (degrees) | 3.65 | 5.2 | 5.5 |

Table 4.8-1

### 4.8.2 Launch Dynamics

Launch drift angles are computed for each configuration to determine their relative adaptability to the ground equipment requirements. Table 4.8-2 lists the results obtained for conventional launch and for launch from a building 200 feet higher than the vehicle length. The results shown are somewhat flexible, since no attempt has been made to control the vehicle drift. If necessary, additional control feedbacks can be used in addition to the attitude error and attitude rate to reduce drift at launch.

LAUNCH CONE ANGLE SUMMARY

| Configuration | AT-41 | APM-67B | APM-41 |
|---|---|---|---|
| Launch from Building (degrees) | 2.2 | 5.0 | 4.7 |
| Conventional Launch (degrees) | 2.7 | 5.5 | 5.4 |

Table 4.8-2

### 4.8.3 Stage Separation

The advanced-technology vehicles are compared on a qualitative basis only. Stage separation for the AT-41 configuration occurs at a dynamic pressure of 300 to 400 psf and a dual-plane separation mode is proposed. Previous studies have indicated that a tailoff time of 10 seconds to the 10-percent thrust level will eliminate nozzle canting requirements. In addition, the use of inert slivers to terminate thrust at about 1 million pounds per motor will reduce total retrorocket requirements to about 1 g on the booster stage. The primary separation plane is at the exit plane of the second-stage nozzle. After separation, a very short coast time (less than 1 second) and a rapid thrust buildup are necessary to keep vehicle divergence under control. An alternate procedure to allow for more extensive preignition procedures and a less restrictive requirement on thrust buildup of second-stage engines is to use a reaction-control system on the second stage. Reaction control would operate for 3 to 5 seconds and, when second-stage thrust builds up, the interstage structure and possibly the reaction-control package would be separated and discarded. A reliable method of disposing of the interstage is necessary to ensure that the second-stage rocket nozzle is not damaged.

Stage separation for the APM-67B vehicle occurs at a dynamic pressure of less than 100 psf. The solid-motor tailoff is 20 to 25 seconds to eliminate nozzle canting requirements and inert slivers are used to terminate thrust at about 10 percent. Six of the seven sustainer-stage engines are gimbaled (6.5 degrees maximum deflection) during the tailoff but are zeroed during separation while retrorockets move the solids along guide rails. Separation is initiated by a single-plane cut near the M-1 gimbal plane shortly after solid-stage thrust goes to zero. Retrorockets mounted on the base-tie structure pull the solid-motor cluster off the sustainer stage. A net retrograde acceleration of 1 g results in about 3 seconds between initiation of the separation and clearance of the sustainer stage. Relative forces and moments between stages are unknown when the solid-motor cluster is in contact with the second-stage rocket plane.

Stage separation for the APM-41 vehicle is similar to that for the APM-67B, except that dynamic pressure is higher and the separation mode is different. The APM-41 staging is accomplished by simultaneously releasing the forward motor attachments. This leaves the motors free to rotate about individual aft-hinge attachments. Aerodynamic forces (and applied forces, if required) start the rotational motion of each case. When the motor attitude with respect to the sustainer stage is sufficient to ensure clearance, the aft-hinge attachment is released. Aerodynamic drag on the motor case and acceleration of the sustainer complete the separation. Because of variations in aerodynamic drag, each motor may release independently (that is, when it achieves the correct attitude). It is felt that the differences in time of aft-hinge release will be so small that there would be no advantage gained by attempting to control the symmetry of the final separation. The APM-41 separation mode should be fairly reliable and is felt to be definitely superior to the guide-rail arrangement of the APM-67B and the

dual-plane mode of the AT-41. The use of single-plane separation for the AT-41 would simplify the separation. It is felt that second-stage engine-ignition requirements may make use of auxiliary reaction control necessary.

### 4.8.4 Technical Risk

In general, it can be said that solution of control problems associated with the advanced-technology vehicles does not entail a high degree of technical risk. The problems appear to be susceptible to conventional methods of analysis and proven control techniques. It is entirely possible, however, that the solutions might result in requirements which, in turn, constitute a technical risk in the areas of propulsion, flight control equipment, and structures. It is impossible to arrive at a final evaluation of the technical risk at this time because there are many trades between risk and optimization which have not yet been considered. For example, the AT-41 vehicle with single-plane separation at the second-stage nozzle exit plane and reaction control to allow current preignition procedures is well within current technology. However, if vehicle optimization requires that the interstage weight be jettisoned, the dual-plane separation mode introduces an additional element of risk.

The flight control area that presents the greatest degree of technical risk is stage separation. The separation mode of the APM-41 vehicle is considered to be less risky than the separation mode of either the AT-41 or the APM-67B vehicle. If the start-up time for the AT-41 second-stage engine cannot be shortened to the required value, a large reaction-control system would be required during the coast period.

## 4.9 THRUST VECTOR CONTROL

### 4.9.1 Introduction

Each choice of a propulsion system for the advanced-technology concepts of the 1-million-pound-payload NOVA vehicle incorporates a preselected thrust-vector-control (TVC) system as a part of the propulsion package. These selections are as follows:

| Vehicle | Stage | Propulsion | TVC |
|---|---|---|---|
| APM-67B | Booster | Six 260-inch solid | Gimbaled nozzle |
| | Sustainer | Seven modified M-1 liquid | Gimbaled engine |
| APM-41 | Booster | Four 260-inch solid | Chamber-bleed injection |
| | Sustainer | One E-D liquid | Throttling and/or fluid injection |
| AT-41 | 1 | Four 260-inch solid | Chamber-bleed injection |
| | 2 | One E-D liquid | Throttling and/or fluid injection |

The maximum thrust-vector-control deflection for any single stage of the current-technology vehicles was determined to be 4 degrees gimbal angle. A greater equivalent gimbal angle will be required for the parallel-staged advanced-technology vehicles.

A complete preliminary design for the advanced TVC systems is not justifiable or possible prior to further advances in the development of these TVC systems or the associated engines. The discussion of these systems, therefore, is limited to feasibility and development considerations.

### 4.9.2 Summary

The concept of providing thrust vector control by gimbaling is already state of the art and is advocated in the preliminary design of the T65C current-technology vehicle. For the advanced-concept thrust-vector-control systems, the direct-chamber-bleed system for solid-propellant motors is desirable from the standpoint of least complexity and demonstrated feasibility in scalar tests. TVC by throttling of some chambers of a segmented liquid-propellant engine is recommended only if other thrust-vector-control systems cannot be implemented. This recommendation on segmented chamber throttling is made because the development risk due to complexity is the highest of any of the advanced TVC systems studied.

### 4.9.3 Feasibility and Development Considerations

#### 4.9.3.1 Thrust Vector Control by Gimbaling

Of the thrust-vectoring concepts selected for the advanced-technology vehicles, the gimbaling concept for large engines and solid-motor nozzles is by far nearer an operational system than the other selections. The TVC requirements and design for the propulsion systems selected for the APM-67B vehicle will be similar to the current-technology baseline vehicle presented in 3.2.5.3 and 3.2.5.4 for the first and second stages, respectively.

#### 4.9.3.2 Thrust Vector Control by Direct Chamber Bleed (Hot-Gas Injection)

The TVC principle of bleeding a portion of the propulsion chamber gases for injection is desirable because of system simplicity and the elimination of the need for auxiliary pumping power. For the advanced-technology concepts, each 260-inch solid motor in the first stage of the AT-41 vehicle requires approximately 250-pounds-per-second bleed for pitch or yaw control for 4 degrees equivalent gimbal angle. This amounts to 1.6 percent of the axial flow in each control direction. Each motor on the APM-41 vehicle requires approximately 350 pounds per second or 2.2 percent of the axial flow for 5.6 degrees equivalent gimbal angle.

The present feasibility limitations of the chamber-bleed concept are the hardware requirements for transferring and providing flow modulation of the 5500°F erosive bleed gases. Bleed injection has been demonstrated with Lockheed Propulsion Company and Moog Servocontrols, Inc., hot-gas valves. The Lockheed valve is a 90-degree type and the Moog valve is an axial flow type. These valves are capable of handling bleed of a 17-percent aluminized solid propellant for times approximately equal to the burn time of the advanced-technology-vehicle first stage. The flows involved are 7 pounds per second for the Moog valve and 1 pound per second for the Lockheed valve. The ablative parts of the valves are not reusable. After replacing the ablative parts, the Lockheed valve was reused in a 53-second test, during which the valve remained in the full-open position for 7 continuous seconds. For advanced-technology application, further development with increased bleed-flow rates is necessary to establish the degree of practicality of using direct chamber bleed for large rocket-motor thrust vector control.

#### 4.9.3.3 Thrust Vector Control by Segmented-Engine Chamber-Flow Modulation

The principle of providing TVC by modulation of the flow to some of the thrust chambers (or segments) of a segmented engine is the least developed concept of those selected for the advanced-technology vehicles. Based on General Electric studies (References 1 and 2), Aerojet-General studies (Reference 3), and other advanced engine studies, TVC by thrust-chamber flow modulation appears feasible only with engines having a large number of chambers. In addition, throttling by itself is not adequate because the thrust of the chamber in opposition to the one being throttled must be implemented. This implementation not only assists in providing a larger turning moment for the vehicle but is necessary to maintain axial thrust as nearly constant as possible at all times. If axial thrust is to be maintained constant during vectoring, the throttling and implementation percentage magnitudes must be equal. To implement this control principle, a minimum of 20 chambers is advised, with a more practical number being 60 as used in the General Electric studies. To modulate either 20 or 60 chambers for maximum thrust vector control will require half of the chambers to have a 15-percent flow increase above nominal and the remaining half to have a 15-percent flow decrease. The direction of attitude correction is determined by which half of the chambers is increased and which is decreased. Control is available as true pitch or yaw as well as any 6-degree increment between pitch and yaw if 60 chambers are used or as 18-degree increments if 20 chambers are used.

The development of the chamber throttling principle for TVC will require extensive testing to develop an analytical approach by which throttling requirements can be determined for a given vehicle. Throttling limitations in practical engine design and the actual throttling magnitude required are the most serious development considerations for TVC.

#### 4.9.3.4 Thrust Vector Control by Secondary Fluid Injection

Because so little is known of the practicality of TVC by segmented-chamber flow modulation, secondary fluid injection is indicated as an alternate or supplementary TVC system for large segmented engines. As an alternate to the segmented-chamber flow-modulation concept of TVC for a second-stage application, the secondary injection system may impose a severe weight penalty on the vehicle. The effect of this penalty can be somewhat reduced by using one of the propulsion liquid propellants as the secondary injectant, thus reducing the weight required for separate tankage. The feasibility of providing from 4 to 6 degrees equivalent gimbal angle by secondary injection is not questioned. Development of large-size injectors with adequate dynamic response has not been evaluated because the need for such items has not been presented.

The use of secondary fluid injection as a supplement to segmented-chamber flow modulation will reduce the percentage modulation requirements. In addition, use of the combined systems will allow far less injectant weight penalty than would be imposed if injection were the only TVC system. The penalty of combining these systems is to introduce further complexity to systems that by themselves have complex control apparatus. The use of the combined chamber modulation-fluid injection system will not only involve development and analysis of TVC by chamber modulation but will also require analysis of the interaction of throttling and secondary shock effects in the nozzle. It is likely that extensive development time and effort would be required to evaluate and perfect such a thrust-vector-control system.

## 4.10 RELIABILITY

### 4.10.1 Introduction

The three advanced-technology solid NOVA configurations, shown in Section 4.3, Figures 4.3-3, 4.3-4, and 4.3-6, were analyzed and the flight reliability was assessed. The flight reliability was then used as a basis for determining: (1) the number of R&D flights required to achieve the flight test objectives; (2) the number of flights required to achieve an initial operational reliability of 0.75; and (3) the number of successful flights in an operational program consisting of 79 launches. The reliability assessments were based on operation of the vehicle stages from launch to injection into a 567-kilometer orbit. Emphasis was given to evaluating the effect of advanced technology on the potential reliability of the configurations.

### 4.10.2 Summary

The flight reliability of the advanced configurations was assessed on the basis of historical flight data and design information while considering the time available to develop new systems. The advanced vehicles were predicted to achieve higher reliabilities than those achieved with current missile and space launch vehicles.

This higher reliability is primarily the result of advancements in technology, additional launch experience, and the emphasis on system reliability from the initiation of the program.

The APM-41 vehicle has the highest reliability potential of the three advanced-technology configurations with the AT-41 rated second and the APM-67B rated third. The reliability advantage that the APM-41 vehicle has over the AT-41 vehicle is attributed to the advantage of hold-down of the liquid stage. The APM-67B has the advantage of hold-down, but has the disadvantage of an increased number of propulsion units in both the solid and liquid stages, thereby resulting in a lower reliability potential.

Major differences in the assessed reliability of the vehicle systems resulted from the differences in the quantity of propulsion units and the concept of staging. The propulsion system will continue to be the major source of flight failures. The flight control system will continue to be second only to propulsion as a source of flight failure, but with considerably improved reliability over the current-technology systems.

### 4.10.3 Configuration Evaluation

The reliability of the advanced-technology configuration can be expected to be higher than that for current ballistic missiles and space launch vehicles. This is a natural consequence of three factors: (1) additional time to continue the development of systems that are essentially common to all configurations; (2) additional launch operational experience; and (3) additional advancements in technology. Therefore, the level of reliability that can be attained will be somewhat higher for the advanced-technology vehicles than for the current-technology vehicles if the additional time is properly utilized.

Reliability achievable in vehicle operation is dependent on the design, manufacture, and test programs, and operation of the vehicle systems. The operational reliability is defined as the probability that the vehicle will operate properly under actual mission conditions. Once the design is established, the test program, with design improvement feedback from test results, is necessary. Finally, reliability of the launch vehicle will depend on quality control of the systems during manufacture and launch operations. Operational reliability tends to approach the inherent design reliability as experience is gained in the manufacture and operations areas. For the purpose of this study, operational reliability growth is considered a function of the number of launches for each vehicle configuration.

#### 4.10.3.1 Background Data

Evaluation of the advanced-technology configurations is, in part, based on historical flight-failure data of missile and space systems currently in service and development, as discussed in Section 3.5.3. The historical data were used as a

basis for determining the distribution of flight failures by subsystem and for determining the areas that offer the greatest reliability potential.

4.10.3.2 Advanced-Design Reliability

Many of the problems inherent in advancing the state of the art for current-technology configurations will be solved before the advanced configurations are dealt with. It is important to note, however, that systems that pace the development schedule will have the most influence on the level of reliability that can be achieved.

The reliability of the solid motors is predicted to have an initial value of 0.975, increasing to 0.988 in the developed system. The modified M-1 liquid engine used in the second stage of the APM-67B vehicle is predicted to have an initial reliability of 0.988. The high-pressure expansion-deflection engine used in the second stage of the AT-41 and APM-41 vehicles requires a completely new development. Therefore, an initial value of 0.90 is predicted, with growth to 0.95 for the developed system.

Thrust-vector-control systems will remain a problem for the advanced configurations. The direct-chamber-bleed system proposed for the solid motors offers potential reliability improvement over current systems. Reliabilities exceeding those of the current-technology NOVA vehicles are predicted for the advanced vehicles.

Historical failure data are limited to tandem-staged vehicles. In the past, 0.5 to 1.4 percent of the booster launches have experienced separation failures. It is assumed for this study, that separation for the tandem-staged vehicles will be similar to past experience. Separation for the parallel-staged vehicles is predicted to be more difficult because of: (1) more points of separation required; (2) proximity of the stages during separation; and (3) duration of separation proximity. The proximity of the solid motors represents a hazard to the liquid stage that could result in damage. Separation system reliability is lower for the parallel-staged vehicles.

Historically, structural reliability has been shown to be 0.986 for liquid-propellant rockets. However, vehicle structural elements can be made highly reliable by conservative design. In space launch vehicles, higher safety factors will be used, resulting in increased vehicle weight. Weight limitations still exist and some elements of risk must be taken to keep structural weight down so that there is a low probability of structural failure.

Propellant feed systems must be developed to provide the high flow rates required. Automatic monitoring systems must be designed to reduce the hazards of malfunction. Reliable systems can be designed and developed to an operational level. Reliability will depend on such operational factors as contamination, temperature changes, flow rates, and basic design.

Secondary power requirements are high and new auxiliary power units (APU) are required. A reliability of 0.995 is predicted for the stage APU. The guidance, flight control, and electronic subsystems will obviously be developed beyond their present incidence of failure — now about 0.005 for the short flights of missile and space launch vehicles. Since the boost time to low orbit for the NOVA vehicles will be similar to current launch vehicles, the reliability is predicted to be 0.998. If duplication of functions, radio checks, and crew override are planned, the reliability can be improved to the point where these systems will not be a problem.

### 4.10.4 Reliability Assessments

Flight reliability was assessed for each advanced-technology configuration from launch to injection into a 567-kilometer orbit. The reliability assessments are tabulated by subsystem in Table 4.10-1. Two assessments are shown: the initial (first flight) and the developed (twentieth flight). The reliabilities include the effects of design improvements and advancements in technology. The reliability of the total system is approximated by the product of subsystem reliabilities.

### 4.10.5 Flight Reliability Growth

Reliability growth is a result of design improvements and of familiarization with the vehicles and their equipment. Recognized reliability growth on current launch-vehicle programs has been rapid, as discussed in Section 3.5.3. Improvements of 100 to 700 percent over early program reliabilities have been observed. Predictions of reliability growth for the NOVA vehicles are generally less rapid, primarily because initial reliability is higher. Figures 4.10-1, 4.10-2, and 4.10-3 show the growth predictions for the three vehicles. The APM-41 vehicle achieves a slightly higher reliability than the AT-41 because of the advantage of hold-down for the liquid stage. The APM-67B vehicle is less reliable than the other vehicles because of the increased complexity of the system.

ADVANCED-TECHNOLOGY-VEHICLE RELIABILITY ASSESSMENTS

| | AT-41 Reliability | | APM-41 Reliability | | APM-67B Reliability | |
|---|---|---|---|---|---|---|
| | Initial | Developed | Initial | Developed | Initial | Developed |
| First Stage (Booster) | (0.851) | (0.954) | (0.842) | (0.945) | (0.780) | (0.927) |
| Propulsion | 0.904 | 0.992 | 0.904 | 0.992 | 0.859 | 0.988 |
| Thrust Vector Control | 0.977 | 0.984 | 0.977 | 0.984 | 0.957 | 0.970 |
| Guidance/Autopilot | 0.998 | 0.998 | 0.998 | 0.998 | 0.998 | 0.998 |
| Structure | 0.995 | 0.995 | 0.995 | 0.995 | 0.995 | 0.995 |
| Separation | 0.990 | 0.990 | 0.980 | 0.980 | 0.980 | 0.980 |
| Secondary Power | 0.980 | 0.995 | 0.980 | 0.995 | 0.980 | 0.995 |
| Second Stage (Sustainer) | (0.832) | (0.902) | (0.850) | (0.915) | (0.828) | (0.862) |
| Propulsion | 0.900 | 0.950 | 0.920 | 0.970 | 0.919 | 0.932 |
| Thrust Vector Control | 0.984 | 0.984 | 0.984 | 0.984 | 0.970 | 0.970 |
| Guidance/Autopilot | 0.998 | 0.998 | 0.998 | 0.998 | 0.998 | 0.998 |
| Structure | 0.995 | 0.995 | 0.995 | 0.995 | 0.995 | 0.995 |
| Separation | 0.990 | 0.990 | 0.990 | 0.990 | 0.990 | 0.990 |
| Propellant Feed | 0.960 | 0.980 | 0.960 | 0.980 | 0.950 | 0.975 |
| Secondary Power | 0.995 | 0.995 | 0.995 | 0.995 | 0.995 | 0.995 |
| Transfer Stage | (0.972) | (0.980) | (0.972) | (0.980) | (0.972) | (0.980) |
| Propulsion | 0.994 | 0.996 | 0.994 | 0.996 | 0.994 | 0.996 |
| Propellant Feed | 0.996 | 0.998 | 0.996 | 0.998 | 0.996 | 0.998 |
| Thrust Vector Control | 0.998 | 0.999 | 0.998 | 0.999 | 0.998 | 0.999 |
| Guidance/Autopilot | 0.990 | 0.992 | 0.990 | 0.992 | 0.990 | 0.992 |
| Secondary Power | 0.995 | 0.996 | 0.995 | 0.996 | 0.995 | 0.996 |
| Structure | 0.999 | 0.999 | 0.999 | 0.999 | 0.999 | 0.999 |
| Complete Vehicle | (0.688) | (0.843) | (0.696) | (0.847) | (0.628) | (0.783) |

Table 4.10-1

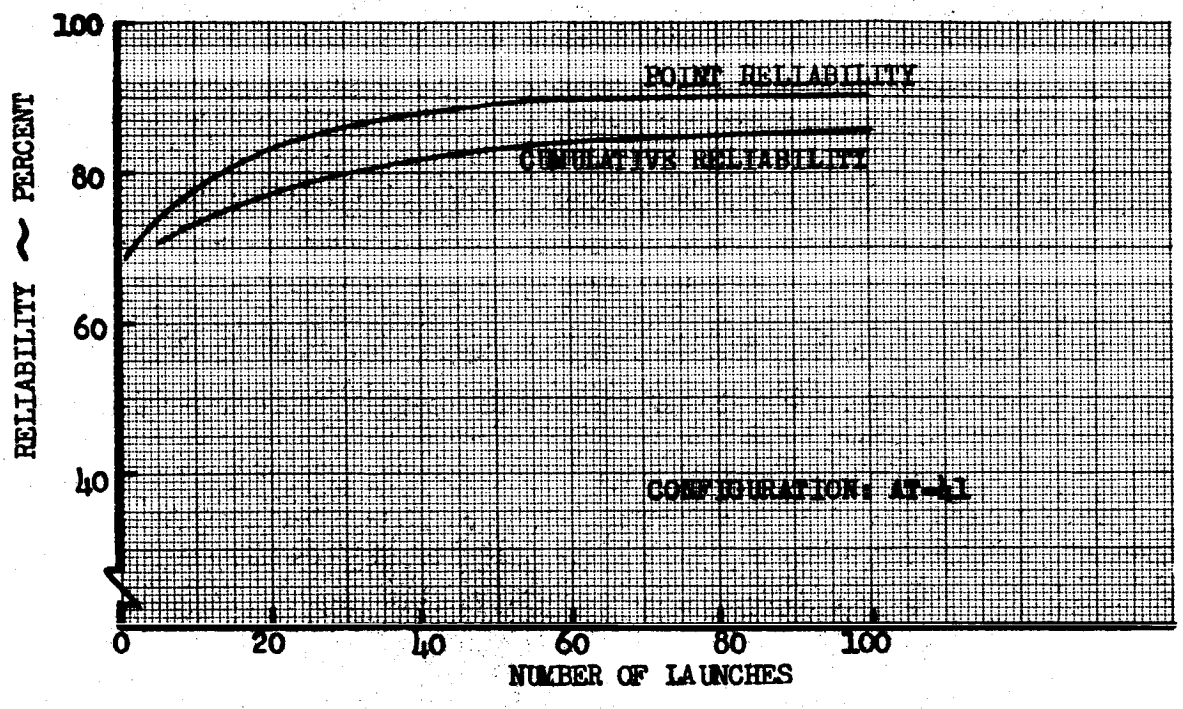



Figure 4.10-1 SOLID NOVA RELIABILITY GROWTH

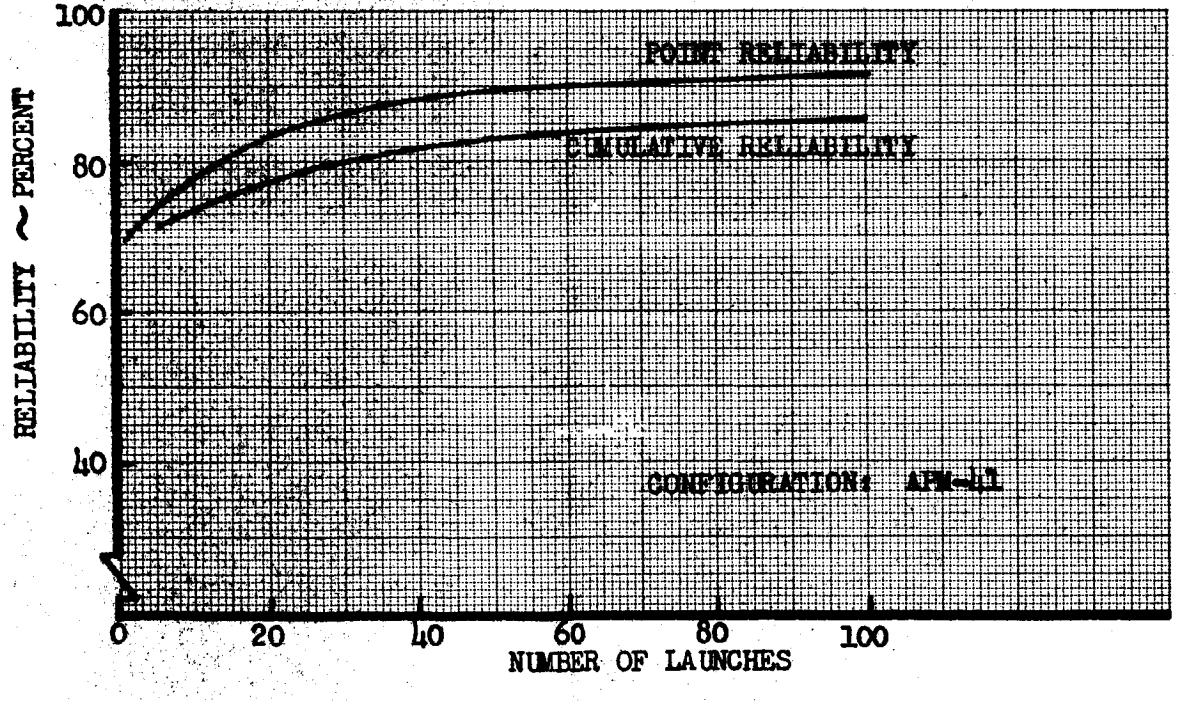



Figure 4.10-2 SOLID NOVA RELIABILITY GROWTH

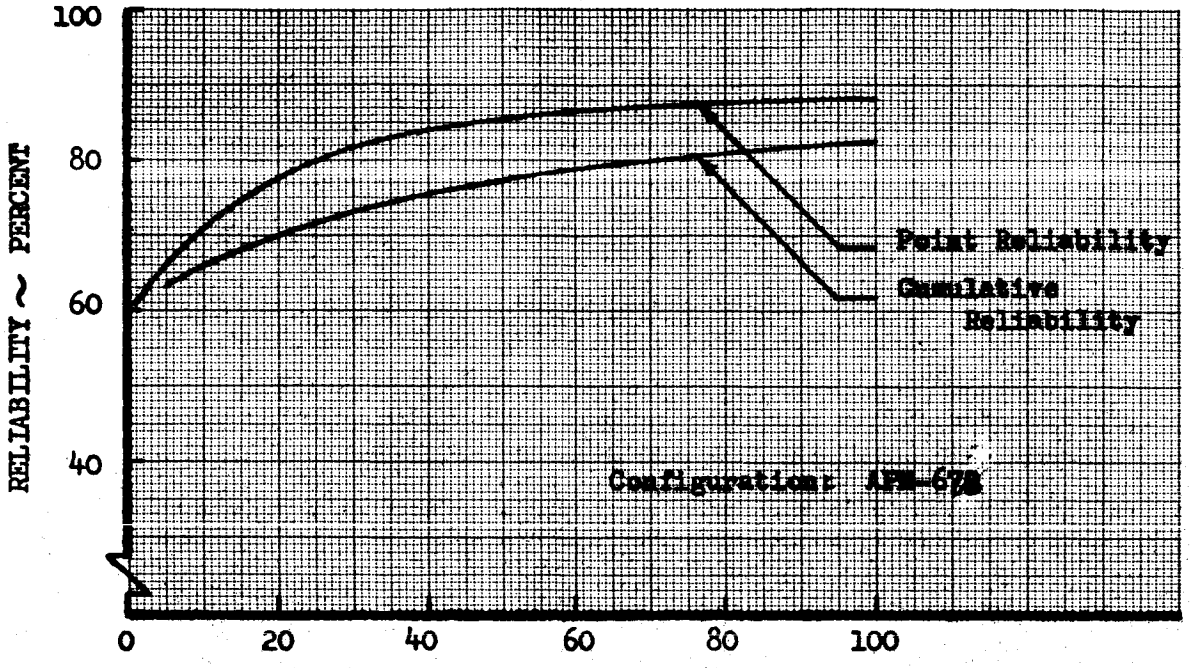



Figure 4.10-3 SOLID NOVA RELIABILITY GROWTH

## 4.10.6 R&D Flight-Test Launches

The expected number of flights to be attempted to achieve the flight test objectives was determined using the cumulative reliability growth curves for each of the vehicle systems. Table 4.10-2 shows the total number of launches required to achieve these objectives. The baseline T65 vehicle is shown for comparison.

FLIGHT-TEST LAUNCHES

| Configuration | Successful Flights to Meet Test Objectives | Expected Number of Attempted Launches |
|---|---|---|
| T65 | 7 | 12 |
| AT-41 | 7 | 10 |
| APM-41 | 9 | 13 |
| APM-67B | 9 | 14 |

Table 4.10-2

### 4.10.7 Initial Operational Reliability

Study ground rules require an initial operational reliability for each vehicle of at least 0.75. The point reliability growth curve was used to determine the expected number of flights prior to an initial flight reliability of 0.75. These values are shown in Table 4.10-3. The baseline T65 vehicle is shown for comparison.

EXPECTED NUMBER OF FLIGHTS PRIOR TO AN INITIAL OPERATIONAL RELIABILITY OF 0.75

| Configuration | Attempted Launches |
|---|---|
| T65 | 13 |
| AT-41 | 7 |
| APM-41 | 6 |
| APM-67B | 15 |

Table 4.10-3

### 4.10.8 Operational Launch Successes

The vehicles were evaluated on the basis of the number of successful launches expected from a 79-launch program. The number of expected successes was determined using the cumulative reliability growth curves for each configuration. These values are shown in Table 4.10-4. The baseline T65D vehicle is shown for comparison.

EXPECTED NUMBER OF FLIGHT SUCCESSES IN 79-LAUNCH OPERATIONAL PROGRAM

| Configuration | Flights |
|---|---|
| T65 | 68 |
| AT-41 | 69 |
| APM-41 | 70 |
| APM-67B | 67 |

Table 4.10-4

## 4.11 MANUFACTURING EVALUATION

The advanced-technology configurations (AT-41, APM-41, and APM-67B) were evaluated and compared with the baseline configuration (T65C). (See Table 4.11-1.)

### 4.11.1 Evaluation Criteria

The following criteria were used to determine which vehicle configuration was most producible:

- Minimum manufacturing manhours;
- Earliest availability;
- Least technical and developmental risk.

### 4.11.2 Manufacturing Plan

The general manufacturing plan, covered in Sections 3.1.7, 3.2.8, and 3.4, is applicable for manufacture of the advanced-technology configurations. No change in technology, such as larger sheet size, was considered in this study. The general plan to use the largest sheet size commercially available was used so that flow time or technical risk was not increased. Maximum sheet size was based on 12-foot width and 10,000-pound billet. The major variables were length, number of engines, type and size of engines, weight, and method of staging. Each vehicle is briefly discussed below.

#### 4.11.2.1 AT-41

Stage I — Quantity of four medium-length solid-booster motors of medium weight having least-complex clustering structure.

Stage II — Short length; moderate weight with one large liquid engine; tandem staging; long development time for engine.

#### 4.11.2.2 APM-41

Booster Stage — Quantity of four short-length, lightweight, solid-booster motors with more complicated lateral staging.

Sustainer Stage — Moderate length; light weight with one large liquid engine; more complicated lateral staging and long-lead-time engine.

#### 4.11.2.3 APM-67B

Booster Stage — Quantity of six medium-length, medium-weight, solid-booster motors with most-complicated parallel staging.

BLANK

MANUFACTURING EVALUATION

| CONFIGURATION NUMBER | FIRST STAGE (BOOSTER) | | | | | | SECOND STAGE (SUSTAINER) | | | | | | COMBINED FIRST AND SECOND STAGE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Case Length (feet) | Weight (pounds) | No. Eng. | Flow Time to First Launch | Facil. & Equip. | Rank | Length Less Engines (feet) | Weight | No. Eng. | Flow Time to First Launch | Facil. & Equip. | Rank | No. 1 Wt. Rank | Flow Time Rank | Mfg. Cost Rank | Remarks |
| T65C | 156 | 2,757,000 | 6 | May 69 | $ 15M<br>$ 20M | 1.06 | 157 | 735,150 | 5<br>M-1 | July 69 | $ 60M<br>$ 15M | 1.93 | 2.99 | 1 | 4 | Test stand is pacing item |
| AT-41 | 125 | 1,332,000 | 4 | Nov. 74 | $ 15M<br>$ 20M | 0.61 | 169 | 695,800 | 1<br>L-<br>9.35H | April 75 | $ 60M<br>$ 15M | 1.93 | 2.54 | 3 | 1 | Single large liquid engine is pacing item |
| APM-41 | 85 | 817,000 | 4 | April 75 | $ 15M<br>$ 20M | 0.35 | 181 | 619,540 | 1<br>L-<br>9.5H | April 75 | $ 60M<br>$ 15M | 2.25 | 2.60 | 4 | 2 | Single large liquid engine is pacing item |
| APM-67B | 103 | 1,295,000 | 6 | Dec. 69 | $ 15M<br>$ 20M | 0.51 | 205 | 784,930 | 6<br>M-1<br>(mod) | Dec. 69 | $ 60M<br>$ 15M | 2.44 | 2.95 | 2 | 3 | Test stand is pacing item |

Table 4.11-1

Sustainer Stage — Greatest length; heaviest weight with six medium-sized liquid engines using most-complicated parallel staging.

4.11.2.4 T65C

Stage I — Quantity of six longest and most-heavy solid-booster motors with simple tandem staging.

Stage II — Moderate length and weight with seven moderate-sized liquid engines using least-complicated tandem staging.

The order of rank by flow time from best to worst is: T65C, APM-67B, AT-41, APM-41.

The order of rank by manufacturing cost is: AT-41, APM-41, APM-67B, T65C.

## 4.12 MANUFACTURING FACILITIES

The following is a general analysis of the manufacturing facilities required for the advanced-technology concepts. Generally, the advanced concepts do not present different facility problems than the baseline configuration (T65C), but only encounter different magnitudes of the same problems. One exception to this is the use of a large high-pressure engine on two of the configurations. This extremely large item will require facilities that are not presently available and were not required for the baseline configurations.

### 4.12.1 AT-41

The reduced number of first-stage cases and the shorter length of this stage with respect to the T65C will reduce the facility requirements for the motor case, nozzle, and propellant plants. The solid-propellant material-preparation and mixing requirements are approximately one-half of those required for the baseline configuration. Casting, finishing, and storage facilities would also be reduced both in number and size.

The reduced number and shorter length of the solid motors would decrease the requirements at the solid-motor substage assembly facility. Storage positions would be reduced in number, the buildings for substage assembly could be reduced in size, and the overall site-support facilities would be similarly reduced.

The facility requirements for second-stage hardware would be approximately the same as required for the T65C since the tank diameter remains unchanged and the length does not change significantly. However, completely new second-stage engine facilities would be required to accommodate the extremely large single engine. This would include completely new static-firing facilities for the engine.

### 4.12.2 APM-67B

The booster motors for this configuration are slightly reduced in length and total amount of propellant required compared to the T65C. This would create slight reductions in requirements at the motor-case facility and the motor manufacturing plant. No reduction would be experienced at the nozzle manufacturing facility. A slight reduction in requirements could be obtained at the solid-motor substage assembly facility from the reduced quantity and distance requirements, and decreased length of the solid motors.

The increased length of the sustainer stage over the T65C would require minor increases in building height for the stage manufacturing plant in those areas where vertical assembly, cleaning, and testing would be accomplished. No change would be required for the engine manufacturing and test facilities for the sustainer-stage engine.

The clustering structure for the parallel-staged vehicle would require more area for assembly but should still be within the capability of existing facilities since it could be manufactured and shipped in sections.

### 4.12.3 APM-41

This configuration would have requirements for booster motor manufacturing similar to the AT-41 vehicle since the number and length of the solid motors are also reduced. Here again, the first-stage motor case, nozzle, and propellant plants would have proportionately reduced requirements.

The sustainer-stage requirements are also approximately equivalent to those for the AT-41 second stage. The stage tankage and structure would have similar requirements to those for the baseline configuration, and the engine facility requirements would be entirely new because of the large single engine.

Clustering structure for this vehicle would consist of small individual links attached to the basic vehicle structure. Existing facilities would have the capability of producing these items.

## 4.13 GROUND SUPPORT CONSIDERATIONS

### 4.13.1 Introduction

Preliminary launch support and assembly concepts were developed for the three advanced-technology vehicle configurations. The configurations were then qualitatively evaluated on the basis of these concepts to determine their relative merit from a ground support standpoint. The baseline current-technology vehicle was similarly evaluated for comparison with the advanced-technology vehicles. The items considered in the evaluation and the evaluation results form the combined effort of Martin-Denver and Boeing.

### 4.13.2 Summary

Of the four vehicle configurations evaluated, AT-41 is the most desirable and APM-41 is second by a small but significant margin, with both substantially more desirable from ground support considerations than T65C and APM-67B. The features favoring AT-41 include the major items of simpler vehicle-launch support interface, lighter and simpler support structure, better exhaust control, and lighter and simpler flame deflector. The advantage of AT-41 for these items is substantial.

Features favoring APM-41 include the major item of least indicated overall cost and the minor items of least total liftoff thrust, smallest solid motors, smallest overall launch building height, and least explosive equivalent. The advantage of APM-41 in thrust level, explosive equivalent, and launch building height is very small, but the advantage in motor size is significant.

As the advanced-technology vehicles and their ground support requirements become more clearly defined, trade studies should be made to verify or modify the conclusions stated herein.

### 4.13.3 Launch Support Interface and Vehicle Assembly Concepts

Vehicle AT-41 will be erected, aligned, and supported in the same manner as the previous four-motor 500K-payload study vehicle (see Reference 4). The vehicle-launch support interface will consist of a system of 12 jacks, three under each motor. The jacks and support platform beams will be increased in size to handle the larger loads. The launch platform and flame deflector will be similar to the design in the previous study, including the center column.

Vehicle APM-67B will be supported by a system of 18 jacks carried by six individual piers as shown in Figure 4.13-1, with each motor supported by three jacks. It is assumed that the main vehicle structural ties are shear blocks between each motor and the liquid sustainer stage so that the jacks may also support the sustainer stage through the solid-motor base-skirt extension. Using this support concept, the solid motors will be erected first

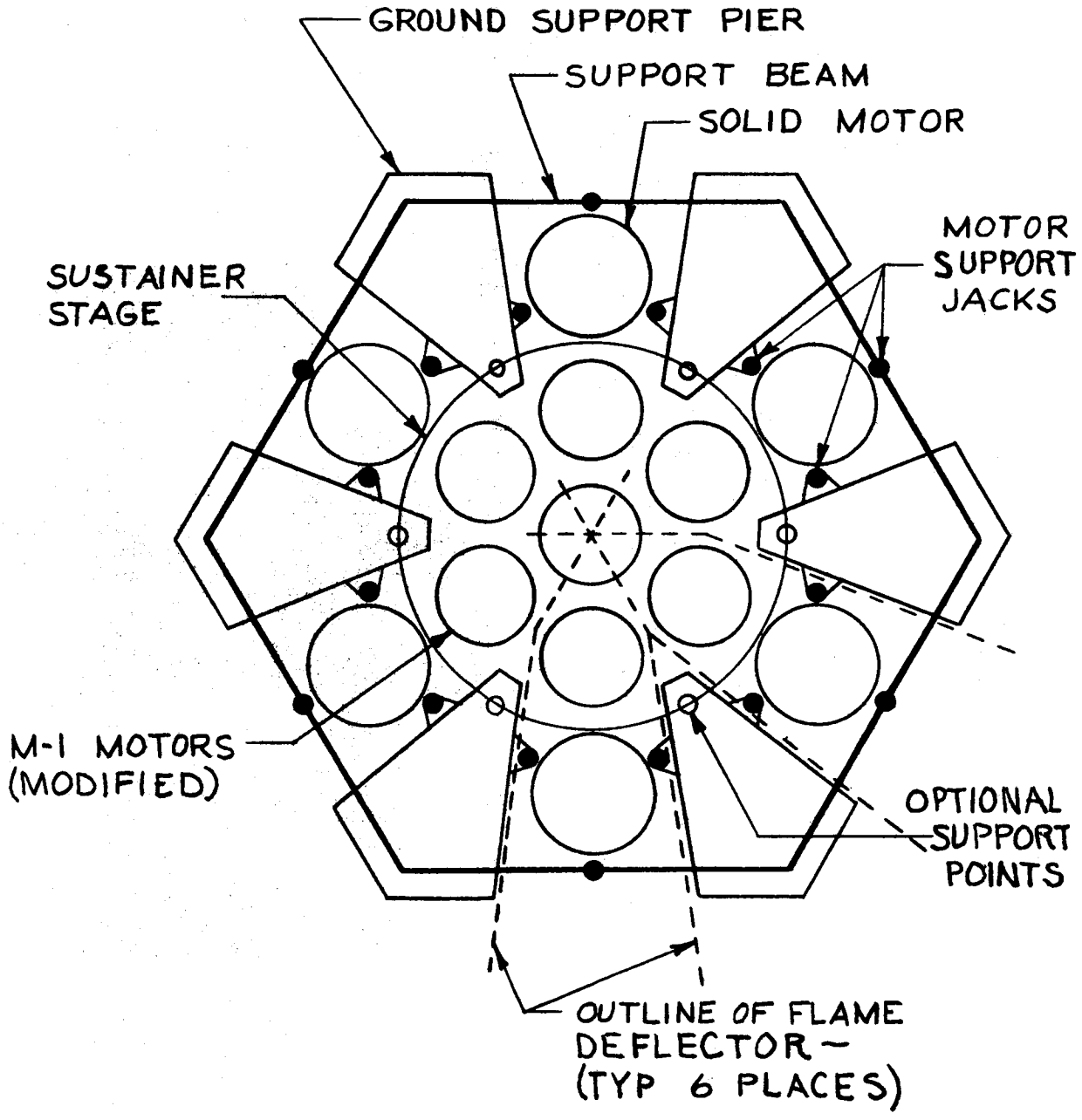



Figure 4.13-1 SUPPORT STRUCTURE CONCEPT
Configuration APM-67B

and aligned. The sustainer stage will then be lowered between the motors, engaging the guide rails, until it rests on the solid-motor shear blocks.

The jacks will be carried by brackets on the piers and by beam structures spanning between the piers. Six piers will be used to minimize beam spans and deflections and to ensure adequate lateral rotational stiffness of the support structure as a whole.

Six separate and independent flame deflectors will be used, one for each solid motor, with the deflector profiles continuous to the centerline of the vehicle to deflect the liquid engine exhaust. The deflector sidewalls will also project inward until adjacent walls meet to furnish maximum protection to the support piers. Such a deflector results in a much higher launch structure and a greater refurbishment problem. Each deflector will be removable from its position between two adjacent piers for refurbishment and to allow access for motor handling equipment.

As an alternate solution, the center sustainer stage can be supported directly by six adjustable jacks or wedges mounted on the support piers. This concept will allow the sustainer stage to be installed on the platform prior to erection of the solid motors.

Vehicle APM-41 will be erected, aligned, and supported on a system of 12 adjustable jacks supported by two parallel sidewalls as shown in Figure 4.13.2. Each solid motor will be supported by three jacks. The liquid sustainer engine will be supported by the solid motors through their attaching structure. In using this support concept, it will be necessary to erect and align the solid motors first. The sustainer stage will then be lowered between the solid motors until it rests on the solid-motor attaching structure. The jacks will be carried by brackets on the sidewalls and by beam structures spanning between the walls.

A two-way flame deflector with its crest at the centerline of the vehicle will be used. The deflector will be designed to separate along the crest so that it can be removed from under the platform in two parts. The crest of the deflector will be designed as an expendable ablative shield to protect the primary deflector structure and to minimize refurbishment. The deflector sidewalls will project upward sufficiently high to minimize exhaust impingement damage to the side walls. Such a deflector results in a relatively high launch platform and magnifies the refurbishment problem.

### 4.13.4 Ground Support Evaluation

The three advanced-technology configurations (AT-41, APM-67B, and APM-41) and the baseline current-technology configuration (T65C) were qualitatively evaluated with respect to the following items affecting ground support requirements of the vehicles.

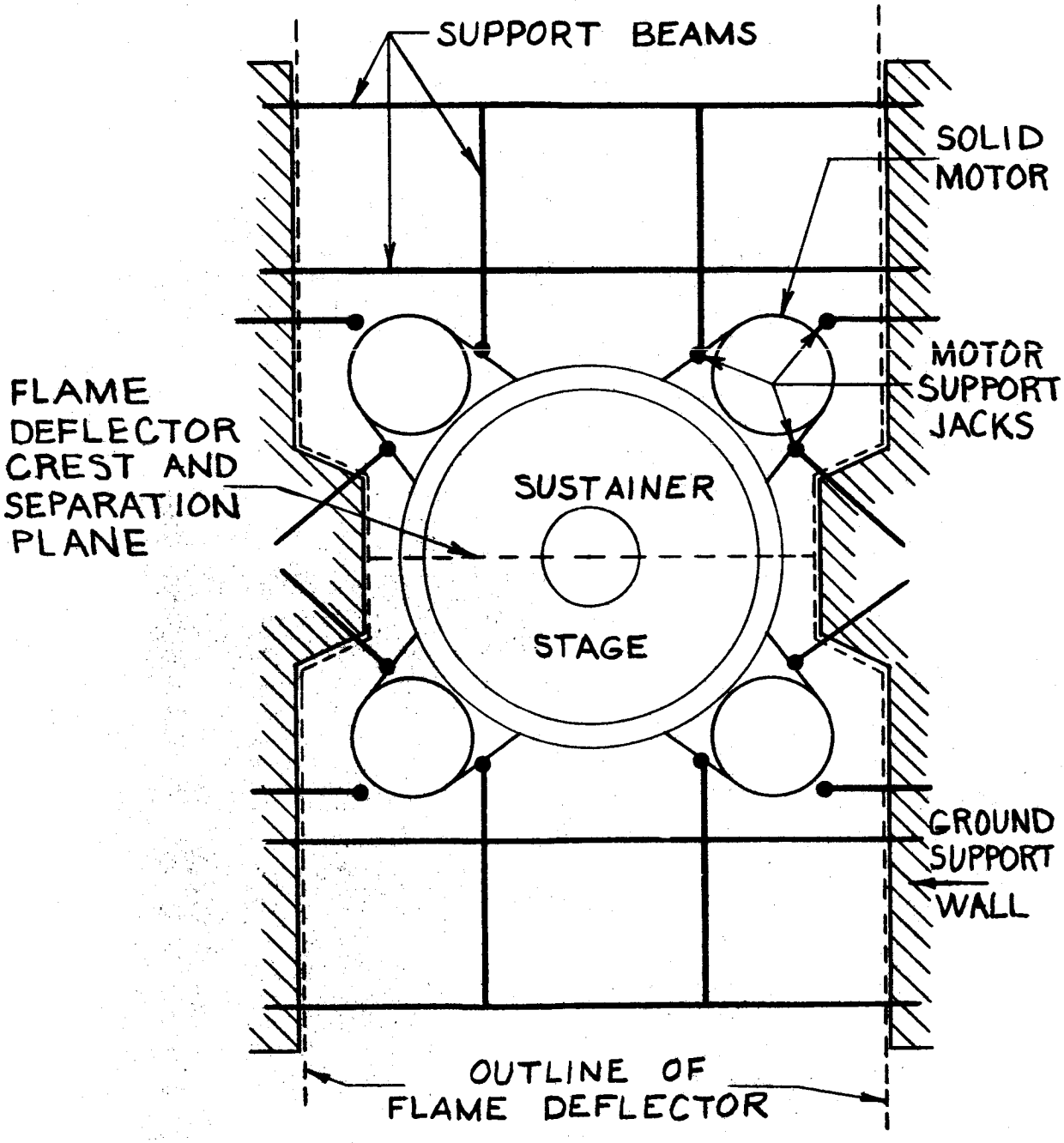



Figure 4.13-2 SUPPORT STRUCTURE CONCEPT
Configuration APM-41

#### 4.13.4.1 Vehicle-Launch Support Interface

Twelve support jacks are used for T65C, AT-41, and APM-41, but the interface with the tandem vehicles is simpler because of the compact motor cluster and the absence of a center engine. More jacks are required for APM-67B, and T65C is considerably heavier. Therefore, AT-41 is rated best in this category.

#### 4.13.4.2 Launch Support Structure Size and Complexity

The compactness of the motor cluster and the absence of a center motor on AT-41 and T65C results in a simpler and smaller support structure. The grossly greater weight of T65C will offset any advantage due to its compactness and AT-41 is rated best by a wide margin.

#### 4.13.4.3 Size and Complexity of Flame Deflectors and Effects of Exhaust Impingement

The compactness of the motor cluster on the tandem vehicles results in a smaller flame deflector. The absence of a center engine eliminates exhaust impingement on the crest of the deflector, thereby simplifying the deflector and reducing refurbishment required. Furthermore, the four-motor arrangement requires the least flame-deflector height. Because of a lower liftoff thrust than T65C, AT-41 is rated best and has a great advantage over APM-41.

#### 4.13.4.4 Launch Building Height

The overall length of the parallel-staged vehicles is considerably less than that of the tandem-staged vehicles, thereby resulting in a lower launch building. This is partially offset by the requirement for higher flame deflectors for the parallel-staged vehicles. Further offsetting the height advantage of the parallel-staged vehicles, is their much greater overall diameter resulting in much greater beam and crane spans. Vehicle APM-41, although requiring greater building spans, results in the lowest launch building and therefore is rated the best, but only by a very small margin over AT-41.

#### 4.13.4.5 Complexity of Vehicle Assembly Operations

The differences in the complexity of assembly of the vehicles at the launch site are so small that no choice can be made.

#### 4.13.4.6 Complexity of Solid-Motor Handling and Transportation

Weight and size of the individual motors determine the complexity of handling and transporting the solid motors. Vehicle APM-41 has the smallest solid motors and is therefore rated best.

4.13.4.7 Acoustic Effects

The acoustic power level is basically determined by the total liftoff thrust of the vehicle. Since APM-41 has slightly less thrust than AT-41 it is rated best by a slight margin.

4.13.4.8 Explosive Equivalent of Propellant Load

The explosive equivalent of the vehicle propellant is determined by the total propellant load. Vehicle APM-41 has a slightly smaller propellant load than AT-41 and therefore is rated best by a small margin.

4.13.4.9 Potential for Using a Mobile Assembly and Launch Concept

Both AT-41 and APM-41 are within the weight capability of mobile transporter-launchers. Since the weight difference between the two is small and mobile assembly and launch of solid-motor-boosted vehicles have been ruled out of the present study, no choice is made.

4.13.4.10 Potential for Using Base or "Liftoff" Umbilical Connections

A potential exists for use of liftoff-type umbilical connections located at the base of the parallel-staged vehicles. Upper-stage umbilicals would, however, still be required to service the spacecraft so that any net advantage is insignificant and no basis for a choice exists.

4.13.4.11 Access to Critical Components for Servicing

Servicing of the parallel-staged vehicles may be slightly simplified because of slightly easier access to critical vehicle compartments. The advantage of this is insignificant, because convenient access to all vehicle levels must be provided in any case. In addition, the concentration of work at one level could possibly cause congestion in the area, which would actually delay the servicing work. The use of a single sustainer engine should decrease the amount of time required to service the engine as compared to performing the same type of function on a number of engines. However, major problems in the single-nozzle large-thrust engine would develop in servicing, maintenance, and starting requirements. Testing and alignment of the flight control system could present major problems. It is apparent that no logical basis for a choice exists in this category.

4.13.4.12 System Cost

Considering all aspects of the ground support system, including support structure, launch building, flame deflector, refurbishment of launch area structures, real estate requirements, transportation and handling, assembly and checkout, and many other items, total system costs tend to favor vehicle APM-41.

### 4.13.5 Conclusions

Upon consideration of all items above, taking into account the degree of advantage offered by one vehicle over another for each item and considering the significance of each item itself, vehicle AT-41 is selected as the most favorable configuration. Vehicle APM-41 is rated second by a small but significant margin. Vehicles T65C and APM-67B are approximately equal to each other — both being substantially less desirable than the others.

## 4.14 DEVELOPMENT TEST REQUIREMENTS

### 4.14.1 General

This section summarizes the development test requirements for NOVA advanced-technology vehicle configurations APM-67B, APM-41, and AT-41. These test requirements cover the four major tasks in the systems testing program for each vehicle.

- Stage-development static firings
- Flight-test stage-acceptance static firings
- Flight-test vehicle assembly and test
- Flight tests

This discussion does not include test requirements for the development activities preceding the systems testing portion of the program.

The systems testing requirements are discussed in broad terms only, to identify major aspects of the development requirements and to provide bases for comparison between the three advanced-technology configurations and the T65C current-technology configuration. Summary schedules indicating milestones and general program phasing are presented in Section 4.15.

### 4.14.2 Stage-Development Static Testing

The development static testing will fulfill four basic test requirements:

- Integration of the liquid rocket engine and accessories with the stage structure and associated propulsion system equipment
- Evaluation of performance and function of the integrated propulsion system
- Evaluation of performance and function of the complete flight stage, including all airborne systems
- Reliability demonstrations and evaluation of design refinements

The development static firings of the liquid stage must be phased into the overall development program so that a sufficient number of static firings

may be accomplished to establish confidence in propulsion system integrity and in general stage flightworthiness prior to acceptance captive firing of the first flight stage and the first flight test, respectively.

### 4.14.3 Flight-Test Stage-Acceptance Static Firings

The stage-acceptance static-firing tests will be conducted to verify the functional integrity of the propulsion system and other airborne systems during countdown and simulated launch and flight. These tests will complement other nonfiring stage-acceptance tests conducted before and after the static tests.

### 4.14.4 Flight-Test Vehicle Assembly and Test

These operations will consist of systematic assembly and checkout of the flight-test vehicle, culminating in simulated countdown and launch to verify launch readiness of the integrated vehicle.

### 4.14.5 Flight Tests

Flight tests will be conducted to evaluate the performance of the complete flight vehicle in its intended mission.

### 4.14.6 Summary of Test Requirements

In general, the development test requirements for the APM-67B, APM-41, and AT-41 are very similar to those for the T65C. The major difference in the program will lie in the relative phasing of the various tasks.

The transtage test requirements will be the same for all stages and relative phasing of the development tasks will be approximately the same.

The large liquid stages for the advanced-technology configurations are similar in size to the T65C second stage, and the same general test requirements for stage development static firings and acceptance static firings will apply. The relative phasing will vary, however, since the AT-41 liquid stage is a second stage and APM-67B and APM-41 liquid stages are "first" stages. Also, it is estimated that the APM-41 and AT-41 stages employing the expansion-deflection engine will require a greater interval between start of development static test and start of acceptance static test than will the APM-67B stage employing modified M-I engines.

The prelaunch assembly-and-test requirements for the various vehicles will pose slightly different facility and equipment requirements; however, the processing time should be approximately the same for all vehicles.

The flight-test requirements for the vehicles are generally the same; however, it is estimated that the parallel-staged APM-67B and APM-41 vehicles will

require more flights than the tandem-staged AT-41 and T65C to fully evaluate the combined solid-liquid boost phase and the staging sequence.

## 4.15 DEVELOPMENT PROGRAM

### 4.15.1 Introduction

The comparison schedule for advanced-technology NOVA vehicles is based on the following assumptions:

- Contract go-ahead is assumed to be July 1, 1964.
- Sustainer or second stage R&D engine delivery is January 1971, and PFRT engine delivery is January 1972. PFRT development time will be interpolated from NASA Memo M-P&VE-PA-29-63 dated January 15, 1963.
- R&D modified M-1 engine delivery is January 1, 1967, and PFRT delivery is July 1, 1967.
- Solid booster development for the APM-67B, APM-41, and AT-41 requires the same development time as for the T65C.
- Propulsion, dynamic, and structural vehicle-development testing will be performed at the Mississippi Test Facility.
- Flight tests will be accomplished at the AMR complex, utilizing new launch buildings and facilities.
- Water transportation will be utilized for transportation of the stages to the Mississippi Test Facility and AMR.
- After acceptance captive firing is complete, the liquid sustainer (APM-41 of APM-67B) or second stage (AT-41) will be transported back to the manufacturing site for refurbishing before shipment to AMR.
- APM-67B will require a total of 14 launches, of which nine must be successful. All 14 launches will require live solid-booster and liquid-sustainer stages.
- APM-41 will require 13 launches, of which nine must be successful. All 13 launches will require live solid-booster and liquid-sustainer stages.
- AT-41 will require 10 launches, of which seven must be successful. The first launch will utilize dummy second and upper stages. The second launch will require a live second stage.

### 4.15.2 Comparison Schedule

The APM-67B, APM-41, and AT-41 programs are developed on a summary schedule basis for the purpose of comparison (see Figure 4.15-1). The solid booster stage development and schedule for the advanced-technology NOVA configurations are the same as for the first-stage solid booster of the T65C.

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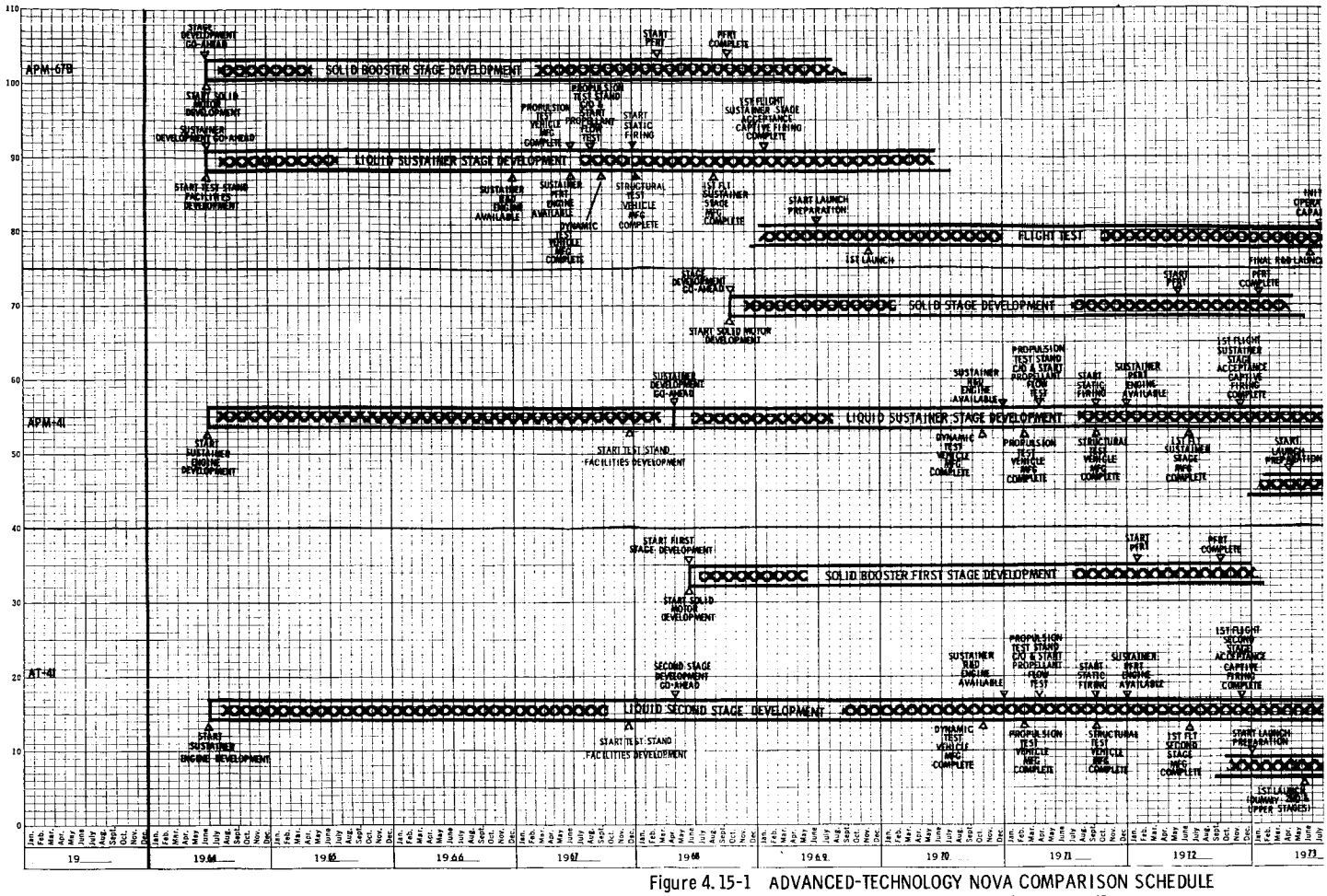
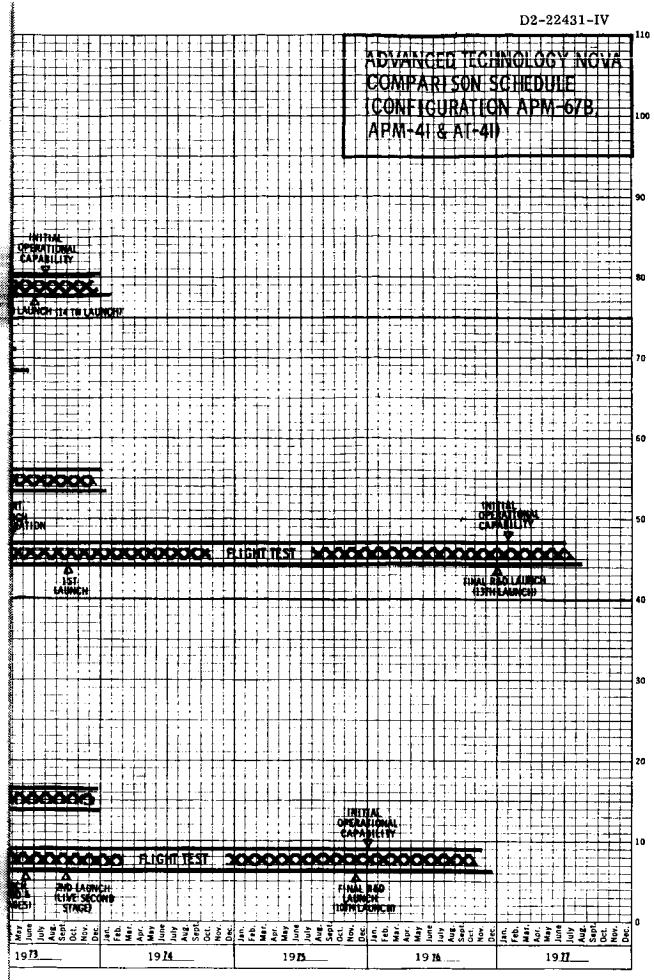



Figure 4.15-1 ADVANCED-TECHNOLOGY NOVA COMPARISON SCHEDULE
Configurations APM-67B, APM-41, and AT-41


ADVANCED TECHNOLOGY NOVA
COMPARISON SCHEDULE
(CONFIGURATION APM-67B,
APM-41 & AT-41)
INITIAL OPERATIONAL CAPABILITY
LAUNCH 114 TO LAUNCH
INITIAL OPERATIONAL CAPABILITY
FLIGHT TEST
1ST LAUNCH
FINAL BAD LAUNCH (33TH LAUNCH)
INITIAL OPERATIONAL CAPABILITY
FLIGHT TEST
2ND LAUNCH (LIVE SECOND STAGE)
FINAL BAD LAUNCH (10TH LAUNCH)
110
100
90
80
70
60
50
40
30
20
10
0
1973
1974
1975
1976
1977

The major milestones for comparison of the three configurations are:

- Initial operational capability
- Test-stand availability
- Liquid-engine availability

The latter two major milestones are discussed in the appropriate configuration schedule analysis.

APM-67B has the earliest initial operational capability of the advanced-technology NOVA configurations — nine years after development go-ahead in July 1964 or mid-1973 initial operational effectivity. APM-41 initial operational capability occurs the latest of the three configurations — early 1977, or 12.5 years after start of engine development in July 1964. Initial operational capability for the AT-41 occurs in early 1976 — 11.5 years after start of engine development.

4.15.2.1 APM-67B Schedule Analysis

The APM-67B NOVA liquid-sustainer-stage development and schedule are compatible with the current-technology T65C NOVA liquid second stage. The associated schedule problem of the APM-67B is the 38-month development time for the liquid-stage propulsion test stand. The test-stand critical development time restricts the earliest scheduling of propulsion system development testing by 6 months (i.e., the propulsion test vehicle can be completed at the time that the R&D engines are available, thereby allowing the "Propulsion Test Stand Checkout" and "Start Propellant Flow Test" milestones to commence in February 1967.

Present planning requires a minimum of 9 months of liquid-propulsion-developmental-system static firing to fulfill the basic test requirements (see Sections 3.6.3, 3.3.5, and 4.14.2). In essence, developmental static firing is phased into the program to accomplish a sufficient number of static firings necessary to establish confidence in propulsion system integrity and in the general stage flightworthiness prior to acceptance captive firing of the first flight stage.

For further detail analysis and schedule understanding, the "Start Static Firing" milestone is scheduled 8 months before the first flight sustainer stage (APM-41) or second stage (AT-41) "Manufacturing Completion" milestone. Accomplishment of the "Manufacturing Completion" milestone includes factory acceptance testing. After the "Manufacturing Completion" milestone, shipping the stage to the Mississippi Test Facility and installation of the stage on the test stand require an additional month, at which time propulsion-system development testing will have been through a total of 9 months of static firing before the start of acceptance captive firing of the first-flight liquid stage.

Finally, it should be noted that either the R&D or the PFRT modified M-1 engines could be employed on the initial propulsion test vehicle. For R&D

engines (available January 1967), installation and checkout are accomplished prior to the propulsion test vehicle "Manufacturing Completion" milestone. For PFRT engines (available July 1967), installation of the engines can be accomplished after manufacturing completion including factory acceptance test. By this method, an adequate time of 6 weeks (exclusive of shipping time) exists for PFRT engine installation and checkout between the "Propusion Vehicle Manufacturing Complete" and "Propulsion Test Stand Checkout" and "Start Propellant Flow Test" milestones.

Furthermore, during the development of the test-stand facilities, effective program control management may establish an earlier availability of the test stand, thereby resulting in optimum scheduling and utilization.

4.15.2.2 APM-41 and AT-41 Schedule Analysis

The APM-41 and AT-41 require the same development time for vehicles, associated facilities, liquid-propellant-stage launching employment, and engine development. The configurations both employ the Rocketdyne hydrogen-fueled expansion-deflection engine; therefore, for each program, the first delivery of the R&D engine is January 1971 (6.5 years after engine development) and first delivery of the PFRT engine is January 1972 (7.5 years after engine development). Engine development go-ahead occurs in July 1964.

To obtain the earliest propulsion system development test, R&D engines are installed on the propulsion test vehicle. The liquid sustainer stage (APM-41) and second stage (AT-41) "Manufacturing Competion" milestones occur 9 months after the "Start Static Firing" milestone. This phasing sequence enables a minimum of 9 months scheduled static firing (see APM-67B schedule analysis for basic test requirements reference) before starting the acceptance captive firing. With the propulsion system development test schedule requirement, earlier manufacturing completion of the liquid sustainer stage (APM-41) or liquid second stage (AT-41) is not feasible.

It should be noted that AT-41 first launch is 4 months earlier than the APM-41. The earlier AT-41 launch is a result of:

- The tandem configuration
- First-flight dummy second and upper stages
- Timely availability of the solid-booster first stage

The AT-41 second launch, with live second stage occurs at the same time as the APM-41 first launch. This being the case, the liquid stages for both programs are compatible.

## 4.16 CONFIGURATION EVALUATION

### 4.16.1 Introduction

The vehicle systems described in Section 4.3 for advanced-technology vehicle configurations AT-41, APM-67B, and APM-41 are evaluated in this section. Criteria for evaluation are performance, producibility, development risk, growth potential, reliability, operational availability, development cost, and cost effectiveness. The method of analysis is described in Section 3.1.15. The advanced vehicles are compared with the T65D configuration. The purpose of the advanced-technology vehicle studies is to indicate advantages that may accrue from a longer developmental time period.

### 4.16.2 Summary

The three advanced-technology configurations were analyzed and compared on the basis of eight evaluation criteria. These configurations were further compared to the T65 baseline current-technology configuration to show the areas that may improve with advancements in technology possible from the later schedules.

The APM-41 configuration, which was selected as the most desirable vehicle, offers advantages in performance, growth potential, development cost, and cost effectiveness when compared with the T65D.

### 4.16.3 Criteria

The weighting of the individual criteria for the advanced configurations will differ from that used in evaluation of the preliminary configurations (Section 3.1.15) because of the program objectives. The advanced vehicles will not be available until 1 to 5 years later than the T65D. Therefore, the advanced configurations cannot meet a 1975 Mars window.

Major emphasis in consideration of advanced configurations is placed on advantages which may warrant program delay or result from deferment of a decision to start program implementation. However, the accuracy with which values for development, time, and cost can be estimated decreases with increase in length of time being considered.

The pacing item in the AT-41 and APM-41 advanced configurations is the engine development program. Deferring a decision for the vehicle program implementation until a later time will not delay the possible operational date.

### 4.16.4 Evaluation Criteria

The comparative rating for each vehicle configuration is accomplished by using eight systems-evaluation criteria. The considerations used to assign the quantitative and qualitative values are discussed in 3.1.15.3 for each evaluation criterion. The cost effectiveness and performance criteria differ slightly from those in 3.1.15.3. The cost effectiveness criterion is evaluated on the basis of a 79-launch operational program instead of the 140 launches used in the current-technology evaluation. The performance and cost effectiveness criteria are evaluated using the effective payload to a 225-kilometer orbital altitude instead of a 567-kilometer altitude.

### 4.16.5 System Evaluation and Selection

A matrix of the system evaluation criteria and the vehicle configuration is shown on Table 4.16-1. The AT-41 and APM-41 vehicle configurations are rated best in performance, growth potential, development cost, and cost effectiveness. The APM-41 is rated better in these areas than the AT-41. However, the APM-41 has a higher development risk and a later operational date (February 1977) than any other vehicle configuration being evaluated. The APM-41 vehicle is a parallel-staged configuration that will require a larger launch pad installation. The advantages of reducing the vehicle height and the disadvantages of increasing the size of the launch pad for the parallel-staged configurations are discussed in Section 4.13.

The AT-41 vehicle configuration has the second best cost-effectiveness rating, but also has a high development risk. The risk is lower than the APM-41 because it is tandem staged but is higher than the T65D and the APM-67B configurations because of the large liquid engine.

The APM-41 vehicle configuration is rated the best vehicle if the operational date of February 1977 is acceptable. Additional cost to accelerate the vehicle development has not been considered herein. This would require a new system evaluation using new system study ground rules. The AT-41 vehicle configuration is rated second best with an operational date of January 1976.

SYSTEM EVALUATION MATRIX

| | T65D | AT-41 | APM-67B | APM-41 |
|---|---|---|---|---|
| Performance | | | | |
| $WO_1$ (millions of pounds) | 38.062 | 24.344 | 29.950 | 21.975 |
| Payload/$WO_1$ ratio | 0.0293 | 0.0453 | 0.0368 | 0.0501 |
| Producibility* | 1 | 1 | 3 | 4 |
| Development Risk* | 1 | 3 | 2 | 4 |
| Growth Potential* | 3 | 1 | 2 | 1 |
| Reliability | | | | |
| Operational (Cumulative for 79 launches) | 0.886 | 0.873 | 0.848 | 0.886 |
| Operational Availability | | | | |
| Date of First Operational Vehicle (Start July 1, 1964) | July 1972 | Jan. 1976 | August 1973 | Feb. 1977 |
| Development Cost (billions of dollars) | 3.143 | 2.836 | 3.064 | 2.938 |
| Cost Effectiveness ($/lb Payload) (79 launches) | | | | |
| Operating Cost Effectiveness | 74 | 63 | 70 | 51 |
| Total Cost Effectiveness | 147 | 136 | 143 | 117 |

* Qualitative rating from best (1) to poorest (4).

Table 4.16-1

## REFERENCES

1. DDR-60-128, "Large Plug Nozzle Research Program, Volume I," General Electric Company, July 15, 1960.

2. DDR-60-128, "Large Plug Nozzle Research Program, Volume II," General Electric Company, July 15, 1960.

3. LRP 153 Revision A, "Design Parameters for Large Liquid-Propellant Rocket Engines," Aerojet-General Corporation, August 1, 1960.

4. SSD-TDR-62-144, "Study of Large Launch Vehicles Using Solid First Stages," The Boeing Company, December 1962.

# 5.0 COSTING, FUNDING, AND COST ANALYSIS

## 5.1 INTRODUCTION

This section describes the results of studies performed to determine system costs for the current-technology T65D configuration and for the APM-41, APM-67B, and AT-41 advanced-technology vehicles. Cost summaries have been broken down to show the following cost elements.

- Development cost
- Facilities cost
- Tooling costs
- Ground support equipment costs
- Operational program costs.

Each of these cost elements has been broken down further according to the recommended NASA cost breakdown for NOVA studies.

Total cost summaries show two types of cost estimates:

- Definitive Cost Estimates — based on system production and implementation in accordance with the established designs.
- Budgetary Cost Estimates — based on estimated cost increases over and above the definitive cost estimates, resulting from unpredictable development problems and lack of sufficient detail system definition.

Total cost summaries are shown for:

- T65D Configuration — Four mission models
- Advanced-Technology Vehicles — Mission Model No. 1 only.

Cost effectiveness in terms of dollars per pound of payload in a 225-kilometer orbit has been determined in accordance with "NOVA Operational Mission Model Ground Rules," published January 18, 1963, by the NASA Future Projects Office.

Effects of system cost elements on cost effectiveness are analyzed. Total system costs for the T65D configuration and the advanced-technology configurations are compared and the effects of system cost elements on this comparison are analyzed.

## 5.2 SUMMARY

Table 5.2-1 shows operational program cost and total system definitive and budgetary costs for the T65D vehicle configuration.

COST SUMMARY T65D VEHICLE
(Dollars in Billions)

| | Mission Model Number (see Section 3.3.3) | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Operational Program | 6.322 | 5.094 | 5.700 | 4.539 |
| Total Program | | | | |
| Definitive | 12.645 | 11.411 | 11.455 | 10.283 |
| Budgetary | 14.858 | 13.499 | 13.464 | 12.173 |

Table 5.2-1

Table 5.2-2 shows operational program costs and total system definitive and budgetary costs for the advanced-technology vehicles for Mission Model No. 1.

COST SUMMARY — ADVANCED-TECHNOLOGY VEHICLES
(Dollars in Billions)

| | Vehicle | | |
|---|---|---|---|
| | APM-41 | APM-67B | AT-41 |
| Operational Program | 4.187 | 5.448 | 4.952 |
| Total Program | | | |
| Definitive | 9.703 | 11.056 | 10.847 |
| Budgetary | 12.052 | 13.564 | 13.405 |

Table 5.2-2

Table 5.2-3 shows the cost-effectiveness comparison between the advanced-technology vehicle and the T65D configuration. This comparison is for Mission Model No. 1 only. In accordance with the NASA ground rules, transtage costs were not included in the cost effectiveness comparison.

COST EFFECTIVENESS COMPARISON

| Vehicle Systems | Reliability (Cum Avg) | Definitive Costing* | | Budgetary Costing* | |
|---|---|---|---|---|---|
| | | Total Program ($/lb) | Operational Program ($/lb) | Total Program ($/lb) | Operational Program ($/lb) |
| T65D | 0.886 | 149 | 75 | 175 | 82 |
| AT-41 | 0.873 | 136 | 62 | 168 | 68 |
| APM-67B | 0.848 | 143 | 71 | 175 | 78 |
| APM-41 | 0.886 | 119 | 51 | 148 | 56 |

*Boeing Solid-Motor Cost, Payload Factor = 0

Table 5.2-3

Cost-effectiveness comparisons of the four mission models for the T65D vehicle are shown in Section 5.4, Table 5.4-4. Examination of these data shows an increase in cost effectiveness (decrease in dollars per pound of payload in orbit) with an increase in the number of operational launches.

In general, it was found that vehicle procurement costs had the greatest influence on cost effectiveness.

Comparison of total system costs for the four vehicle configurations (based on Mission Model No. 1 — 79 operational launches) reveals that the current-technology configuration (T65D) shows the highest cost, with the APM-67B, AT-41, and APM-41 vehicles showing successively lower costs. The greatest cost differences result from launch vehicle costs, which appear to be a function of size and weight. Launch vehicle costs account for more than 50 percent of the cost differences between configurations. Other factors affecting cost differences to a lesser extent are development, launch facilities, and launch operations.

## 5.3 PROGRAM COSTING AND FUNDING

The results of the costing studies are presented in this section. Total system costs have been estimated for the T65D vehicle and three advanced-technology vehicles: APM-41, APM-67B, and AT-41. Program cost estimates for the T65D vehicle are given for Mission Models 1, 2, 3, and 4 (see Section 3.3.3). Program cost estimates for the advanced-technology vehicles are given for Mission Model No. 1 only. Fiscal year funding is shown for the T65D system Mission Model No. 1.

Two types of program cost estimates are provided: definitive and budgetary. Definitive cost estimates are based on cost parameters developed from experience with past programs and make no allowance for unforeseen contingencies or major model changes. Definitive cost estimates permit valid cost comparisons among vehicle configurations. Budgetary cost estimates are based on definitive cost estimates, but provide for the cost of contingencies or growth factors that would cause actual program costs to exceed estimated costs. A more detailed description of budgetary costing techniques is provided in Section 5.3.3.

Cost estimates are provided for all phases of the vehicle development and operational program. The only items that have been excluded from this study are the cost of the payload placed in a 225-kilometer parking orbit. The third stage is considered to be part of the payload. Vehicle costs include the first stage, second stage, transtage, and guidance and control package. The cost summaries itemize the costs for development, facilities, tooling and ground support equipment, as well as the operational program. The costs for all facilities and operations at the Atlantic Missile Range have been provided by The Martin Company, Denver Division. These costs have been included as received. A summarized description of AMR facilities as developed by Martin-Denver is presented

in Section 3.3.7. Detailed cost development is provided in Martin document NASA-CR-63-7, "NOVA Launch Facility Study," dated March 1963.

Costs were estimated for each of the major systems and subsystems of the launch vehicle through the use of a cost model programmed for the 7080 computer. This model uses a parametric estimating approach. Scaling factors are programmed into the computer for each of the items listed in the weight statement; thus 30 or 40 major elements can be considered for each stage. It has been found that this approach permits a more accurate result than a cost parameter for a complete stage, because it develops the proper relationship between the various cost elements of the vehicle.

Composite learning curves used in this study for the major subsystems of the vehicle are as follows:

| | Percent |
|---|---|
| Structure | 88 |
| Solid-Motor Case | 88 |
| Nozzle and Insulation | 90 |
| Liquid Engines | 90 |
| Propulsion Subsystem | 88 |
| Electronics | 90 |
| Solid Propellant | 97 |

In applying these learning curves to the costing of the T65D and advanced-technology vehicles, two modifications were used:

- A 95-percent learning curve was used for the entire R&D flight test vehicle.
- A "B" factor was applied to the above learning curves for the operational vehicle because only one-half of the learning gained in the fabrication of the test flight vehicles could be projected for the operational program.

### 5.3.1 Guidelines and Assumptions

The cost estimates in this study are based on the vehicle designs, operational concepts, and statement of work as defined in the previous sections of this document.

The costs are intended to reflect to a federal agency reasonable costs for goods and services. The costs are based on Fiscal Year 1963 prices and do not include escalation over the life of the program. However, the effects of escalation are shown for the T65D configuration, Mission Model No. 1 funding chart (Table 5.3-1) for reference.

The cost of the payload (including the third stage) and those costs peculiar to the payload have been excluded from system cost estimates. Payload loss factors of 0, 10, and 50 dollars per pound were used in calculating cost effectiveness in accordance with NOVA ground rules.

The estimating approach is based on the assumption that the T65D and the advanced-technology vehicles, including the high-pressure liquid engines, can be developed from the current-technology base with no new materials or major breakthroughs required.

Design and development cost for the second stage of the T65D vehicle assumes that the M-1 engine has not been developed.

Definitive costs are based on the assumption of producing the vehicle systems as described, and do not anticipate major model changes. The estimates are intended to cover minor revisions and changes to the specifications.

New tooling and manufacturing facilities will be procured for the production of the R&D vehicles. Because of the cost and size of the tooling and facilities and the requirement for a specified vehicle reliability at the completion of the development program, soft tooling and temporary facilities are considered inadequate.

It is assumed that the solid-propellant manufacturing facility would be located within a few hundred miles of the Cape. The second-stage manufacturing facility would be located on the Gulf Coast with the liquid-engine manufacturing plant on the West Coast and the other manufacturing facilities located in the Northwest, Midwest, and Atlantic Seaboard.

### 5.3.2 Cost Category Glossary

This section provides general definition of items included in each cost category. Each cost category contains all applicable cost elements such as manufacturing labor, quality control, raw materials, purchased equipment, miscellaneous direct expenses, and fee. It has been assumed that such items as R&D launch facilities and initial tooling produced for the R&D program can also be used for the operational program.

#### 5.3.2.1 Engine Design and Development

For the first (booster) stage, this category includes the entire design and development cost for the 260-inch-solid motor (case, liner, nozzle, and igniter) through preflight rating tests (PFRT). Also included are the costs for five full-scale motors to be used in PFRT. The solid propulsion industry has not determined a requirement for full-scale qualification-test motors. It is assumed that the solid propellant will have been essentially developed on previously funded projects and will be available for this program. Costs for additional motor manufacturing facilities are covered in the facilities section of the cost breakdown. Costs for TVC design and development are included with stage R&D.

For the liquid-propellant second (sustainer) stage and transtage, this category includes all engineering and manufacturing cost to design, produce, and test the engine system (pump, chamber, nozzles, and accessories) through PFRT and qualification tests. New manufacturing and testing facilities that would be required are included in the manufacturing facilities category. Liquid propellants required for engine development have been included in the propellants and high-pressure-gases category.

#### 5.3.2.2 Stage Engineering, Design, and Development Testing

This is the accumulation of the estimated cost for stage system analysis, subsystem design and development, integration, and stage development testing.

Required functions included in this category are: requirements analysis, preliminary design, prototype hardware fabrication, prototype testing, production drawings, test unit fabrication, structural testing, and subsystem design verification. Stage integration, including associate contractor liaison and NASA direction during engineering design and development functions, is included.

5.3.2.3 Flight and Ground Test Engines

For the first (booster) stage, flight-test-engine cost is the cost of the solid motors required for the R&D flight-test program. Ground-test-engine cost is the cost of the inert motors used in transportation and handling tests and stage structural tests.

For the liquid upper stages this category is composed of the cost of the liquid engines used during the flight-test program and the operational hardware or dummy units required for ground test.

5.3.2.4 Flight and Ground Test Stages

This category contains the recurring cost for stage structural components, electrical power, flight control (TVC), telemetry, retro and ullage rocket subsystems, and, in the case of liquid-propellant stages, the pressurization, propellant distribution, and utilization subsystems for R&D flight tests and the ground-test stage.

5.3.2.5 Checkout and Static Test

Stage checkout and static test cost includes only liquid stage development and acceptance tests conducted at the Mississippi Test Facility (MTF). This category contains the cost of operation at the facility, including the cost of stage installation in the test stand, test systems checkout, propellant loading, completion of prefire countdown, and static firing of the test stages. In addition, compatibility checkout cost for ground handling, transportation, and test instrumentation equipment is contained herein.

5.3.2.6 Astrionic Design and Development Testing

This category includes only the cost associated with the design of the vehicle guidance and control system located in the transtage. Costs for the development of other astrionic equipment have been included with the cost of the particular stages in which they would be installed.

5.3.2.7 Astrionics Hardware for Flight Test Vehicles

This category includes costs for the vehicle guidance and control hardware only.

5.3.2.8 Vehicle Systems Engineering and Integration

This is the cost of integration for the first and second stages and the transtage. This effort is primarily a management and engineering function with no hardware costs included.

5.3.2.9 Transportation

Transportation costs are those involved in handling and transporting the finished vehicle hardware. This includes the shipment of components from associate contractors to the stage manufacturing facilities, as well as completed vehicle stages to the test site and to the launch facilities. Transportation costs are quite low because transportation equipment, such as barges, is included in miscellaneous facilities costs. Therefore, the transportation cost of the vehicle stages and motors consists mainly of the costs for tug tow charges. Also included in this category are the anticipated costs to relocate the personnel to staff new production facilities.

5.3.2.10 Launch Operations

These costs were developed by Martin-Denver. Included are costs incurred during the flight-test program for launch-base labor to receive, transport, inspect, assemble, erect, check out, and launch the airborne vehicle; range and general overhead expenses; launch facilities refurbishment; and ground support equipment spares.

5.3.2.11 Propellants and High-Pressure Gases

This category includes the liquid propellants and high-pressure gases for the airborne vehicle. These costs were estimated by The Martin Company, Denver Division, and include amortizing of plant, power, labor, raw materials, barges, transportation to pad, standby propellants, purging, and pressurizing gases. Also included for the development program are the liquid propellants required to develop the second-stage and transtage engines, and the propellants required for test activities at the Mississippi Test Facility. The solid propellant for the first stages is included with the vehicle hardware.

5.3.2.12 Program Management

This category provides costs for overall program management. Included are initiation and coordination of program direction, definition of vehicle and vehicle requirements, initiation and approval of changes to the system, coordination of interfaces between vehicle and launch facilities, and coordination and approval of the contractor's efforts.

### 5.3.2.13 Manufacturing Facilities

It is believed that facilities exist for the manufacture of the Stage I interstage, skirt, cluster structure, TVC, and other accessories. Sectionalized construction of the cluster structure should enable relatively easy shipment to the launch facility. Accordingly, no costs have been included for additional facilities related to these items. Costs shown for solid-motor manufacturing facilities include: case preparation, propellant mixing, casting-curing, motor finishing, and static firing and test. Additional facilities have been included for motor-case and nozzle production.

A new second-stage manufacturing facility will be required. In addition, a new facility will be required to produce the second-stage engines.

### 5.3.2.14 Test Facilities

This category includes additional facilities required at the Mississippi Test Facility. Three test stands for second-stage static tests are included, complete with control centers, computing equipment, checkout and handling equipment, instrumentation, canals and docking facilities, site development, and extension of base utilities. One second-stage-engine test stand is included.

### 5.3.2.15 Launch Facility

This category covers the cost of the complete AMR launch base. Included are all facilities, ground support equipment hardware, and the design/development cost of that ground support equipment that is not considered stage-peculiar. The costs shown were estimated by The Martin Company, Denver Division, and are described in their document. To aid in this estimate, Boeing supplied to Martin-Denver the costs for the following items:

- Test, checkout, and service equipment
- Transportation and handling equipment
- Launch equipment
- Ground recording equipment.

### 5.3.2.16 Miscellaneous Facilities

This category contains transportation equipment, including barges and all associated handling devices, required to transport first stages between the propellant plant, motor hold area, motor storage area, and launch base; transport second stages between factory, static test, and launch base; and transport transtages from factory to launch base.

5.3.2.17 Tooling and Ground Support Equipment

The tooling category includes those nonrecurring tool design and fabrication costs required to support the vehicle manufacturing program. Important elements are labor, overhead, and material for the planning, design, and fabrication of detail tools, jigs, fixtures, and plant handling equipment, slings, dollies, etc., to support manufacturing operations in the fabrication shops, subassembly, and final assembly positions. Sustaining costs for the maintenance of tooling during the fabrication of the vehicles is not included in this tooling category, but rather is a part of tooling and GSE maintenance.

The ground support equipment category includes the cost of designing and developing all items of stage-peculiar ground support equipment and the cost of the ground support equipment hardware used at all locations except AMR. GSE hardware costs for AMR are included in the launch facility costs.

5.3.2.18 Operational Program

Estimated costs to sustain a launch program over a 10-year period are included in this category. Major cost items of the category are:

- Sustaining engineering for product improvement and production liaison
- Recurring vehicle manufacturing costs, consisting of manufacturing and quality control direct and indirect labor, materials, spares, and purchased parts for launch vehicles
- Tooling and GSE maintenance costs for the labor and materials required to repair and replace fabrication tools and items of ground support equipment that are used in the manufacturer's plant for production of the operational launch vehicles.

Additional operational cost items defined previously in this glossary are:

- Propellants and high-pressure gases
- Launch operations
- Transportation
- Program management.

5.3.3 Budgetary Costing

The term budgetary cost has been used for this study to identify the total system cost resulting from the addition of estimated cost increases to the definitive total system cost. These cost increases are the result of unpredicted development problems and program changes.

The basic cost summaries were prepared using definitive costing. Definitive costing is limited to estimating costs specifically for the vehicle and the program

selected without consideration of major contract changes, redirections, and escalations, etc. It assumes that the launch vehicle system being costed will be constructed essentially in accordance with the designs developed in the study and that performance will be essentially as predicted. Historically, this type of cost estimate has been extensively used in preliminary design studies to determine system costs. Its advantage lies in the fact that it permits cost comparisons between competitive systems without the injection of opinion on the relative development risks involved for each system. Accordingly, definitive costing has been used in this study as the basis for comparison of the T65D vehicle configuration and the three advanced-technology vehicle configurations.

Budgetary costing attempts to develop costs for those items that cause the program costs to exceed the estimated costs. These items can generally be associated with inflation and growth in technology. However, inflation has been excluded by direction from this study. Many current space projects have experienced difficulty with actual costs exceeding estimates, and budgetary costing is intended to bridge some of this gap. Estimating technology permits accurate prediction of costs if sufficient design details are available and the statement of work is firm. However, this amount of detail is not normally available for future programs such as NOVA. The accuracy of cost estimates is, then, heavily dependent upon technical appraisal of the program and the potential growth and redirections that may materialize during its lifetime. Estimating technology is bridging this gap, providing more accurate cost estimates today than would have been estimated a year or two ago. Industry experience in solving space-booster cost-estimating problems is constantly being accumulated by estimating staffs. This, in turn, serves to update the estimating techniques.

Budgetary costing should be confined in scope to stay within reasonable limits. Considerations should be limited to cost changes that do not substantially change the booster concept or that do not result from major model changes. It is difficult to draw the dividing line between model changes and major model changes; however, a major model change would be one which would significantly (more than ±20 percent) modify the vehicle performance. In view of the NOVA program's present lack of definition, there is a distinct probability that the vehicle size will change considerably from the present concept before contract award and during the life of the program. This change could either be for a larger, smaller, or a more sophisticated vehicle. Budgetary costing is not intended to cover changes of this magnitude.

Price escalation or inflation has been eliminated from consideration by the study ground rules. Inflation, however, will quite likely have more effect on budgetary costing than any other single item. Based on the T65D program with 79 operational launches and using an assumed price escalation of 4 percent per year, total program costs could increase 40 percent during the lifetime of the program.

The adjustment of the basic costs for the normal type of Engineering Change Proposal (ECP) or any other type of change appears to be of questionable validity.

This assumption excludes major ECP's, model changes, etc. The reason for the foregoing statement is that the run-of-the-mill ECP is reflected in the basic historical data from which the estimator develops his improvement curve slopes. One study on a major program indicated that such changes caused the improvement curve slope to be three percentage points higher than when changes were extracted from the basic data. There is data available that indicates that ECP's amount to approximately 15 to 20 percent, but if this is added to budgetary costing without properly adjusting the improvement curves used, a double charge will result. Therefore, it was elected not to include this item and to use improvement curves derived from historical data which include all changes except major model changes.

By process of elimination, budgetary estimating deals with those elements of cost which as yet are unknown and are usually referred to as state-of-the-art changes both in design and manufacturing technology. Since the assumed program, on which the T65D system and advanced-technology estimates are based, extends from 1963 to 1984, an appraisal of those cost items that are not known to the estimator becomes difficult. The most appropriate tool for the estimator to use is the cost history of previous programs. The percentage increases estimated for use on this program were based on a review of cost records of previous programs. The percentages selected should indicate the proper trends. It should also be anticipated that the percentage of variance will be higher for the R&D program. This is the period when the operational vehicle and system are being defined and developed; consequently, more uncertainties exist. It is during this period that sufficient test vehicles are being launched to ensure prescribed reliability and performance. After a system has been developed and the problems have been generally solved, costs become more predictable. The percentage increases estimated for budgetary costing on this program are as follows:

| Vehicle | T65D | APM-41 | APM-67B | AT-41 |
|---|---|---|---|---|
| R&D, Facilities, Tooling, and GSE | 25 | 35 | 35 | 35 |
| Operational | 10 | 10 | 10 | 10 |

Cost increases have been applied to the entire program rather than individual items. It is not feasible to isolate specific items or areas that might run into problem areas from a cost standpoint. Higher percentages of cost increase are used for the advanced-technology vehicles than for T65D since more problems are likely to arise when the state of the art is extended.

### 5.3.4 Cost Summaries — T65D

#### 5.3.4.1 Cost Summaries — T65D Vehicle With Fiscal Year Funding

This section presents summaries of the total system costs for the T65D vehicle for Mission Model No. 1. Table 5.3-1 shows the total program cost summary.

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TOTAL PROGRAM COST SUMMARY

Cost Summary with Fiscal Year Funding
Vehicle T65D
Mission Model No. 1
(Dollars in Millions)

| Fiscal Year | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEVELOPMENT COST (5.3-2) | 37 | 163 | 281 | 472 | 543 | 448 | 413 | 403 | 345 | 133 | | | | | | | | | | | 3,238 |
| FACILITIES (5.3-3) | 47 | 194 | 270 | 351 | 330 | 331 | 332 | 238 | 219 | 94 | | | | | | | | | | | 2,406 |
| TOOLING (5.3-4) | | 109 | 319 | 93 | | | | | | | | | | | | | | | | | 521 |
| GROUND SUPPORT EQUIPMENT (5.3-4) | | 12 | 35 | 55 | 28 | 16 | 8 | 4 | | | | | | | | | | | | | 158 |
| OPERATIONAL PROGRAM (5.3-5) | | | | | | | 3 | 124 | 502 | 819 | 851 | 699 | 678 | 426 | 489 | 555 | 454 | 503 | 213 | 6 | 6,322 |
| TOTAL PROGRAM DEFINITIVE COSTING | 84 | 478 | 905 | 971 | 901 | 795 | 756 | 769 | 1066 | 1046 | 851 | 699 | 678 | 426 | 489 | 555 | 454 | 503 | 213 | 6 | 12,645 |
| BUDGETARY COST INCREASE | | | | | | | | | | | | | | | | | | | | | |
| 25% Increase for Development, Facilities, Tooling, and Ground Support Equipment | 21 | 121 | 228 | 243 | 225 | 199 | 189 | 160 | 138 | 57 | | | | | | | | | | | 1,581 |
| 10% Increase for Operational Program | | | | | | | | 12 | 50 | 82 | 85 | 70 | 68 | 43 | 49 | 56 | 46 | 50 | 21 | | 632 |
| TOTAL PROGRAM BUDGETARY COST | 105 | 599 | 1133 | 1214 | 1126 | 994 | 945 | 941 | 1254 | 1185 | 936 | 769 | 746 | 469 | 538 | 611 | 500 | 553 | 234 | 6 | 14,858 |
| ESCALATION COST INCREASE | | | | | | | | | | | | | | | | | | | | | |
| Percent of Increase by Year | 4 | 8.16 | 12.49 | 16.99 | 21.66 | 26.53 | 31.59 | 36.85 | 42.32 | 48.01 | 53.93 | 60.09 | 66.49 | 73.15 | 80.08 | 87.28 | 94.77 | 102.56 | 110.66 | 119.09 | |
| Amount of Increase | 4 | 49 | 142 | 206 | 244 | 264 | 299 | 347 | 531 | 569 | 505 | 462 | 496 | 343 | 431 | 533 | 474 | 567 | 259 | 7 | 6,732 |
| TOTAL PROGRAM COST WITH 4% PER YEAR ESCALATION | 109 | 648 | 1275 | 1420 | 1370 | 1258 | 1244 | 1288 | 1785 | 1754 | 1441 | 1231 | 1242 | 812 | 969 | 1144 | 974 | 1120 | 493 | 13 | 21,590 |

Table 5.3-1

Budgetary cost increases and price escalations at the rate of 4 percent per year are included. Costs have been segregated and estimated separately for four major categories.

| | |
|---|---|
| Development cost | Table 5.3-2 |
| Facilities | Table 5.3-3 |
| Tooling and ground support equipment | Table 5.3-4 |
| Operational program | Table 5.3-5 |

The parametric estimating method employed for this study developed costs by vehicle elements rather than accounting elements. Therefore, the vehicle cost elements include all of the cost items that would be applicable, such as manufacturing, installation, inspection, raw material, purchased equipment, and fee.

The following is a summary of vehicle data used for costing of the T65D.

| | |
|---|---|
| Orbital Payload (225-kilometer orbit) | 1,165,000 Pounds |
| First-Stage Weight Prior to Liftoff | 27,914,830 Pounds |
| Second-Stage Weight Prior to Ignition | 8,953,810 Pounds |
| First-Stage Cluster of Six Solid Motor | 260-inch Diameter |
| Motor Construction | Unitized |
| Second Stage Propellant | $LO_2/LH_2$ |
| Second Stage Engines | Five M-1's |
| Vehicle Description | See Section 3.2.11 |
| Vehicle Weight Statements | See Section 3.2.9 |
| Number of Flight-Test Vehicles | 13 |

### 5.3.4.2 Cost Summaries — T65D Vehicle, Four Mission Models

Tables 5.3-6, -7, and -8 present cost summaries of the T65D vehicle system for the four mission models (see Section 3.3.3). Each mission model requires a different number of operational launches as follows:

| Mission Model Description | |
|---|---|
| Mission Number 1 | 79 Operational Launches |
| Mission Number 2 | 60 Operational Launches |
| Mission Number 3 | 71 Operational Launches |
| Mission Number 4 | 53 Operational Launches |

This section includes only the detailed cost summary tables that reflect changes to the T65D cost summaries with fiscal year funding. The development and the

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DEVELOPMENT COST

Cost Summary with Fiscal Year Funding
Vehicle T65D
Mission Model No. 1
(Dollars in Millions)

| Fiscal Year | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| STAGE I | | | | | | | | | | | |
| Motor Design and Development | 10.000 | 30.000 | 40.000 | 50.000 | 50.000 | 20.000 | | | | | 200.000 |
| Stage Engineering, Design, Development, and Test | 7.446 | 28.759 | 40.827 | 38.259 | 31.840 | 25.677 | 24.137 | 24.137 | 24.137 | 11.555 | 256.774 |
| Flight- and Ground-Test Motors | | | 18.447 | 108.837 | 124.825 | 92.235 | 92.235 | 77.477 | 70.099 | 30.745 | 614.900 |
| Flight- and Ground-Test Stages | | | 5.464 | 32.239 | 36.974 | 27.321 | 27.321 | 22.950 | 20.764 | 9.106 | 182.139 |
| Checkout and Static Test | | | | 2.255 | 5.785 | 6.408 | 6.408 | 4.806 | 4.005 | | 29.667 |
| STAGE II | | | | | | | | | | | |
| Engine Design and Development | 13.750 | 41.250 | 55.000 | 68.750 | 68.750 | 27.500 | | | | | 275.000 |
| Stage Engineering, Design, Development, and Test | | 32.980 | 54.794 | 46.484 | 32.980 | 28.566 | 23.890 | 19.477 | 14.801 | 5.714 | 259.686 |
| Flight- and Ground-Test Engines | | | 5.035 | 20.514 | 31.980 | 31.980 | 31.980 | 31.980 | 25.549 | 13.053 | 192.071 |
| Flight- and Ground-Test Stages | | | 8.931 | 36.388 | 56.731 | 56.731 | 56.730 | 56.731 | 45.320 | 23.161 | 340.723 |
| Checkout and Static Test | | | | 5.360 | 12.621 | 17.980 | 17.980 | 17.116 | 15.387 | | 86.444 |
| TRANSTAGE | | | | | | | | | | | |
| Engine Design and Development | | 4.000 | 10.000 | 12.000 | 10.000 | 4.000 | | | | | 40.000 |
| Stage Engineering, Design, Development, and Test | | 4.771 | 10.319 | 8.471 | 6.621 | 5.161 | 4.041 | 3.700 | 3.700 | 1.900 | 48.684 |
| Flight- and Ground-Test Engines | | | 0.059 | 0.373 | 0.373 | 0.373 | 0.292 | 0.236 | 0.177 | 0.059 | 1.942 |
| Flight- and Ground-Test Stages | | | 0.870 | 5.553 | 5.553 | 5.553 | 4.347 | 3.506 | 2.637 | 0.870 | 28.889 |
| Checkout and Static Test | | | | 0.751 | 1.006 | 1.006 | 1.006 | 1.006 | 0.750 | | 5.525 |
| VEHICLE | | | | | | | | | | | |
| Astrionics Design and Development Testing | 1.176 | 6.888 | 14.868 | 15.456 | 13.104 | 10.836 | 8.568 | 6.300 | 4.536 | 2.268 | 84.000 |
| Astrionics Hardware Flight-Test Vehicle | | | 0.634 | 4.046 | 4.046 | 4.046 | 3.167 | 2.555 | 1.921 | 0.634 | 21.049 |
| Vehicle System Engineering and Integration | 1.009 | 8.188 | 10.205 | 8.722 | 6.645 | 6.111 | 6.111 | 5.637 | 4.628 | 2.078 | 59.334 |
| Transportation | 1.042 | 1.564 | 1.564 | 1.042 | 0.521 | 1.042 | 1.564 | 1.042 | 0.521 | 0.521 | 10.423 |
| Launch Operations | | | | | 36.600 | 73.200 | 91.400 | 91.400 | 73.200 | | 365.800 |
| Propellants and High-Pressure Gases | | | | | | | 10.630 | 31.890 | 31.890 | 31.890 | 106.300 |
| Program Management | 1.035 | 3.593 | 4.082 | 4.082 | 3.679 | 3.277 | 2.875 | 2.875 | 2.242 | 1.006 | 28.746 |
| TOTAL DEVELOPMENT | 35.458 | 161.993 | 281.099 | 469.582 | 540.634 | 449.003 | 414.682 | 404.821 | 346.264 | 134.560 | 3,238.096 |

Table 5.3-2

FACILITIES

Cost Summary with Fiscal Year Funding
Vehicle T65D
Mission Model No. 1
(Dollars in Millions)

| Fiscal Year | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MANUFACTURING FACILITIES | | | | | | | | | | | |
| Stage I | | | | | | | | | | | -0- |
| Motors for Stage I | 16.000 | 22.000 | 22.000 | 15.000 | | | | | | | 75.000 |
| Stage II | 11.000 | 45.000 | 19.000 | | | | | | | | 75.000 |
| Engines for Stage II | 20.000 | 30.000 | 30.000 | 20.000 | | | | | | | 100.000 |
| Transtage | | | | | | | | | | | -0- |
| Engines for Transtage | | | | | | | | | | | -0- |
| Total Manufacturing | 47.000 | 97.000 | 71.000 | 35.000 | | | | | | | 250.000 |
| TEST FACILITIES | | | | | | | | | | | |
| Stage I | | | | | | | | | | | -0- |
| Motors for Stage I | | | | | | | | | | | -0- |
| Stage II | | 2.000 | 7.000 | 13.000 | 13.000 | 14.000 | 14.000 | 14.000 | 13.000 | | 90.000 |
| Engines for Stage II | | 2.000 | 4.000 | 3.000 | | | | | | | 9.000 |
| Transtage | | | | | | | | | | | -0- |
| Engines for Transtage | | | | | | | | | | | -0- |
| Total Test Facilities | | 4.000 | 11.000 | 16.000 | 13.000 | 14.000 | 14.000 | 14.000 | 13.000 | | 99.000 |
| LAUNCH FACILITY | | 93.000 | 188.000 | 282.000 | 282.000 | 282.000 | 282.000 | 188.000 | 188.000 | 94.000 | 1,879.000 |
| MISCELLANEOUS FACILITIES | | | | 18.000 | 35.000 | 35.000 | 36.000 | 36.000 | 18.000 | | 178.000 |
| TOTAL FACILITIES PROGRAM | 47.000 | 194.000 | 270.000 | 351.000 | 330.000 | 331.000 | 332.000 | 238.000 | 219.000 | 94.000 | 2,406.000 |

Table 5.3-3

TOOLING AND GROUND SUPPORT EQUIPMENT

Cost Summary with Fiscal Year Funding
Vehicle T65D
Mission Model No. 1
(Dollars in Millions)

| Fiscal Year | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | TOTAL |
|---|---|---|---|---|---|---|---|---|
| TOOL ENGINEERING AND DESIGN | | | | | | | | |
| Stage I | 30.533 | 15.267 | 5.089 | | | | | 50.889 |
| Stage II | 36.105 | 18.053 | 6.018 | | | | | 60.176 |
| Transtage | 1.105 | 0.553 | 0.184 | | | | | 1.842 |
| Total | 67.743 | 33.873 | 11.291 | | | | | 112.907 |
| TOOL FABRICATION | | | | | | | | |
| Stage I | 18.379 | 128.656 | 36.759 | | | | | 183.794 |
| Stage II | 21.734 | 152.135 | 43.467 | | | | | 217.336 |
| Transtage | 0.666 | 4.665 | 1.334 | | | | | 6.665 |
| Total | 40.779 | 285.456 | 81.560 | | | | | 407.795 |
| TOTAL TOOLING PROGRAM | 108.522 | 319.329 | 92.851 | | | | | 520.702 |
| GROUND SUPPORT EQUIPMENT DESIGN | | | | | | | | |
| Stage I | 4.000 | 12.000 | 16.000 | 6.000 | 2.000 | | | 40.000 |
| Stage II | 5.000 | 15.000 | 21.000 | 8.000 | 3.000 | | | 52.000 |
| Transtage | 3.000 | 8.000 | 10.000 | 4.000 | 1.000 | | | 26.000 |
| Total | 12.000 | 35.000 | 47.000 | 18.000 | 6.000 | | | 118.000 |
| GROUND SUPPORT EQUIPMENT FABRICATION | | | | | | | | |
| Stage I | | | 3.000 | 4.000 | 4.000 | 3.000 | 1.000 | 15.000 |
| Stage II | | | 3.000 | 4.000 | 4.000 | 3.000 | 2.000 | 16.000 |
| Transtage | | | 2.000 | 2.000 | 2.000 | 2.000 | 1.000 | 9.000 |
| Total | | | 8.000 | 10.000 | 10.000 | 8.000 | 4.000 | 40.000 |
| TOTAL GROUND SUPPORT EQUIPMENT | 12.000 | 35.000 | 55.000 | 28.000 | 16.000 | 8.000 | 4.000 | 158.000 |

Table 5.3-4

OPERATIONAL PROGRAM

Cost Summary with Fiscal Year Funding
Vehicle T65D
Mission Model No. 1
(Dollars in Millions)

| Fiscal Year | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SUSTAINING ENGINEERING AND PRODUCT IMPROVEMENT | | | | | | | | | | | | | | | |
| Stage I | 1.027 | 3.698 | 7.397 | 20.341 | 25.683 | 24.245 | 22.602 | 20.958 | 19.314 | 17.465 | 15.821 | 14.177 | 10.684 | 2.055 | 205.467 |
| Stage II | 1.648 | 4.945 | 10.832 | 23.783 | 28.728 | 27.315 | 25.431 | 23.548 | 21.193 | 19.545 | 17.896 | 16.248 | 12.009 | 2.355 | 235.476 |
| Transtage | 0.094 | 0.330 | 0.644 | 1.635 | 1.855 | 1.760 | 1.682 | 1.572 | 1.493 | 1.398 | 1.257 | 1.069 | 0.739 | 0.189 | 15.717 |
| Astrionics | 0.131 | 0.499 | 0.972 | 2.548 | 3.258 | 3.128 | 2.943 | 2.732 | 2.548 | 2.365 | 2.076 | 1.681 | 1.156 | 0.236 | 26.273 |
| Vehicle | 0.250 | 0.785 | 1.641 | 3.708 | 4.636 | 4.387 | 3.994 | 3.638 | 3.246 | 2.889 | 2.497 | 2.140 | 1.569 | 0.285 | 35.665 |
| VEHICLE PROCUREMENT (Incl. Spares) | | | | | | | | | | | | | | | |
| Stage I | | 13.100 | 51.284 | 75.811 | 75.254 | 62.433 | 53.235 | 38.742 | 43.759 | 49.054 | 42.086 | 35.397 | 17.280 | | 557.435 |
| Stage I Motor | | 56.118 | 219.697 | 324.773 | 322.381 | 267.457 | 228.055 | 165.966 | 187.458 | 210.144 | 130.294 | 151.638 | 74.028 | | 2,388.009 |
| Stage II | | 17.834 | 69.819 | 103.210 | 102.452 | 84.997 | 72.475 | 52.744 | 59.574 | 66.783 | 57.299 | 48.190 | 23.526 | | 758.903 |
| Stage II Engines | | 15.555 | 60.895 | 90.018 | 89.357 | 74.133 | 63.212 | 46.001 | 51.959 | 58.247 | 49.973 | 42.031 | 20.519 | | 661.900 |
| Transtage | | 2.401 | 9.401 | 13.897 | 13.795 | 11.444 | 9.758 | 7.102 | 8.021 | 8.992 | 7.715 | 6.489 | 3.168 | | 102.183 |
| Transtage Engines | | 0.155 | 0.606 | 0.896 | 0.889 | 0.738 | 0.629 | 0.458 | 0.517 | 0.580 | 0.498 | 0.418 | 0.204 | | 6.588 |
| Astrionics Equipment | | 2.226 | 8.716 | 12.885 | 12.790 | 10.614 | 9.048 | 6.585 | 7.437 | 8.337 | 7.153 | 6.016 | 2.937 | | 94.744 |
| PROPELLANTS AND HIGH-PRESSURE GASES | | | 7.372 | 22.116 | 26.966 | 19.400 | 32.010 | 7.372 | 12.222 | 17.266 | 9.894 | 32.010 | 7.372 | | 194.000 |
| TRANSPORTATION | | | 0.342 | 1.025 | 1.250 | 0.899 | 1.484 | 0.342 | 0.567 | 0.801 | 0.459 | 1.484 | 0.342 | | 8.995 |
| LAUNCH OPERATIONS | | | 29.146 | 87.438 | 106.613 | 76.700 | 126.555 | 29.146 | 48.321 | 68.263 | 39.117 | 126.555 | 29.146 | | 767.000 |
| PROGRAM MANAGEMENT | 0.174 | 0.648 | 1.296 | 2.567 | 2.791 | 2.642 | 2.469 | 2.268 | 2.094 | 1.894 | 1.869 | 1.869 | 1.869 | 0.474 | 24.924 |
| TOOLING AND GSE MAINTENANCE | | 5.614 | 21.977 | 32.487 | 32.249 | 26.754 | 22.813 | 16.602 | 18.752 | 21.021 | 18.035 | 15.169 | 6.808 | 0.597 | 238.878 |
| TOTAL OPERATIONAL PROGRAM | 3.324 | 123.908 | 502.037 | 819.138 | 850.947 | 699.046 | 678.395 | 425.776 | 488.475 | 555.044 | 453.939 | 502.581 | 213.356 | 6.191 | 6,322.157 |

Table 5.3-5

TOTAL PROGRAM COST SUMMARY

Vehicle T65D
Cost Comparison of Four Mission Models
(Dollars in Millions)

| Mission Model | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Number of Operational Launches | 79 | 60 | 71 | 53 |
| DEVELOPMENT COST (5.3-2) | 3,238.096 | 3,238.096 | 3,238.096 | 3,238.096 |
| FACILITIES (5.3-7) | 2,406.000 | 2,400.000 | 1,838.000 | 1,827.000 |
| TOOLING (5.3-4) | 520.702 | 520.702 | 520.702 | 520.702 |
| GROUND SUPPORT EQUIPMENT (5.3-4) | 158.000 | 158.000 | 158.000 | 158.000 |
| OPERATIONAL PROGRAM (5.3-8) | 6,322.157 | 5,093.888 | 5,700.192 | 4,539.099 |
| TOTAL PROGRAM — DEFINITIVE COSTING | 12,644.955 | 11,410.686 | 11,454.990 | 10,282.897 |
| BUDGETARY COST INCREASE | | | | |
| 25% Increase for Development, Facilities, Tooling, and Ground Support Equipment | 1,580.700 | 1,579.200 | 1,438.700 | 1,435.950 |
| 10% Increase for Operational Program | 632.218 | 509.389 | 570.019 | 453.910 |
| TOTAL PROGRAM — BUDGETARY COST | 14,857.873 | 13,499.275 | 13,463.709 | 12,172.757 |

Table 5.3-6

FACILITIES

Cost Summary
Vehicle T65D
Cost Comparison of Four Mission Models
(Dollars in Millions)

| Mission Model | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Number of Operational Launches | 79 | 60 | 71 | 53 |
| MANUFACTURING FACILITIES | | | | |
| Stage I | | | | |
| Motors for Stage I | 75.000 | 75.000 | 75.000 | 75.000 |
| Stage II | 75.000 | 75.000 | 75.000 | 75.000 |
| Engines for Stage II | 100.000 | 100.000 | 100.000 | 100.000 |
| Transtage | | | | |
| Engines for Transtage | | | | |
| Total Manufacturing Facilities | 250.000 | 250.000 | 250.000 | 250.000 |
| TEST FACILITIES | | | | |
| Stage I | | | | |
| Motors for Stage I | | | | |
| Stage II | 90.000 | 90.000 | 90.000 | 90.000 |
| Engines for Stage II | 9.000 | 9.000 | 9.000 | 9.000 |
| Transtage | | | | |
| Engines for Transtage | | | | |
| Total Test Facilities | 99.000 | 99.000 | 99.000 | 99.000 |
| LAUNCH FACILITY | 1,879.000 | 1,881.000 | 1,322.000 | 1,325.000 |
| MISCELLANEOUS FACILITIES | 178.000 | 170.000 | 167.000 | 153.000 |
| TOTAL FACILITIES PROGRAM | 2,406.000 | 2,400.000 | 1,838.000 | 1,827.000 |

Table 5.3-7

OPERATIONAL PROGRAM

Cost Summary
Vehicle T65D
Cost Comparison of Four Mission Models
(Dollars in Millions)

| Mission Model | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Number of Operational Launches | 79 | 60 | 71 | 53 |
| SUSTAINING ENGINEERING AND PRODUCT IMPROVEMENT | | | | |
| Stage I | 205.467 | 162.505 | 187.609 | 146.145 |
| Stage II | 235.476 | 185.792 | 214.830 | 166.874 |
| Transtage | 15.717 | 12.372 | 14.333 | 11.095 |
| Astrionics | 26.273 | 19.954 | 23.612 | 17.625 |
| Vehicle | 35.665 | 28.055 | 32.443 | 25.198 |
| VEHICLE PROCUREMENT (Incl. Spares) | | | | |
| Stage I | 557.435 | 438.933 | 508.025 | 393.962 |
| Stage I Motors | 2,388.009 | 1,828.306 | 2,166.810 | 660.142 |
| Stage II | 758.903 | 628.493 | 692.264 | 537.552 |
| Stage II Engines | 661.900 | 522.722 | 603.779 | 469.173 |
| Transtage | 102.183 | 80.381 | 93.115 | 72.095 |
| Transtage Engines | 6.588 | 5.163 | 5.994 | 4.623 |
| Astrionics Equipment | 94.744 | 71.960 | 85.153 | 63.564 |
| PROPELLANTS AND HIGH-PRESSURE GASES | 194.000 | 161.800 | 179.200 | 147.500 |
| TRANSPORTATION | 8.995 | 6.832 | 8.084 | 6.035 |
| LAUNCH OPERATIONS | 767.000 | 727.000 | 642.000 | 623.000 |
| PROGRAM MANAGEMENT | 24.924 | 24.924 | 24.924 | 24.924 |
| TOOLING AND GSE MAINTENANCE | 238.878 | 188.696 | 218.017 | 169.592 |
| TOTAL OPERATIONAL PROGRAM | 6,322.157 | 5,093.888 | 5,700.192 | 4,539.099 |

Table 5.3-8

tooling and ground support equipment costs remain the same as presented in Tables 5.3-2 and 5.3-4. Fiscal year funding would not vary sufficiently from the previous summaries to warrant the inclusion of separate funding schedules.

### 5.3.5 Cost Summaries — Advanced-Technology Vehicles APM-41, APM-67B, and AT-41

Table 5.3-9 summarizes vehicle data used to estimate costs for the three advanced-technology vehicles.

Tables 5.3-10, -11, 12, -13, and -14 are cost summaries showing total system costs, development facility costs, tooling and ground support equipment costs, and operational program costs, respectively. T65D vehicle costs have been included for comparison. Fiscal year funding has not been included since it will not vary sufficiently from the T65D funding schedules to warrant preparation of additional schedules.

### 5.3.6 Cost Summary — Vehicles T65D, APM-41, APM-67B, and AT-41, Using NASA-Recommended Solid-Motor Costs

System cost estimates shown in Sections 5.3.4 and 5.3.5 reflect solid-motor costs that are considered reasonable projections based on experience with current programs, and on industry estimates of solid-motor cost trends with increasing size and production rate. NASA has recommended the use of solid-motor costs that are higher than those used in Boeing estimates. NASA has also requested that system cost figures based on these solid-motor costs be included in this document. Boeing has been unable to reconcile the solid-motor costs recommended by NASA with Boeing estimates. However, in accordance with NASA MSFC request, Table 5.3-15 is provided to show total program costs based on the use of NASA-recommended solid-motor costs. Costs are shown for the T65D vehicle and the three advanced-technology vehicles, based on Mission Model No. 1. All costs remain as shown on Table 5.3-10 (Definitive Costing) except for the additions to the solid-motor costs.

The solid motor prices given by NASA were for the 50th unit, exclusive of TVC, and are as follows:

- At 3 million pounds gross weight, Unit No. 50, learning curve = 97 percent. the per-pound delivered cost is $3.00.

- At 6 million pounds gross weight, Unit No. 50, learning curve = 97 percent, the per-pound delivered cost is $2.75.

SUMMARY OF VEHICLE DATA FOR COSTING

| | APM-41 | APM-67B | AT-41 |
|---|---|---|---|
| Orbital Payload (pounds) (225-kilometer orbit) | 1,100,000 | 1,100,000 | 1,100,000 |
| First-Stage Weight Prior to Liftoff (pounds) | 9,208,595 | 16,212,620 | 13,828,620 |
| Second-Stage Weight Prior to Ignition (pounds) | 11,504,520 | 13,782,700 | 10,015,030 |
| First-Stage Cluster of Solid Motors | Four 260-Inch Dia. | Six 260-Inch Dia. | Four 260-Inch Dia. |
| Motor Construction | Unitized | Unitized | Unitized |
| Second-Stage Propellant | $LO_2/LH_2$ | $LO_2/LH_2$ | $LO_2/LH_2$ |
| Second-Stage Engines | Rocketdyne L-9H Toroidal | Seven M-1's | Rocketdyne L-9H Toroidal |
| Vehicle Description | See 4.3.4.3 | See 4.3.4.1 | See 4.3.4.2 |
| Weight Statements | See 4.6.3.2 | See 4.6.3.3 | See 4.6.3.1 |
| Operational Launches (Mission No. 1) | 79 | 79 | 79 |
| Number of Flight-Test Vehicles | 13 | 14 | 10 |

Table 5.3-9

TOTAL PROGRAM COST SUMMARY

T65D Vehicle and Advanced-Technology Vehicles
Mission Model No. 1
(Dollars in Millions)

| Vehicle | T65D | APM-41 | APM-67B | AT-41 |
|---|---|---|---|---|
| DEVELOPMENT COST (5.3-11) | 3,238.096 | 3,007.302 | 3,063.762 | 3,012.204 |
| FACILITIES (5.3-12) | 2,406.000 | 2,046.266 | 2,004.150 | 2,313.166 |
| TOOLING (5.3-13) | 520.702 | 304.461 | 382.270 | 411.555 |
| GROUND SUPPORT EQUIPMENT (5.3-13) | 158.000 | 158.000 | 158.000 | 158.000 |
| OPERATIONAL PROGRAM (5.3-14) | 6,322.157 | 4,187.090 | 5,448.175 | 4,951.900 |
| TOTAL PROGRAM DEFINITIVE COSTING | 12,644.955 | 9,703.119 | 11,056.357 | 10,846.825 |
| BUDGETARY COST INCREASE | | | | |
| For Development, Facilities, Tooling and Ground Support Equipment | (25%) 1,580.700 | (35%) 1,930.610 | (35%) 1,962.864 | (35%) 2,063.224 |
| For Operational Program | (10%) 632.218 | (10%) 418.709 | (10%) 544.818 | (10%) 495.190 |
| TOTAL PROGRAM BUDGETARY COST | 14,857.873 | 12,052.438 | 13,564.039 | 13,405.239 |

Table 5.3-10

DEVELOPMENT COST

T65D Vehicle and Advanced-Technology Vehicles
Mission Model No. 1
(Dollars in Millions)

| Vehicle | T65 | APM-41 | APM-67B | AT-41 |
|---|---|---|---|---|
| STAGE I | | | | |
| Motor Design and Development | 200.000 | 165.000 | 175.000 | 180.000 |
| Stage Engineering, Design, Development, and Test | 256.774 | 153.498 | 199.959 | 215.409 |
| Flight- and Ground-Test Motors | 614.900 | 251.802 | 358.035 | 201.259 |
| Flight- and Ground-Test Stages | 182.139 | 87.913 | 166.013 | 129.510 |
| Checkout and Static Test | 29.667 | 14.021 | 21.764 | 12.757 |
| STAGE II | | | | |
| Engine Design and Development | 275.000 | 735.000 | 310.000 | 725.000 |
| Stage Engineering, Design, Development, and Test | 259.686 | 261.386 | 333.801 | 271.279 |
| Flight- and Ground-Test Engines | 192.071 | 86.673 | 278.685 | 67.038 |
| Flight- and Ground-Test Stages | 340.723 | 344.934 | 381.654 | 258.343 |
| Checkout and Static Test | 86.444 | 97.111 | 86.444 | 97.111 |
| TRANSTAGE | | | | |
| Engine Design and Development | 40.000 | 40.000 | 40.000 | 40.000 |
| Stage Engineering, Design, Development, and Test | 48.684 | 48.684 | 48.684 | 48.684 |
| Flight- and Ground-Test Engines | 1.942 | 1.941 | 2.106 | 1.439 |
| Flight- and Ground-Test Stages | 28.889 | 28.889 | 31.343 | 21.428 |
| Checkout and Static Test | 5.525 | 5.525 | 5.525 | 5.525 |
| VEHICLE | | | | |
| Astrionics Design and Development Testing | 84.000 | 84.000 | 84.000 | 84.000 |
| Astrionics Hardware Flight Test Vehicle | 21.049 | 22.961 | 21.049 | 15.309 |
| Vehicle System Engineering and Integration | 59.334 | 59.334 | 59.334 | 59.334 |
| Transportation | 10.423 | 9.884 | 10.020 | 10.033 |
| Launch Operations | 365.800 | 313.300 | 323.000 | 371.400 |
| Propellant and High-Pressure Gases | 166.300 | 166.700 | 98.600 | 168.600 |
| Program Management | 28.746 | 28.746 | 28.746 | 28.746 |
| TOTAL DEVELOPMENT | 3,238.096 | 3,007.302 | 3,063.762 | 3,012.204 |

Table 5.3-11

FACILITIES

Cost Summary
T65D Vehicle and Advanced Technology Vehicles
Mission Model No. 1
(Dollars in Millions)

| Vehicle | T65 | APM-41 | APM-67B | AT-41 |
|---|---|---|---|---|
| MANUFACTURING FACILITIES | | | | |
| Stage I | | | | |
| Motors for Stage I | 75.000 | 49.666 | 67.050 | 49.666 |
| Stage II | 75.000 | 75.000 | 82.500 | 75.000 |
| Engines for Stage II | 100.000 | 215.000 | 100.000 | 215.000 |
| Transtage | | | | |
| Engines for Transtage | | | | |
| Total Manufacturing Facilities | 250.000 | 339.666 | 249.550 | 339.666 |
| TEST FACILITIES | | | | |
| Stage I | | | | |
| Motors for Stage I | | | | |
| Stage II | 90.000 | 90.000 | 90.000 | 90.000 |
| Engines for Stage II | 9.000 | 20.000 | 9.000 | 20.000 |
| Transtage | | | | |
| Engines for Transtage | | | | |
| Total Test Facilities | 99.000 | 110.000 | 99.000 | 110.000 |
| LAUNCH FACILITIES | 1,879.000 | 1,418.600 | 1,477.600 | 1,685.500 |
| MISCELLANEOUS FACILITIES | 178.000 | 178.000 | 178.000 | 178.000 |
| TOTAL FACILITIES PROGRAM | 2,406.000 | 2,046.266 | 2,004.150 | 2,313.166 |

Table 5.3-12

TOOLING AND GROUND SUPPORT EQUIPMENT

Cost Summary
T65D Vehicle and Advanced Technology Vehicles
Mission Model No. 1
(Dollars in Millions)

| Vehicle | T65 | APM-41 | APM-67B | AT-41 |
|---|---|---|---|---|
| TOOL ENGINEERING AND DESIGN | | | | |
| Stage I | 50.889 | 5.451 | 7.237 | 27.621 |
| Stage II | 60.176 | 49.864 | 64.434 | 49.665 |
| Transtage | 1.842 | 1.843 | 1.843 | 1.843 |
| Total | 112.907 | 57.158 | 73.514 | 79.129 |
| TOOL FABRICATION | | | | |
| Stage I | 183.794 | 30.462 | 30.504 | 116.422 |
| Stage II | 217.336 | 210.176 | 271.588 | 209.339 |
| Transtage | 6.665 | 6.665 | 6.664 | 6.665 |
| Total | 407.795 | 247.303 | 308.756 | 332.426 |
| TOTAL TOOLING PROGRAM | 520.702 | 304.461 | 382.270 | 411.555 |
| GROUND SUPPORT EQUIPMENT DESIGN | | | | |
| Stage I | 40.000 | 40.000 | 40.000 | 40.000 |
| Stage II | 52.000 | 52.000 | 52.000 | 52.000 |
| Transtage | 26.000 | 26.000 | 26.000 | 26.000 |
| Total | 118.000 | 118.000 | 118.000 | 118.000 |
| GROUND SUPPORT EQUIPMENT FABRICATION | | | | |
| Stage I | 15.000 | 15.000 | 15.000 | 15.000 |
| Stage II | 16.000 | 16.000 | 16.000 | 16.000 |
| Transtage | 9.000 | 9.000 | 9.000 | 9.000 |
| Total | 40.000 | 40.000 | 40.000 | 40.000 |
| TOTAL GROUND SUPPORT EQUIPMENT | 158.000 | 158.000 | 158.000 | 158.000 |

Table 5.3-13

OPERATIONAL PROGRAM

Cost Summary
T65D Vehicle and Advanced Technology Vehicles
Mission Model No. 1
(Dollars in Millions)

| Vehicle | T65 | APM-41 | APM-67B | AT-41 |
|---|---|---|---|---|
| SUSTAINING ENGINEERING AND PRODUCT IMPROVEMENT | | | | |
| Stage I | 205.467 | 125.513 | 138.902 | 147.123 |
| Stage II | 235.476 | 186.458 | 241.908 | 192.857 |
| Transtage | 15.717 | 15.717 | 15.717 | 15.717 |
| Astrionics | 26.273 | 26.273 | 26.273 | 26.273 |
| Vehicle | 35.665 | 35.665 | 35.665 | 35.665 |
| VEHICLE PROCUREMENT (Incl. Spares) | | | | |
| Stage I | 557.435 | 251.188 | 354.556 | 525.850 |
| Stage I Motors | 2,388.009 | 973.212 | 1,595.348 | 1,304.595 |
| Stage II | 758.903 | 1,007.561 | 971.965 | 969,930 |
| Stage II Engines | 661.900 | 306.139 | 717.129 | 302.805 |
| Transtage | 102.183 | 102.183 | 102.183 | 102.183 |
| Transtage Engines | 6.588 | 6.588 | 6.588 | 6.588 |
| Astrionics Equipment | 94.744 | 94.744 | 94.744 | 94.744 |
| PROPELLANTS AND HIGH PRESSURE GASES | 194.000 | 203.000 | 217.000 | 217.000 |
| TRANSPORTATION | 8.995 | 5.775 | 6.134 | 8.724 |
| LAUNCH OPERATIONS | 767.000 | 656.700 | 677.000 | 778.600 |
| PROGRAM MANAGEMENT | 24.924 | 24.924 | 24.924 | 24.924 |
| TOOLING AND GSE MAINTENANCE | 238.878 | 165.450 | 222.139 | 198.322 |
| TOTAL OPERATIONAL PROGRAM | 6,322.157 | 4,187.090 | 5,448.175 | 4,951.900 |

Table 5.3-14

TOTAL PROGRAM COST SUMMARY

T65D Vehicle and Advanced-Technology Vehicles APM-41, APM-67B, and AT-41
Using NASA Recommended Solid-Motor Costs
Mission Model No. 1
(Dollars in Millions)

| Vehicle | T65D | APM-41 | APM-67B | AT-41 |
|---|---|---|---|---|
| Development Cost (5.3-11) | 3,238.096 | 3,007.302 | 3,063.762 | 3,012.204 |
| Increase in cost resulting from the use of NASA-recommended solid-motor cost | 533.256 | 158.330 | 362.394 | 130.031 |
| Subtotal — Development Cost | 3,771.352 | 3,165.632 | 3,426.156 | 3,142.235 |
| Facilities (5.3-12) | 2,406.000 | 2,046.266 | 2,004.150 | 2,313.166 |
| Tooling (5.3-13) | 520.702 | 304.461 | 382.270 | 411.555 |
| Ground Support Equipment (5.3-13) | 158.000 | 158.000 | 158.000 | 158.000 |
| Operational Program (5.3-14) | 6,322.157 | 4,187.090 | 5,448.175 | 4,951.900 |
| Increase in cost resulting from the use of NASA-recommended solid-motor cost | 3,743.274 | 1,299.145 | 2,325.407 | 1,931.829 |
| Subtotal — Operational Cost | 10,065.431 | 5,416.235 | 7,773.582 | 6,883.729 |
| Total Program Cost Using NASA-Recommended Solid-Motor Costs | $16,921.485 | $11,090.594 | $13,744.158 | $12,908.685 |

Table 5.3-15

The total motor costs that result are tabulated below:

| | Vehicle | | | |
|---|---|---|---|---|
| | T65D | APM-41 | APM-67B | AT-41 |
| Gross Weight of Motor (pounds) | 4,423,433 | 2,210,928 | 2,668,868 | 3,319,475 |
| Dollars per Pound of No. 1 Motor | 3.80 | 4.08 | 4.03 | 3.95 |
| Total Cost of No. 1 Motor (dollars in millions) | 16.809 | 9.021 | 10.756 | 13.112 |
| Total Cost of Solid Motors Required for Flight Test and Operational Programs (dollars in millions) | 7,351.0 | 1,616.4 | 3,056.2 | 2,323.4 |

The use of the solid-motor costs furnished by NASA has a significant effect on total systems costs. A summary of cost changes given as percent increases to costs is shown below:

| | Vehicle | | | |
|---|---|---|---|---|
| | T65D | APM-41 | APM-67B | AT-41 |
| Development Cost | 16.5 | 11.6 | 11.8 | 11.0 |
| Operational Cost | 59.2 | 29.4 | 42.7 | 39.0 |
| Total Program Cost | 33.8 | 16.5 | 24.3 | 20.7 |

## 5.4 SYSTEMS COST-EFFECTIVENESS ANALYSES AND COMPARISONS

Cost effectiveness analyses were conducted in accordance with "NOVA Operational Mission Model Ground Rules," dated January 18, 1963, published by the NASA Future Projects Office. Cost effectiveness was calculated in terms of dollars per pound of payload delivered to the 225-kilometer orbit. Two measures of cost effectiveness were used:

- Operational Cost Effectiveness — Recurring costs divided by the payload delivered to the 225-kilometer orbit.
- Total Cost Effectiveness — Total program costs divided by the payload delivered to the 225-kilometer orbit.

Cost of the transtage was not included in the determination of cost effectiveness. Payload loss factors of 0, 10, and 50 dollars per pound were used as specified in the ground rules.

Cost effectiveness was determined for the T65D vehicle for each of the four mission models specified by the ground rules and defined in detail in Section 3.3.3. For the advanced-technology vehicles, cost effectiveness was determined for Mission Model No. 1 only, using a payload loss factor of 0.

Cost effectiveness values were also calculated for the T65D and advanced-technology vehicles, using NASA-recommended solid-motor costs. These calculations were made for Mission Model No. 7 only, with zero payload-loss factor.

For each configuration, major cost items were analyzed for their influence on cost effectiveness. System costs for the T65D and advanced-technology configurations were reviewed and compared to evaluate significant cost factors and trends.

### 5.4.1 Cost Effectiveness — T65D Configuration

Cost effectiveness for the current-technology vehicle (T65D) has been calculated using cost data presented earlier in Section 5.3. Other data such as missions and payload cost per pound are as defined in the NASA ground rules.

Specifically, the data and sources used for computing dollar-per-pound costs are as listed below:

- Successful and total launches from Section 3.3.3
- Payload weight per launch to a 225-kilometer orbit from 3.2.2.4
- Payload loss cost factors (PLF) of 0, 10, and 50 dollars per pound, as specified in the NASA ground rules
- Total program costs and operational program costs with both definitive and budgetary type estimates from Section 5.3

Total program costs and operational program costs have no transtage costs included. Operational program costs are recurring-type costs only.

5.4.1.1 Development of Costs

Methodology followed in development of dollar-per-pound costs may be seen in Tables 5.4-1, 5.4-2, and 5.4-3. In Table 5.4-1, the cost per pound of payload lost is derived by multiplying the NASA payload-cost-per-pound factor by the weight of payload lost for each of the four missions considered. The weight of payload lost is determined by multiplying the payload-per-launch weight by the number of payloads lost. The difference between the two launch rates is the number of launches failed or payloads lost. Tables 5.4-2 and 5.4-3 are summary tables of cost of payloads lost and operational program or total program costs for definitive- or budgetary-type cost estimates as taken from Section 5.3. Table 5.4-4 shows the dollar-per-pound of payload in orbit costs for all of the missions, payload factors, and system cost summaries. This cost is the system cost divided by the total payload in orbit.

5.4.1.2 Cost-Effectiveness Curves

The comparison of cost effectiveness is shown in the four curves of Figures 5.4-1, 5.4-2, 5.4-3, and 5.4-4. Each figure shows the curves for one of the four missions considered. Dollars per pound of payload in orbit is plotted versus the payloads-lost cost factor for the four system costs listed below:

- Definitive total system cost
- Definitive operational program cost
- Budgetary total system cost
- Budgetary operational program cost

5.4.1.3 Cost-Effectiveness Analysis

Cost-effectiveness values vary for the four missions considered. An analysis of major cost items or groups of cost items and their effects on cost effectiveness follows:

Launch Facilities Costs — Because of the Mars mission requirements, six pads are required for Missions 1 and 2; Four pads are required for Missions 3 and 4. The cost of these facilities distributed over the total payload weights placed in orbit for each mission results in a high cost of 30.5 dollars per pound for Mission 2 and a low cost of 18 dollars per pound for Mission 3.

Development Costs — The development costs are the same for all four missions. Costs per pound of payload in orbit are directly affected here by the number of successful launches made. The proration of this cost shows a low of 36.9 dollars per pound for Mission 1 and a high of 56.1 dollars per pound for Mission 4.

| COST OF PAYLOADS LOST | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mission | Wt/Launch | Successful Launches | Total Launches | Launches Lost | Payload Wt. Lost | Cost of Payloads Lost | | |
| | | | | | | PFL = 0 | PLF = 10 | PLF = 50 |
| 1 | 1,165,000 | 70 | 79 | 9 | 10,485,000 | 0 | 104,850,000 | 524,250,000 |
| 2 | 1,165,000 | 53 | 60 | 7 | 8,155,000 | 0 | 81,550,000 | 407,750,000 |
| 3 | 1,165,000 | 63 | 71 | 8 | 9,320,000 | 0 | 93,200,000 | 466,000,000 |
| 4 | 1,165,000 | 46 | 53 | 7 | 8,155,000 | 0 | 81,550,000 | 407,750,000 |

Table 5.4-1

| SUMMARY OF OPERATIONAL AND PAYLOADS-LOST COST* (Dollars in Thousands) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mission | Operational Program Cost | | Operational Program Cost + Payloads-Lost Cost | | | | | |
| | | | Definitive | | | Budgetary | | |
| | Definitive | Budgetary | PLF = 0 | PLF = 10 | PLF = 50 | PLF = 0 | PLF = 10 | PLF = 50 |
| 1 | 6,076,652 | 6,684,317 | 6,076,652 | 6,181,502 | 6,600,902 | 6,684,317 | 6,789,167 | 7,208,567 |
| 2 | 4,904,058 | 5,394,464 | 4,904,058 | 4,985,608 | 5,311,808 | 5,394,464 | 5,476,014 | 5,802,214 |
| 3 | 5,477,985 | 6,025,784 | 5,477,985 | 5,571,185 | 5,943,985 | 6,025,784 | 6,118,984 | 6,491,784 |
| 4 | 4,370,097 | 4,807,107 | 4,370,097 | 4,451,647 | 4,777,847 | 4,807,107 | 4,888,657 | 5,214,857 |

* Costs do not include transtage costs.

Table 5.4-2

SUMMARY OF TOTAL PROGRAM AND PAYLOADS-LOST COST
(Dollars in Thousands)

| Mission | Total Program Costs* | | Total Program Cost + Payloads-Lost Cost | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Definitive | | | Budgetary | | |
| | Definitive | Budgetary | PLF = 0 | PLF = 10 | PLF = 50 | PLF = 0 | PLF = 10 | PLF = 50 |
| 1 | 12,125,854 | 14,245,820 | 12,125,854 | 12,230,704 | 12,650,104 | 14,245,820 | 14,350,670 | 14,770,070 |
| 2 | 10,947,260 | 12,948,467 | 10,947,260 | 11,028,810 | 11,355,010 | 12,948,467 | 13,030,017 | 13,356,217 |
| 3 | 10,959,187 | 12,877,287 | 10,959,187 | 11,052,387 | 11,425,187 | 12,877,287 | 12,970,487 | 13,343,287 |
| 4 | 9,840,299 | 11,644,860 | 9,840,299 | 9,921,849 | 10,248,049 | 11,644,860 | 11,726,410 | 12,052,610 |

* Total program costs do not include transtage costs.

Table 5.4-3

## COST EFFECTIVENESS COMPARISON

| Mission and Type of System Cost | | Dollars/Pound of Payload in Orbit | | |
|---|---|---|---|---|
| | | PLF = 0 | PLF = 10 | PLF = 50 |
| 1 | Operational Definitive | 75 | 76 | 81 |
| 2 | | 79 | 81 | 86 |
| 3 | | 75 | 76 | 81 |
| 4 | | 82 | 83 | 89 |
| 1 | Operational Budgetary | 82 | 83 | 88 |
| 2 | | 87 | 89 | 94 |
| 3 | | 82 | 83 | 88 |
| 4 | | 90 | 91 | 97 |
| 1 | Total Definitive | 149 | 150 | 155 |
| 2 | | 177 | 179 | 184 |
| 3 | | 149 | 151 | 156 |
| 4 | | 184 | 185 | 191 |
| 1 | Total Budgetary | 175 | 176 | 181 |
| 2 | | 210 | 211 | 216 |
| 3 | | 175 | 177 | 182 |
| 4 | | 217 | 219 | 225 |

Table 5.4-4

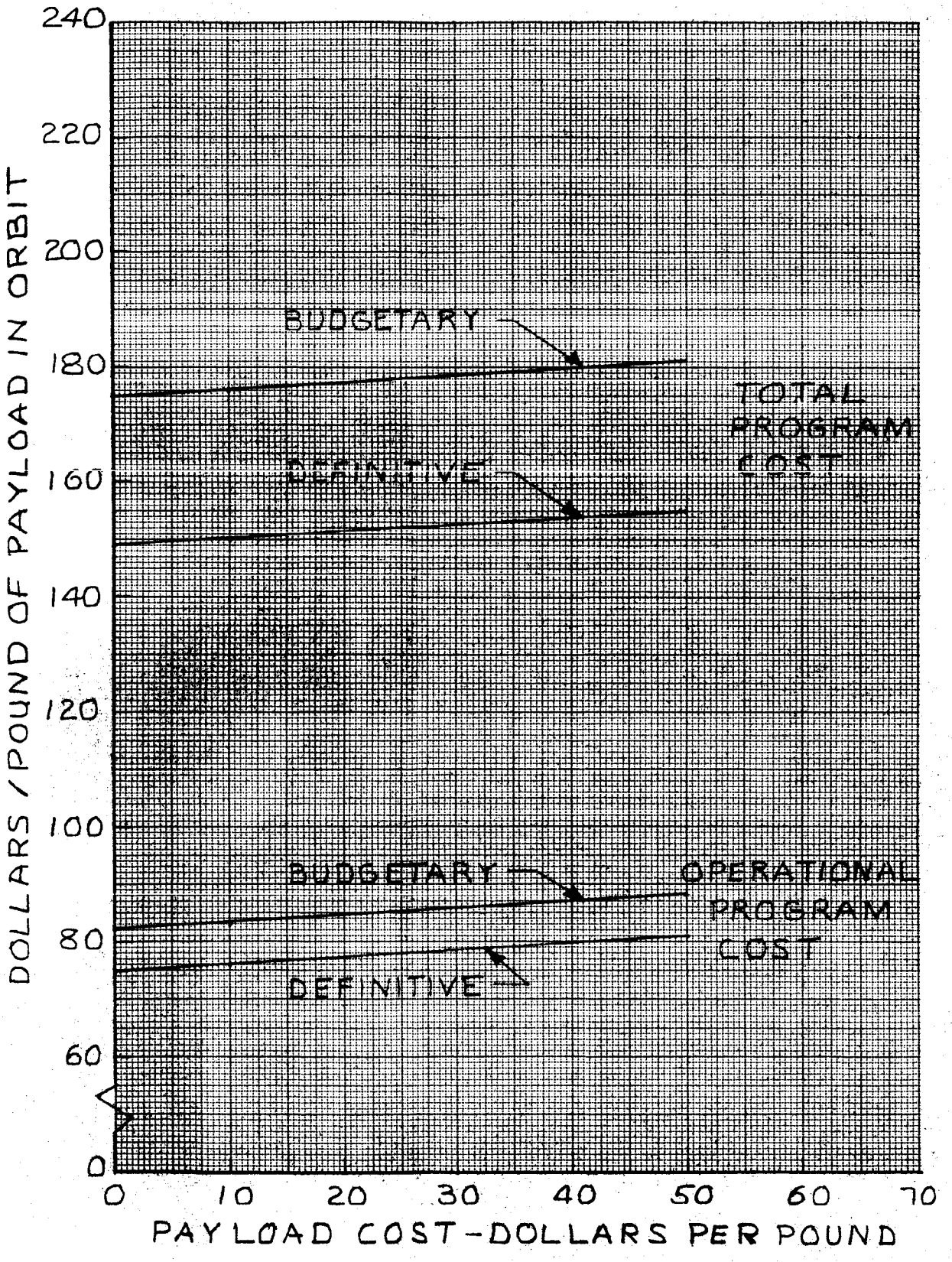



**Figure 5.4-1 COST EFFECTIVENESS COMPARISON**
**Mission Model No. 1**

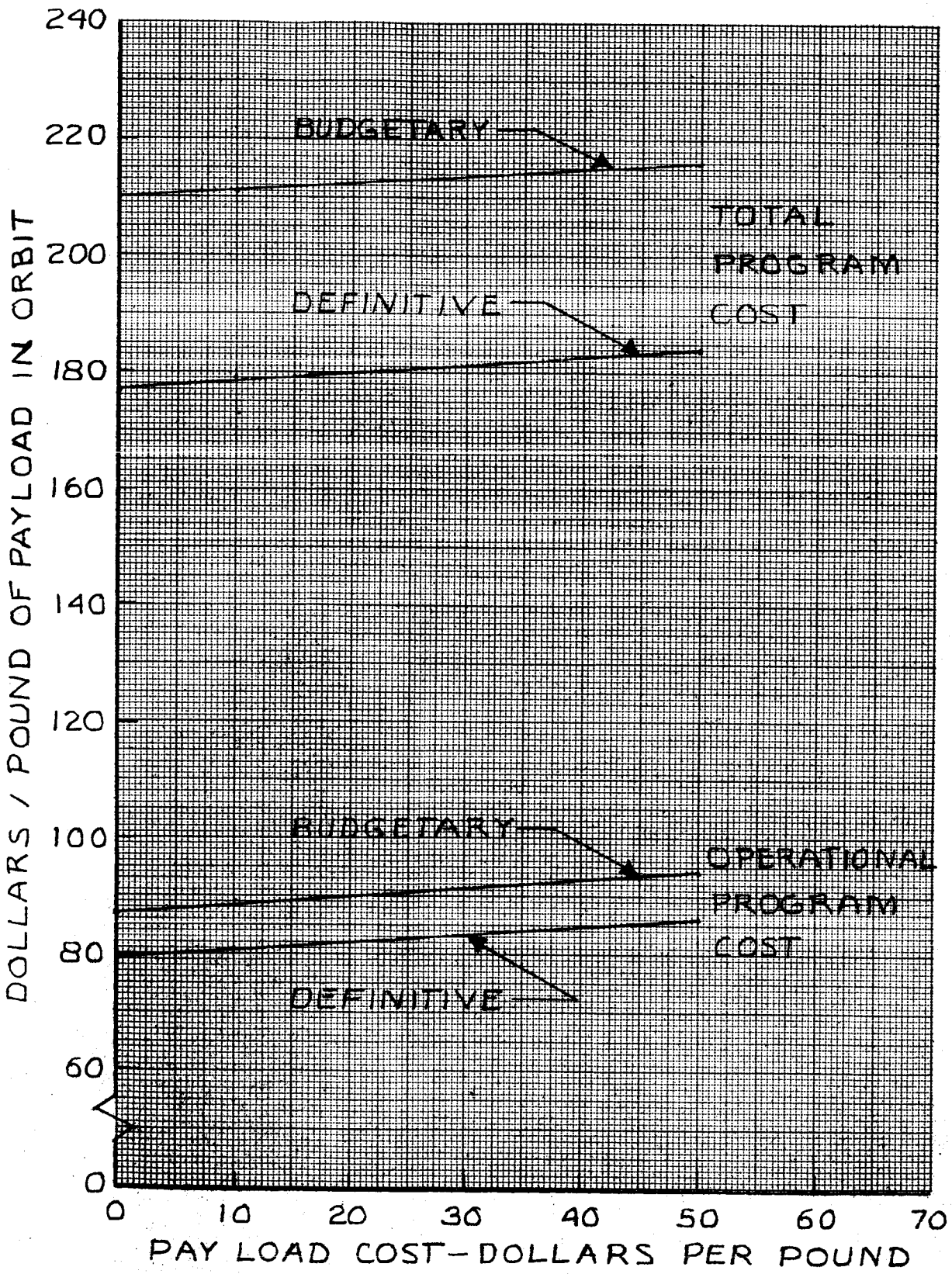



**Figure 5.4-2 COST EFFECTIVENESS COMPARISON**
**Mission Model No. 2**

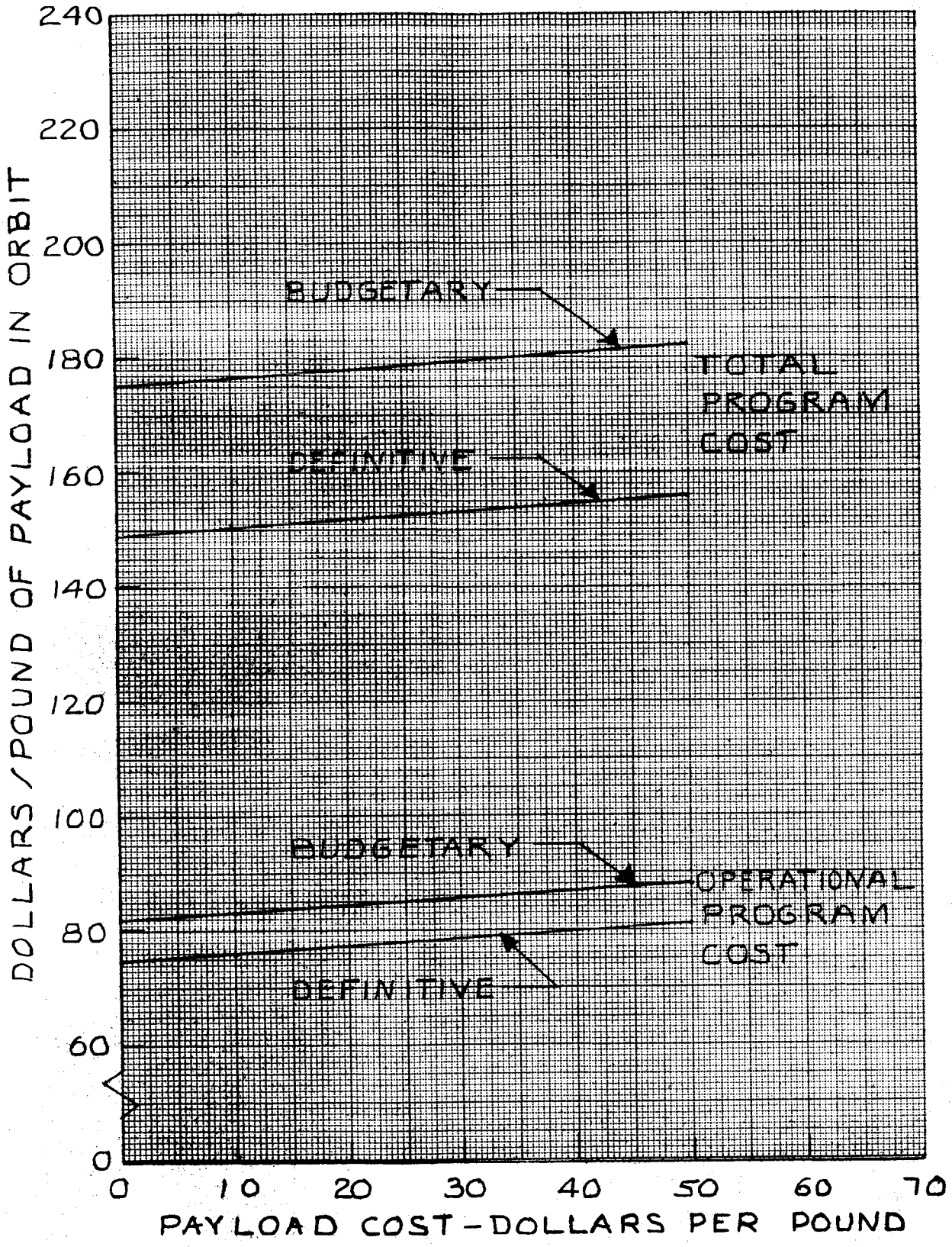



**Figure 5.4-3 COST EFFECTIVENESS COMPARISON**
**Mission Model No. 3**

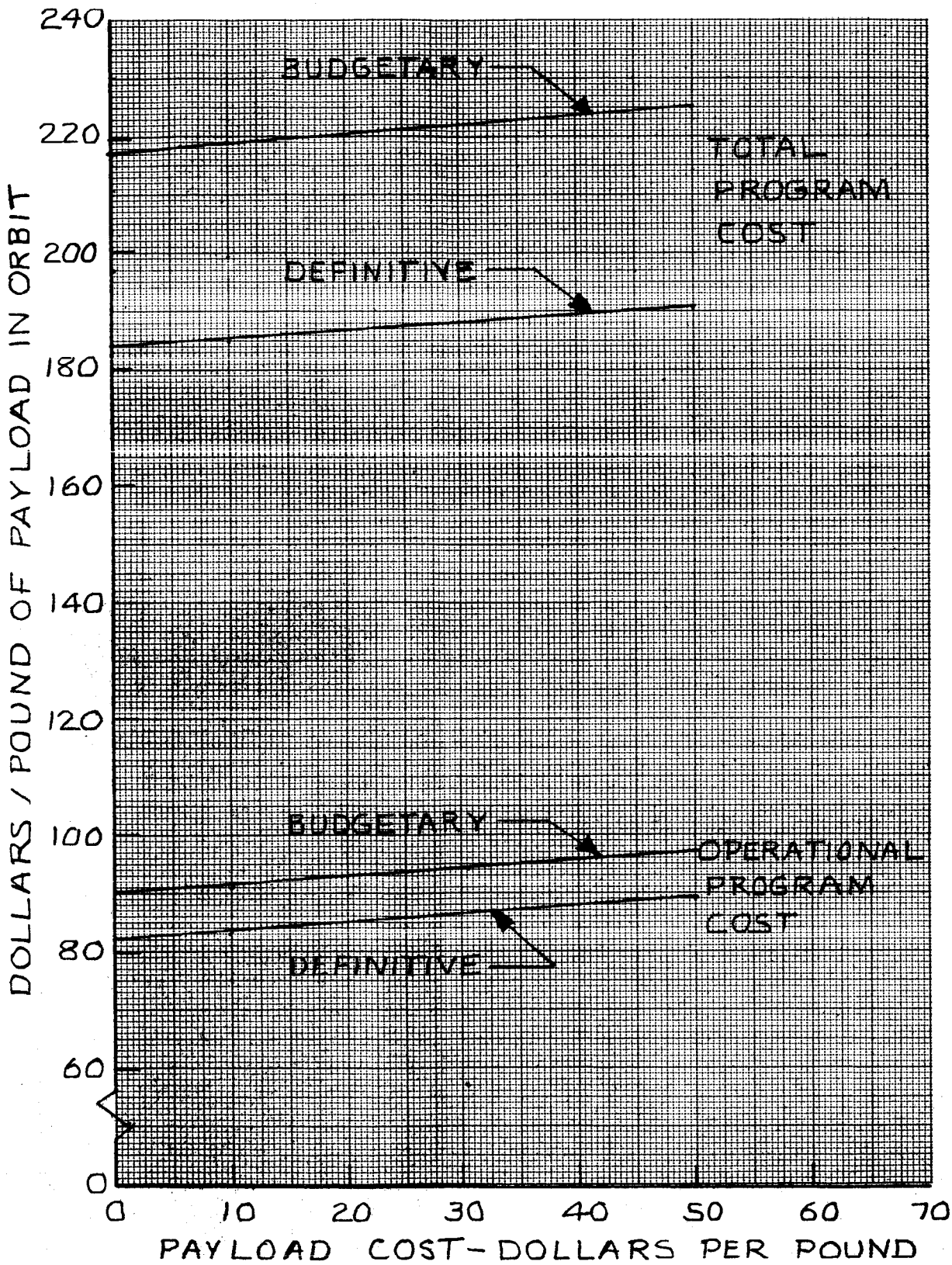



**Figure 5.4-4 COST EFFECTIVENESS COMPARISON**
**Mission Model No. 4**

Fixed Costs — Some items of cost are the same, or "fixed", for each of the four missions. These items are: ground support equipment design and fabrication; tool engineering, design and fabrication; manufacturing facilities; and test facilities. The proration of these costs over the payloads placed in orbit results in a high of 18.8 dollars per pound for Mission 4 and a low of 12.4 dollars per pound for Mission 1.

Airborne Vehicle and Spares — These costs are a significant part of the total dollar-per-pound cost. However, the variance due to learning-curve effect on the different production quantities is not as large as might be expected. The cost range for first- and second-stage vehicles and spares is 53.5 dollars per pound for Mission 1 and 57.1 dollars per pound for Mission 4.

The column chart, Figure 5.4-5, shows the effects discussed above. The composite effect of these factors is a reduction in cost per pound in orbit with increasing launch rates or total launches. Resultant cost effectiveness comparisons are summarized in Table 5.4-4.

### 5.4.2 Cost Effectiveness — Advanced-Technology Vehicles

Cost effectiveness of three advanced-technology vehicles (AT-41, APM-67B, and APM-41) has been calculated using total and operational program definitive- and budgetary-type cost estimates from Section 5.3. Mission 1, which requires a total of 79 launch attempts, has been selected for this analysis. Data used and their source are listed below:

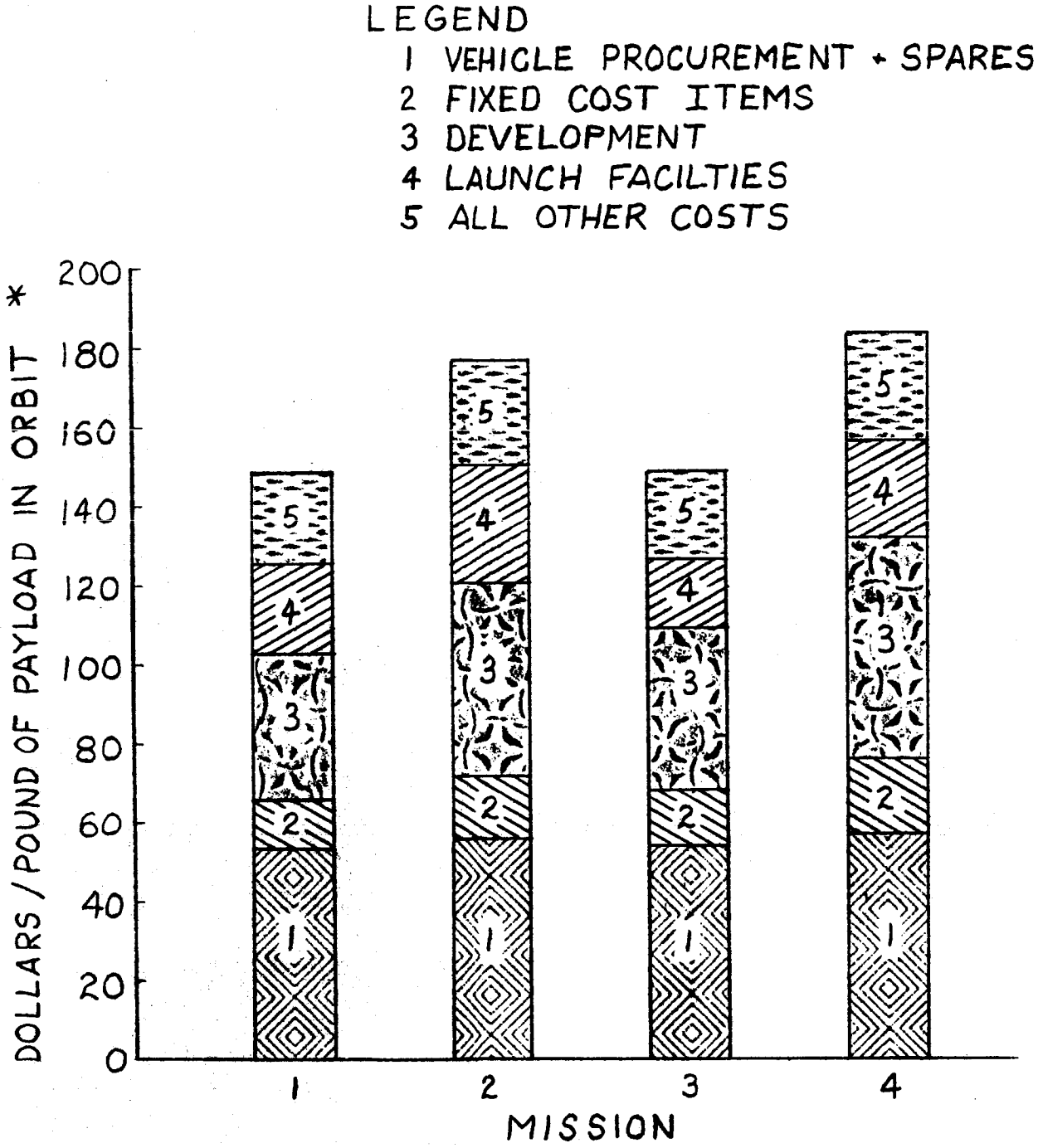
- Payload weight per launch to a 225-kilometer orbit — 1,100,000 pounds
- Payloads-lost factor of 0 dollars per pound
- Average cumulative reliabilities from Section 4.10
- Total program and operational program system costs from Section 5.3

#### 5.4.2.1 Development of Costs

The method of developing the dollar per pound of payload in orbit costs used for the cost-effectiveness comparison of this section is evident in Tables 5.4-5 and 5.4-6. The system cost shown in Table 5.4-6 is divided by the total payload in orbit, Table 5.4-5, to determine the cost in dollars per pound in orbit. The number of successful launches is the product of the total launches (79) and the vehicle cumulative average reliability.

#### 5.4.2.2 Cost-Effectiveness Comparison

The comparison of the three advanced-technology vehicles on a cost effectiveness basis for four types of system costs is shown in Table 5.4-7. Corresponding cost effectiveness figures for the T65D vehicle are included for comparison.




* TOTAL PROGRAM DEFINITIVE COSTS LESS TRANSTAGE COSTS

**Figure 5.4-5 COST EFFECTIVENESS ANALYSIS**

TOTAL PAYLOAD IN ORBIT

| Vehicle | Reliability | Total Launches | Successful Launches | Payload Wt/Launch | Total Payload In Orbit |
|---|---|---|---|---|---|
| AT-41 | 0.873 | 79 | 69 | 1,100,000 | 75,900,000 |
| APM-67B | 0.848 | 79 | 67 | 1,100,000 | 73,700,000 |
| APM-41 | 0.886 | 79 | 70 | 1,100,000 | 77,000,000 |

Table 5.4-5

SYSTEM COSTS*
(Dollars in Thousands)

| | Operational Program Costs | | Total Program Costs | |
|---|---|---|---|---|
| Vehicle | Definitive | Budgetary | Definitive | Budgetary |
| AT-41 | 4,706,395 | 5,177,035 | 10,341,427 | 12,784,328 |
| APM-67B | 5,202,670 | 5,722,937 | 10,534,638 | 12,921,094 |
| APM-41 | 3,941,585 | 4,335,744 | 9,182,106 | 11,410,447 |

*Costs do not include transtage costs.

Table 5.4-6

COST EFFECTIVENESS COMPARISON

| | Dollars Per Pound of Payload in Orbit | | | | |
|---|---|---|---|---|---|
| | Operational Program Costs | | Total Program Costs | | Reliability (Cum. Avg.) |
| Vehicle | Definitive | Budgetary | Definitive | Budgetary | |
| AT-41 | 62 | 68 | 136 | 168 | 0.873 |
| APM-67B | 71 | 78 | 143 | 175 | 0.848 |
| APM-41 | 51 | 56 | 119 | 148 | 0.886 |
| T65D | 75 | 82 | 149 | 175 | 0.886 |

Table 5.4-7

5.4.2.3 Cost-Effectiveness Analysis

Cost-effectiveness values vary for the three advanced-technology vehicles (AT-41, APM-67B, and APM-41) under consideration. An analysis of the seven groupings of cost items shown in Figure 5.4-6 and their influence on the cost effectiveness follows:

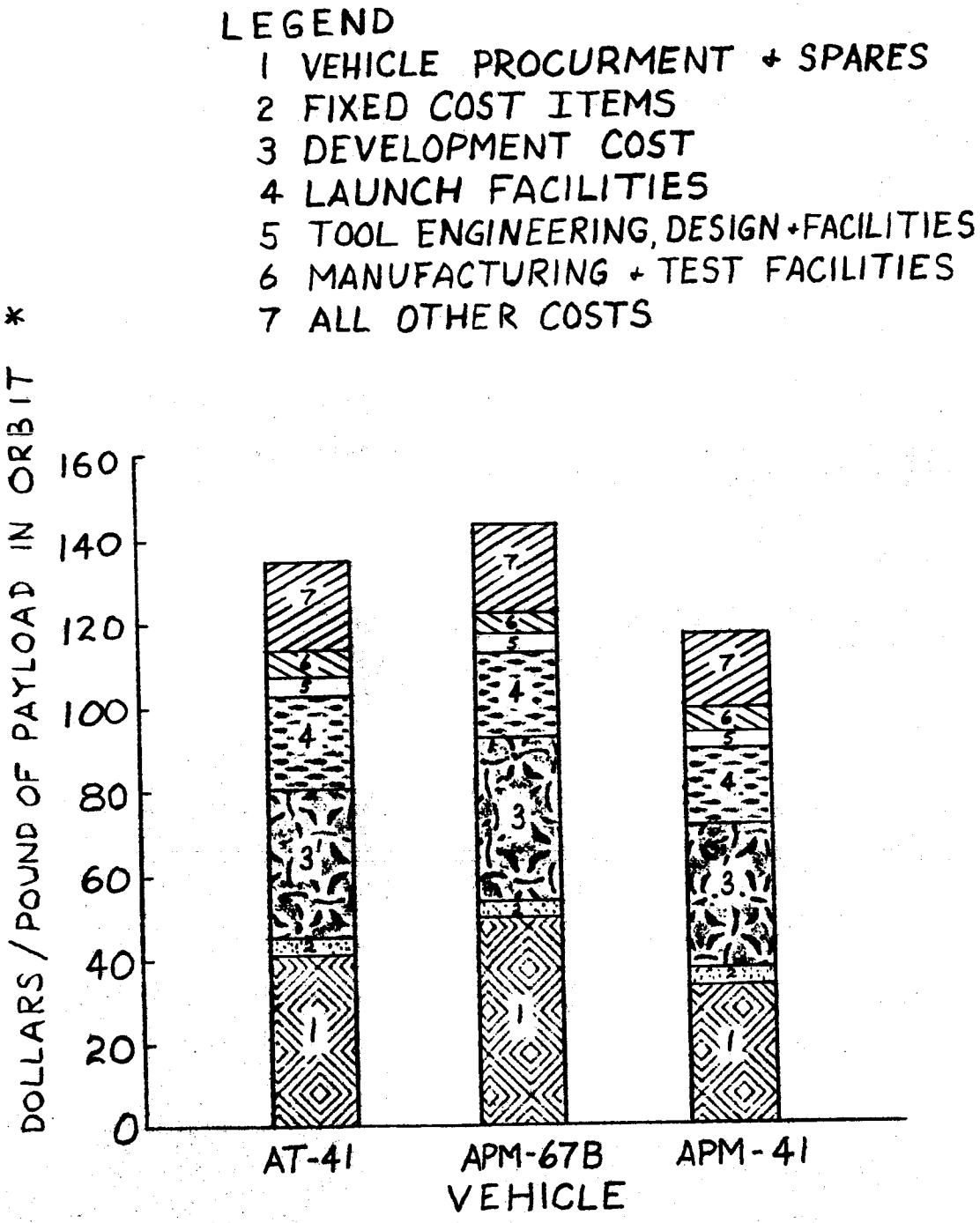
Vehicle Procurement and Spares — This item shows a more significant change in cost for the various vehicles than any other item examined. It varies from a low of 33.0 dollars per pound in orbit for the APM-41 vehicle to a high of 49.4 dollars per pound for the APM-67B vehicle. The cost is related to the size of the vehicle. The total weight of the first stage, the inert weight of the second stage, and the clustering of the second-stage engines have the greatest effect on cost. In this case, the APM-67B vehicle has the greatest weight, while the APM-41 has the least weight of the three.

Fixed Items — These items included GSE design and fabrication, miscellaneous facilities, and program management. These costs were nearly the same for all vehicles. The only variation was due to the difference in pounds of payload in orbit for the different vehicles. They varied from 4.2 to 4.4 dollars per pound.

Development Costs — The development costs for the three types of vehicles distributed over their respective total payloads placed in orbit result in little variation with a high of 38.4 dollars per pound in orbit for the APM-67B vehicle and low costs of 36.8 dollars per pound and 36.0 dollars per pound for the AT-41 and APM-41, respectively. Factors affecting development costs and their influence on cost effectiveness are motor, engine, and stage design and development, vehicle size, and number of flight tests required. The effects of vehicle size and number of flight tests required overshadow the effects of design and development costs. Thus, the APM-67B vehicle, which is the largest of the three configurations and requires the greatest number of flight tests, shows the greatest influence of development costs on cost effectiveness.

Launch Facilities — These costs vary from a high of 22.2 dollars per pound in orbit for the AT-41 vehicle to 18.4 dollars per pound for the APM-41 vehicle. The AT-41 vehicle, which is a tandem vehicle, will require a taller assembly and launch building than the parallel-type vehicles. This taller building, with its increased cost, results in a higher influence on cost effectiveness for the AT-41 vehicle system.

Tool Engineering, Design, and Fabrication — These costs show very little influence on overall system cost effectiveness. Their effects vary from a high of 5.3 dollars per pound in orbit for the AT-41 vehicle to a low of 3.8 dollars per pound for the APM-41 vehicle.




* TOTAL PROGRAM DEFINITIVE COSTS LESS TRANSTAGE COSTS

Figure 5.4-6 COST EFFECTIVENESS ANALYSIS

Manufacturing and Test Facilities — These costs also show very little influence on overall cost effectiveness. Their effects vary from 4.7 dollars per pound in orbit for the APM-67B vehicle to 5.9 dollars per pound for the AT-41 vehicle.

All Other Costs — These costs include sustaining engineering, propellants, transportation, launch operations and tooling, and GSE maintenance costs. They cause variations in cost effectiveness from 20.9 dollars per pound in orbit for the APM-67B vehicle to 17.9 dollars per pound for the APM-41 vehicle. The weight of the vehicle seems to have the greatest effect. The height of the vehicle can also have considerable effect and, in this case, the influence of height on launch operations cost for the higher but lighter AT-41 vehicle resulted in almost the same cost effectiveness increment (20.8 dollars per pound) as for the APM-67B vehicle.

The column chart, Figure 5.4-6, shows the results discussed above. Resultant cost effectiveness comparisons are summarized in Table 5.4-7.

### 5.4.3 Effects of NASA-Recommended Solid-Motor Costs on Cost Effectiveness

Cost effectiveness of the T65D vehicle and the three advanced-technology vehicles (APM-41, APM-67B, and AT-41) using NASA-recommended solid-motor costs has been calculated. Mission No. 1, which requires 79 launch attempts, was used in this analysis. Data used and their sources are:

- Payload weight per launch to a 225-kilometer orbit — 1,165,000 pounds for the T65D vehicle and 1,100,000 for the advanced-technology vehicles
- Payload lost factor of 0 dollars per pound
- Average cumulative reliabilities from Section 4.10
- Total-program and operational-program system costs using NASA-recommended solid-motor costs from Section 5.3

#### 5.4.3.1 Development of Costs

The method of developing the dollars per pound of payload in orbit costs used for the cost effectiveness comparison of this section is evident in Tables 5.4-8 and 5.4-9. The system cost shown in Table 5.4-8 is divided by the total payload in orbit, Table 5.4-9, to determine the cost in dollars per pound of payload in orbit.

#### 5.4.3.2 Cost Effectiveness Comparison

The comparison of the T65D vehicle with the three advanced-technology vehicles on a cost effectiveness basis (using NASA-recommended solid-motor costs) is shown in Table 5.4-9. This table shows that the APM-41 vehicle has the best

cost effectiveness, followed, in order, by AT-41, APM-67B, and T65D. Table 5.4-7, which reflects Boeing-estimated costs for the solid motors, indicates the same order of cost effectiveness for the vehicles under consideration. NASA-recommended solid-motor costs, therefore, have the effect of increasing the dollars per-pound-of-payload-in-orbit cost without changing the order of cost effectiveness of the four vehicles under consideration.

SYSTEM COSTS*
(Dollars in Thousands)

| Vehicle | Operational Program | Total Program |
|---|---|---|
| T65D | 9,819,926 | 16,402,384 |
| APM-41 | 5,170,730 | 10,569,581 |
| APM-67B | 7,528,077 | 13,222,439 |
| AT-41 | 6,638,224 | 12,403,287 |

* Costs do not include transtage and astrionics costs
(Costs are based on NASA-recommended solid-motor costs)

Table 5.4-8

COST EFFECTIVENESS COMPARISON

| Vehicle | Total Pounds Payload in Orbit | Dollars Per Pound of Payload in Orbit | |
|---|---|---|---|
| | | Operational Program | Total Program |
| T65D | 81,550,000 | 120 | 201 |
| APM-41 | 77,000,000 | 67 | 137 |
| APM-67B | 73,700,000 | 102 | 179 |
| AT-41 | 75,900,000 | 87 | 163 |

Table 5.4-9

### 5.4.4 Cost Comparisons

The three advanced-technology vehicles (AT-41, APM-41, and APM-67B) were costed from conceptual engineering studies for comparison with the T65D current-technology vehicle. In this section, the important elements of the system costs are compared. The reasons for major differences in cost elements are discussed.

#### 5.4.4.1 System Cost

The system costs for major elements of the four configurations are presented graphically in Figure 5.4-7. The current-technology vehicle (T65D) shows the highest cost, with the APM-67B, AT-41, and APM-41 showing successively lower costs. Greatest differences result from the vehicle costs with lesser differences in development, facilities, and operations.

The costs have been estimated from engineering descriptions of the system and vehicle configurations. The important differences in the vehicles are in the quantity and length of first-stage motors, the quantity and size of hydrogen engines and tankage size used, the staging concept, separation concept, and the mode of operation of the liquid stages. Subsystems are functionally similar for all configurations. The transtage and astrionics equipment are identical. The descriptions of the technical design are discussed in Sections 3.0 and 4.0. These descriptions are the basis for the estimates and create the differences in costs for the four systems. Table 5.4-10 below summarizes some of the salient characteristics of each system contributing to the differences in total costs.

| | T65D | AT-41 | APM-67 | APM-41 |
|---|---|---|---|---|
| First-stage weight | | | | |
| Motors (lbs x $10^6$) | 27.35 | 13.34 | 16.09 | 9.10 |
| Equipment and structure (lbs x $10^6$) | 0.568 | 0.468 | 0.125 | 0.108 |
| Second-stage weight | | | | |
| Engines (lbs x $10^6$) | 0.100 | 0.089 | 0.122 | 0.093 |
| Equipment and structure (lbs x $10^6$) | 0.497 | 0.677 | 0.761 | 0.702 |
| Number of flight tests | 13 | 10 | 14 | 13 |
| Operational flights | 79 | 79 | 79 | 79 |
| Second-stage engine | | | | |
| Quantity and type | 5 M-1 | 1 L-9H Toroidal | 7 M-1 | 1 L-9H Toroidal |
| Vacuum thrust each (lbs x $10^6$) | 1.5 | 11.1 | 1.5 | 11.2 |

Table 5.4-10

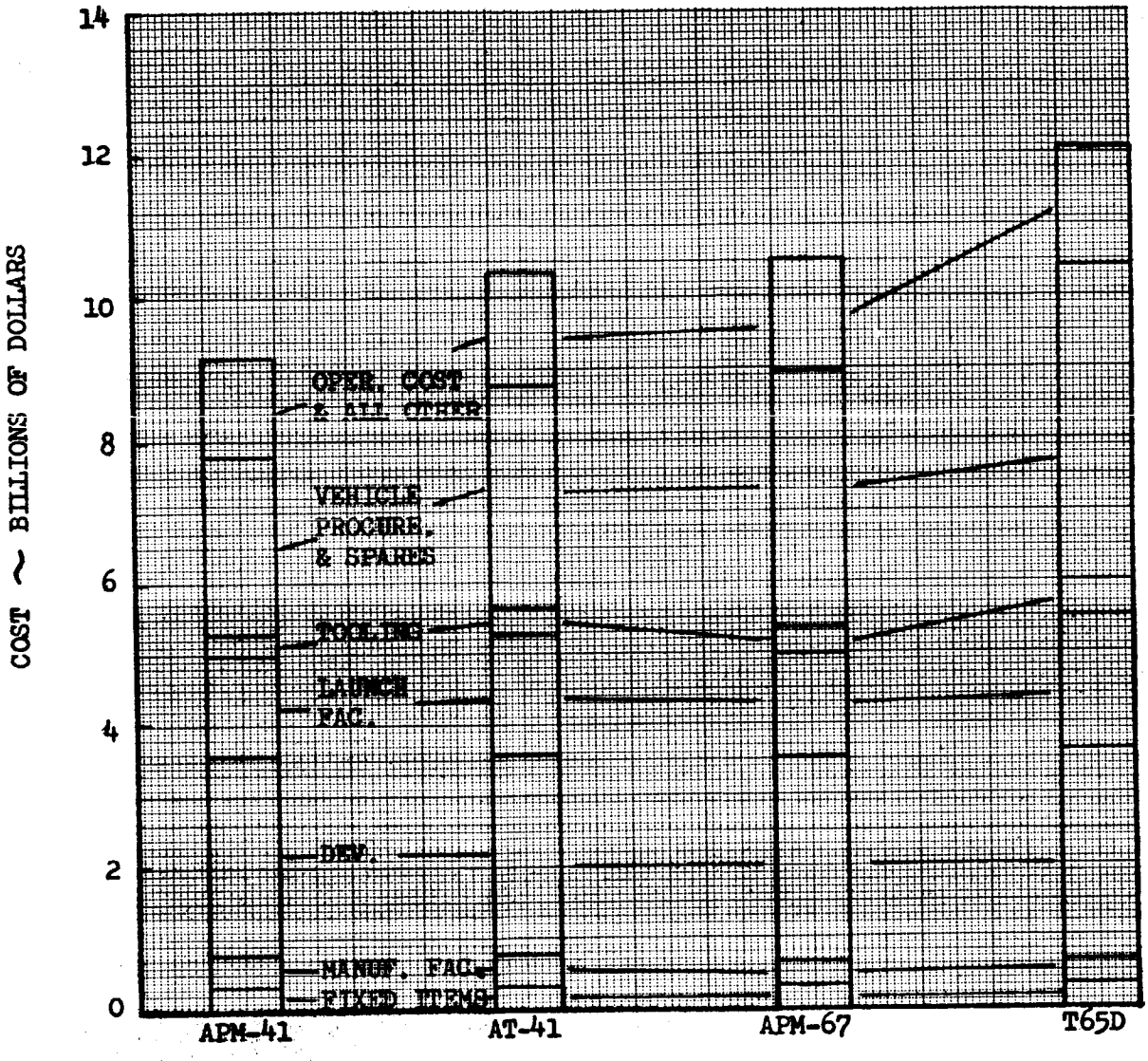



Figure 5.4-7 LAUNCH SYSTEM COST COMPARISON

Airborne, Vehicle Cost — The major differences in vehicle cost come from the airborne vehicle. The vehicle contributes more than 25 percent of the system cost and accounts for more than 50 percent of the difference between the systems. Figure 5.4-8 shows the vehicle and spares procurement costs for the four systems. Spares are estimated at 3 percent of the total vehicle procurement.

The procurement costs are shown to have a relationship to the weight of configurations of similar designs and comparable design factors. Figures 5.4-9, -10, and -11 show graphically the trends in vehicle costs with size. Costs are shown for a quantity of 92 vehicles. A slight adjustment to the cost shown in the summaries is necessary in two concepts to fit this quantity because of the difference in required number of flight tests.

Stage cost, which does not include motors, is shown in Figure 5.4-9. The low point for APM-41 relative to APM-67 is partly attributable to the stage-separation concept. As discussed in the design sections, the solid motors are peeled off on the APM-41, whereas on the APM-67 the solid motors slide back on rails. The use of rails increases the stage weight and contributes to the complexity and cost.

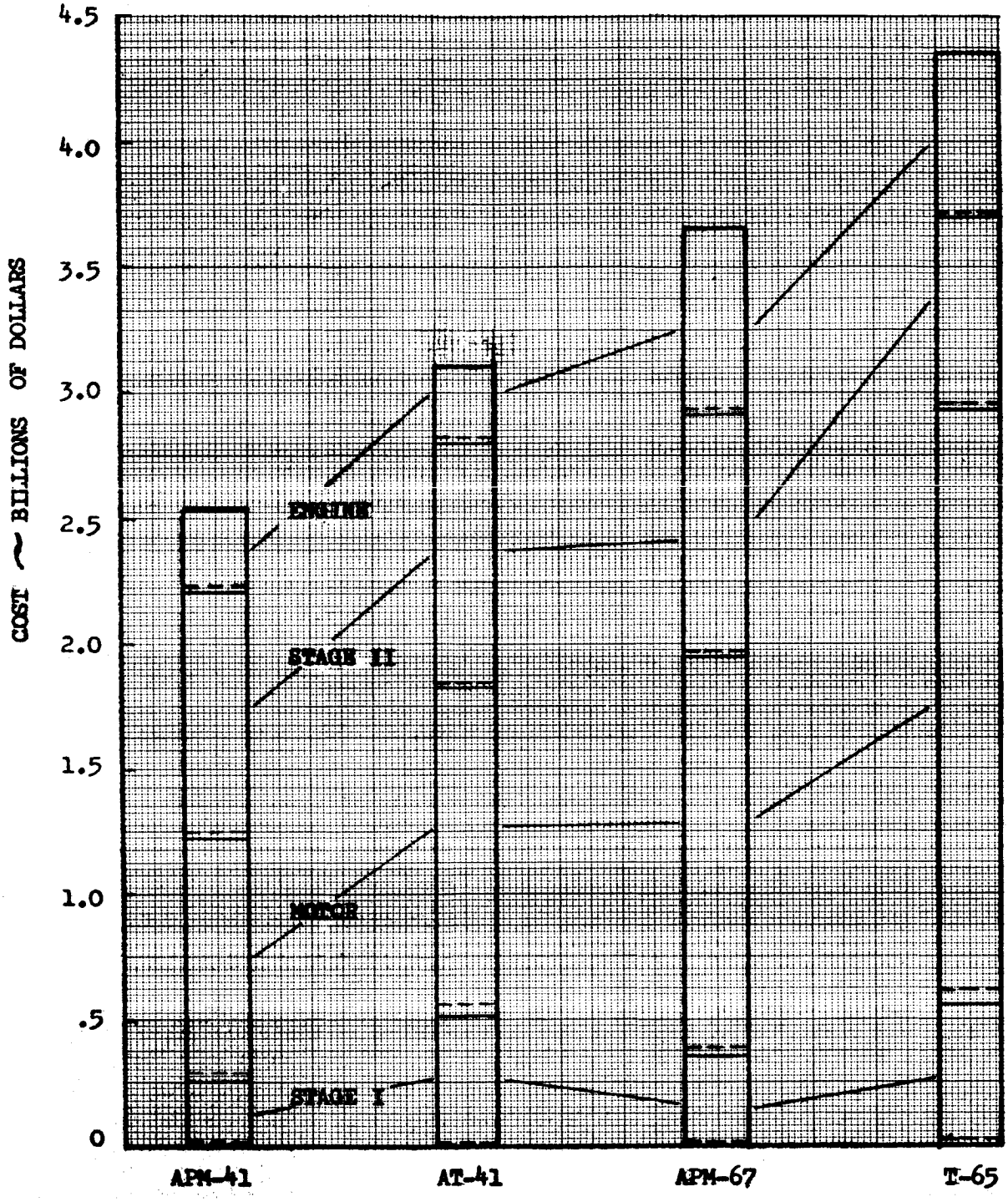



Figure 5.4-8 VEHICLE PROCUREMENT COST COMPARISON

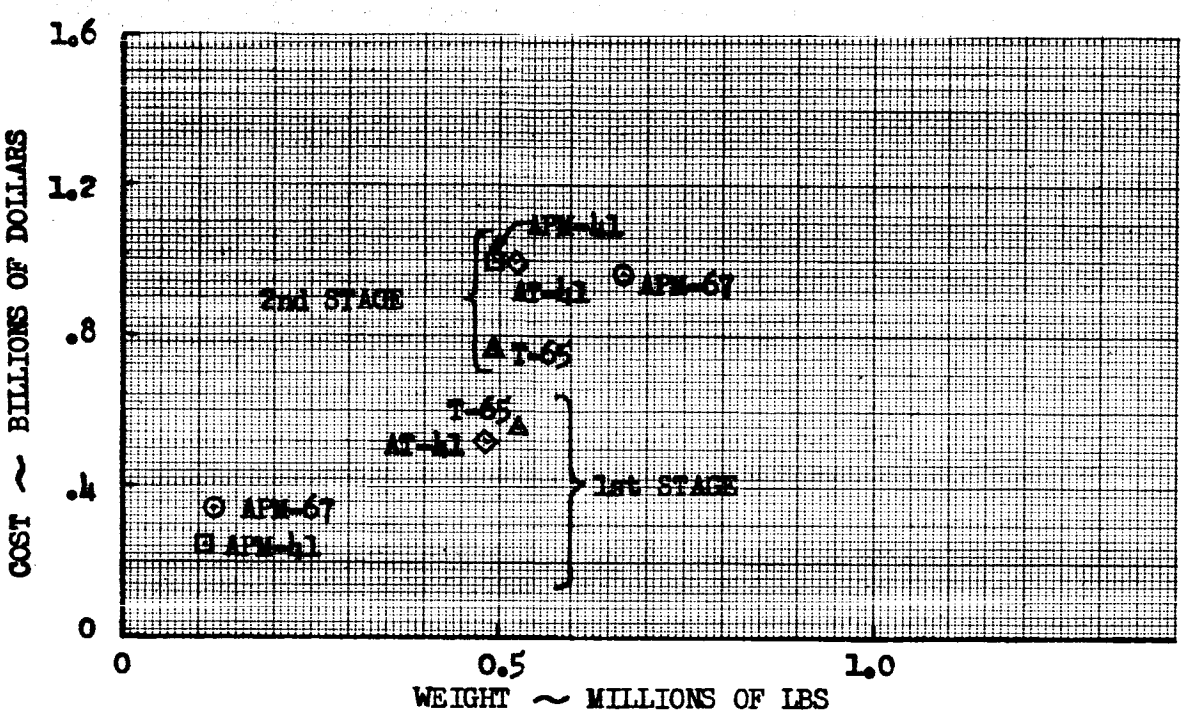



Figure 5.4-9 STAGE COSTS
(Less Engines and Motors)

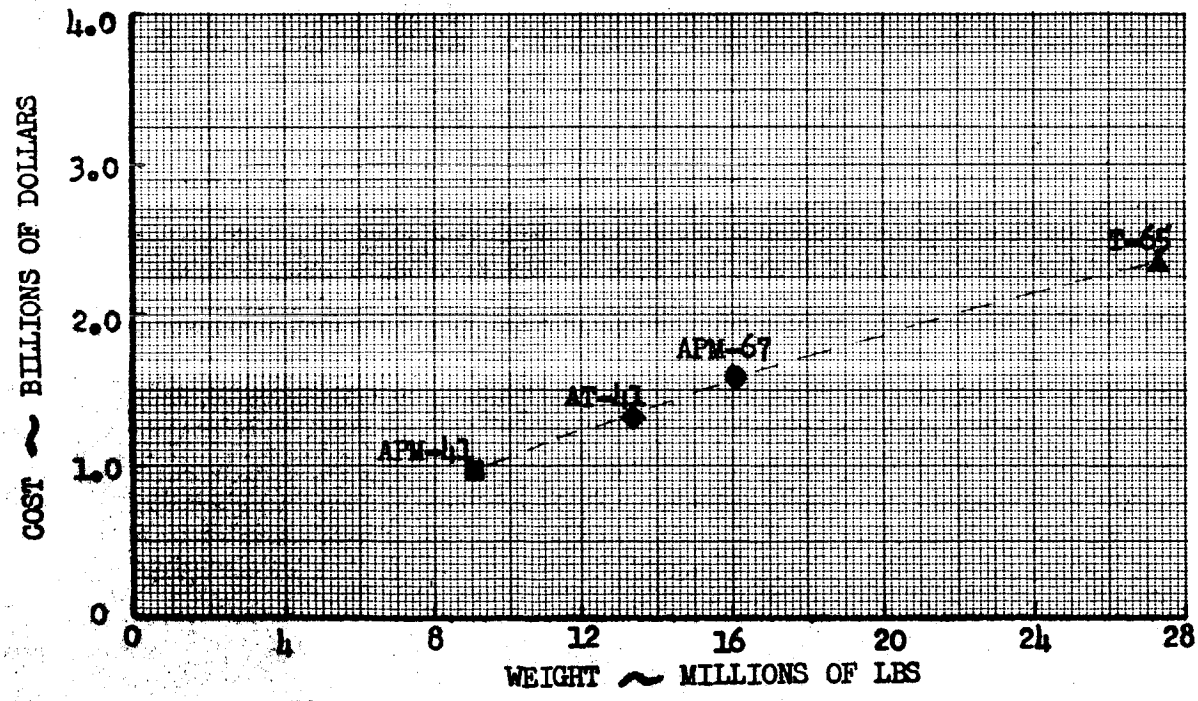



Figure 5.4-10 SOLID MOTOR COSTS

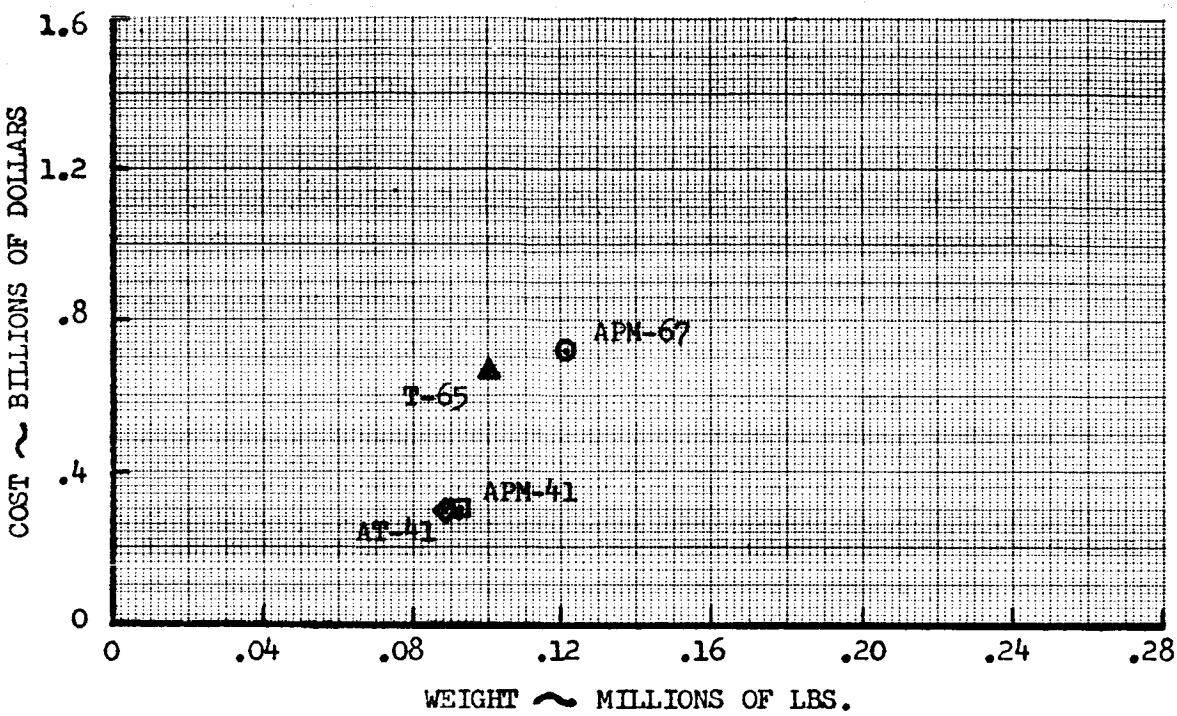



**Figure 5.4-11 SECOND STAGE ENGINE COSTS**

The solid-motor costs in the first stage are shown in Figure 5.4-10. The curve of cost is nearly linear with increasing weight. Liquid-rocket-engine costs are shown in Figure 5.4-11. The M-1 engines used in the T65D and APM-67 are more expensive in total than is the new-design engine of about $11 \times 10^6$ pounds thrust used in the remaining two configurations. The engine for the APM-41 is slightly higher in cost than for the AT-41. Essentially, the two engines are alike except that AT-41 engine design is of lower thrust.

Development —The difference in development cost contributes about 3 percent of the difference between the systems. There are three primary areas that cause the differences. These are in (1) the engine development, (2) the engineering of the vehicle, and (3) the flight test program. Figure 5.4-12 shows the major cost elements of the development program.

The large hydrogen engine contributes heavily to development costs of the APM-41 and AT-41 when compared with the smaller M-1 used in the other two vehicles. The higher test-vehicle costs of the T65D and APM-67B vehicles are a function of vehicle weight and the number of flight tests required.

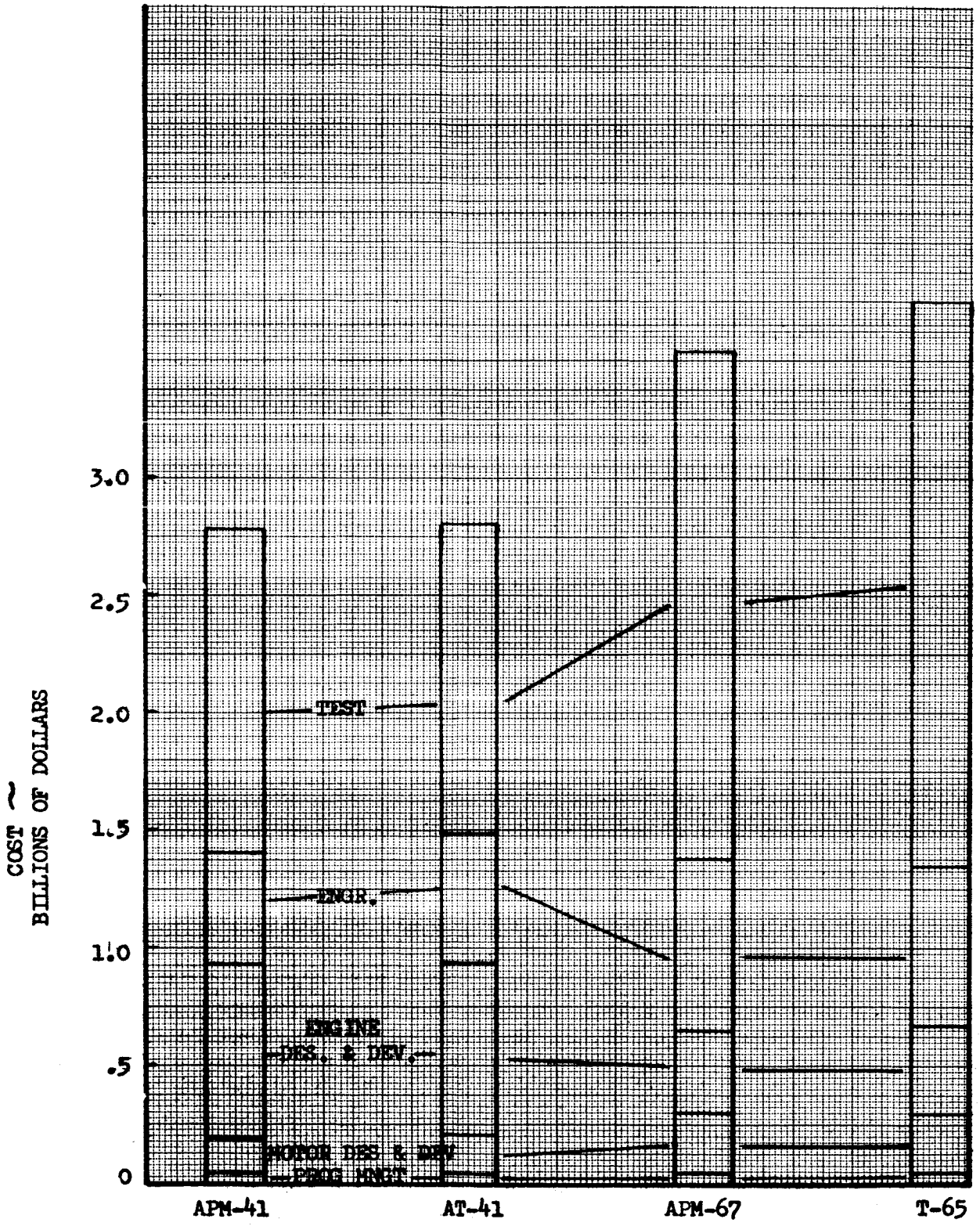



Figure 5.4-12 DEVELOPMENT COST COMPARISON

Manufacturing and Test Facilities, Tooling, and GSE—Manufacturing and test facilities, tooling, and GSE contribute less than 10 percent of the total system cost. The manufacturing facilities include those required for the large hydrogen engines. Facilities for static test and engineering-development tests are essentially the same for all configurations. There is some difference in tooling between configurations, with the tandem-staged vehicles requiring the most tooling. GSE cost for the configurations is the same. Figure 5.4-13 compares these items. Differences that occur in various items offset each other so that the net result shows comparable totals.

Launch Facilities —Launch facility costs are taken directly from Martin-Denver estimates and are shown in Section 5.3. Figure 5.4-14 shows the costs. These costs contribute about 20 percent of the total, and 10 percent of the difference between configurations. Vehicle height is the primary cause of cost variation.

Ground Operations —This category includes all recurring expenditures for launch operations except vehicle costs. The comparison of ground operations is shown in Figure 5.4-15. Primary items of importance are shown. Sustaining engineering is approximately 12 percent of the vehicle procurement cost. Propellant and gases vary slightly between configurations because of the different quantities required. Launch operation costs include manning, launch facility refurbishment, and other launch site recurring expenditures. These costs were furnished by Martin-Denver. These items compose about 15 percent of the total system, but the differences account for only about 5 percent of the total difference between systems.

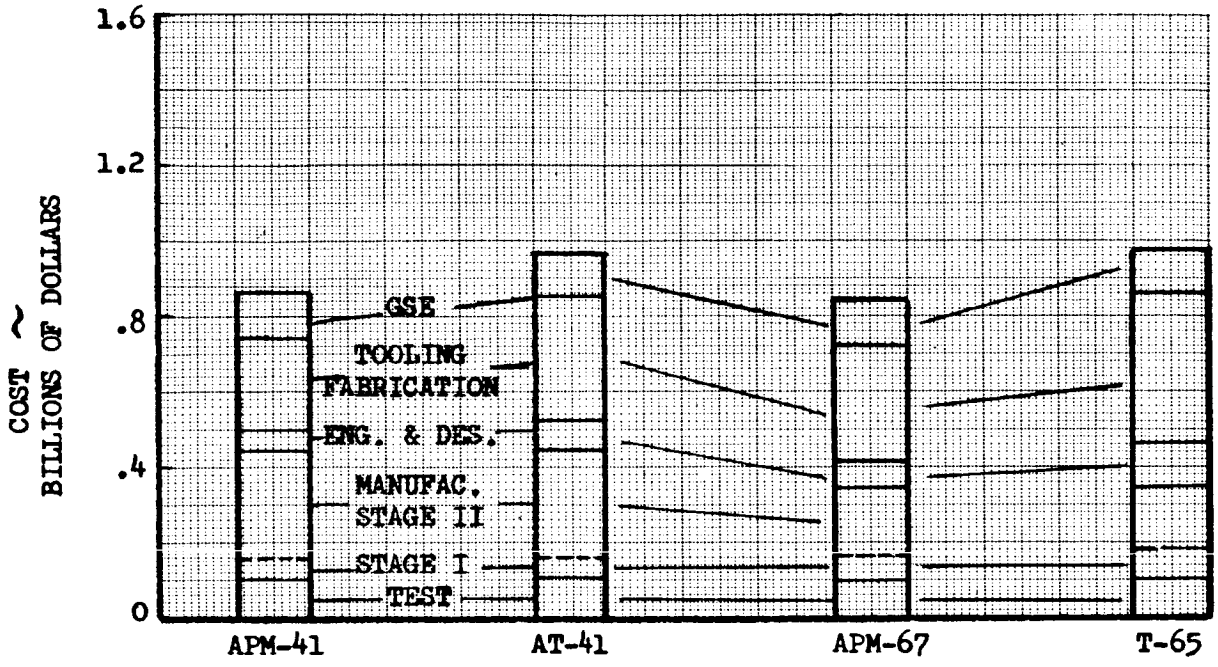



Figure 5.4-13 MANUFACTURING AND TEST FACILITIES
Tooling and GSE Cost Comparison

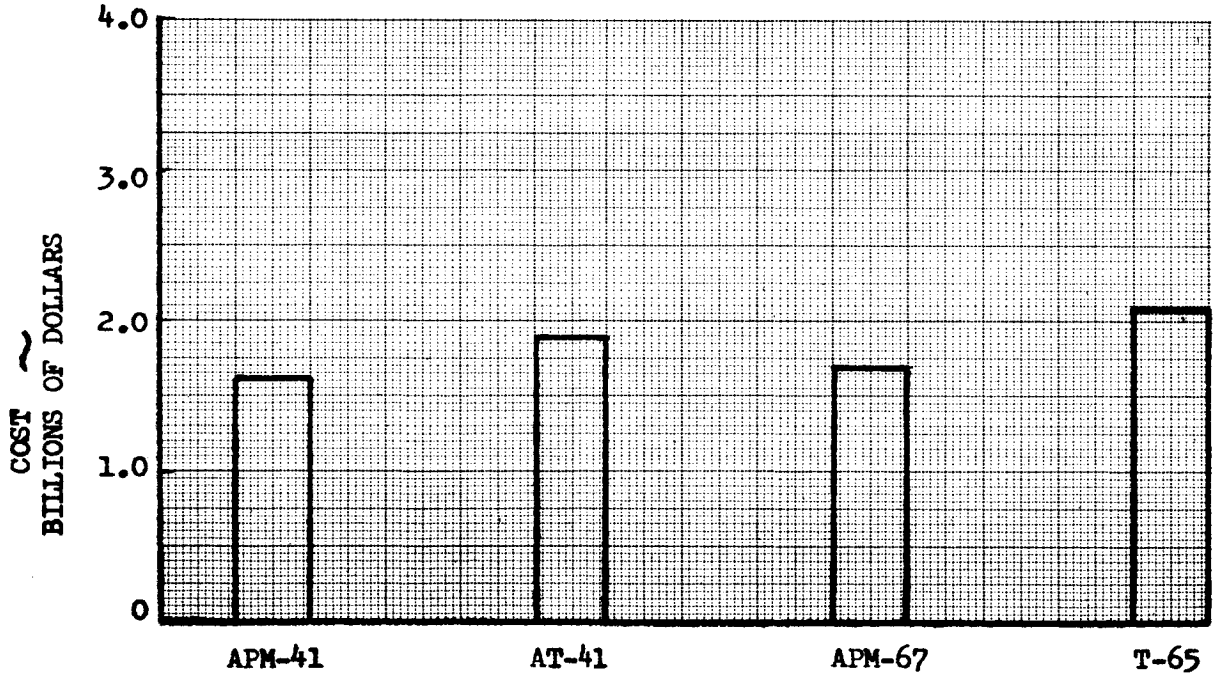



Figure 5.4-14 LAUNCH FACILITY COST COMPARISON

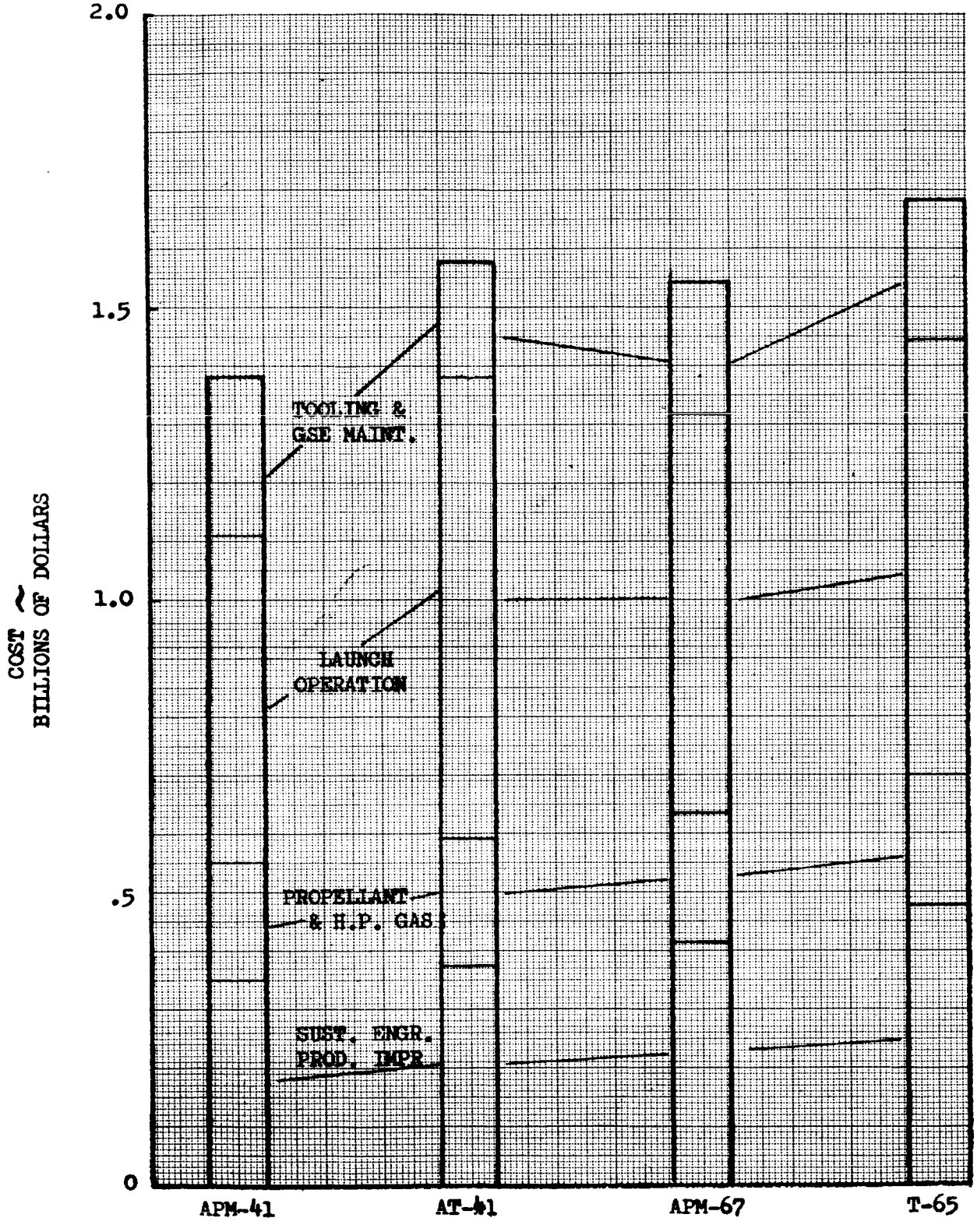



Figure 5.4-15 GROUND OPERATIONS COST COMPARISON