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**GEORGE C. MARSHALL**

**SPACE  
FLIGHT  
CENTER**

**HUNTSVILLE, ALABAMA**

# **LAUNCH VEHICLE ENGINES PROJECT DEVELOPMENT PLAN**

**January 1, 1967**

**National Aeronautics and Space Administration**

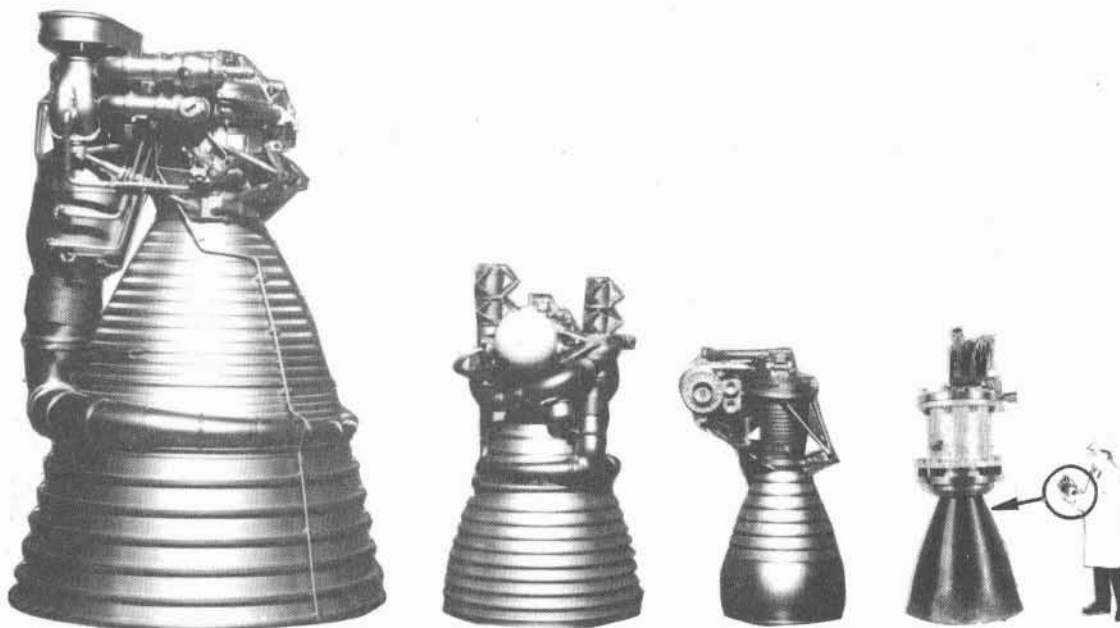
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NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

**LAUNCH VEHICLE ENGINES  
PROJECT DEVELOPMENT PLAN**

January 1, 1967



**INDUSTRIAL OPERATIONS  
ENGINE PROGRAM OFFICE**

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## LAUNCH VEHICLE ENGINES PROJECT DEVELOPMENT PLAN


This document is an official release of Manned Space Flight and its requirements shall be implemented by all cognizant elements of the Manned Space Flight Program.

This document has been prepared in accordance with the requirements of NASA General Management Instruction 4-1-1, and OMSF Instruction MP 9320.044.

The effective date of this document is January 1, 1967.

  
for William D. Brown  
Manager, Engine Program Office

  
Edmund F. O'Connor  
Director, Industrial Operations

  
Wernher von Braun  
Director, Marshall Space Flight Center

Approved:

\_\_\_\_\_  
Samuel C. Phillips  
Major General, USAF  
Apollo Program Director

# TABLE OF CONTENTS

Page

## PART I. PROJECT SUMMARY

A.	Introduction . . . . .	1-1
B.	Mission Objectives . . . . .	1-4
1.	F-1 Engine . . . . .	1-4
2.	H-1 Engine . . . . .	1-4
3.	J-2 Engine . . . . .	1-4
4.	Space Engines . . . . .	1-4
C.	Cost and Manpower . . . . .	1-8
D.	Time Requirements . . . . .	1-8
1.	F-1 Engine . . . . .	1-8
2.	H-1 Engine . . . . .	1-8
3.	J-2 Engine . . . . .	1-8
4.	Space Engines . . . . .	1-9

## PART II. JUSTIFICATION, HISTORY AND RELATED WORK

A.	Justification . . . . .	2-1
1.	F-1 Engine . . . . .	2-1
2.	H-1 Engine . . . . .	2-1
3.	J-2 Engine . . . . .	2-1
4.	Space Engines . . . . .	2-1
B.	History and Related Work . . . . .	2-3
1.	F-1 Engine . . . . .	2-3
a.	General . . . . .	2-3
b.	Development History . . . . .	2-4
c.	Production History . . . . .	2-4
d.	Management History . . . . .	2-5
e.	Technical History . . . . .	2-5
2.	H-1 Engine . . . . .	2-5
a.	General . . . . .	2-5
b.	Development History . . . . .	2-7
c.	Production History . . . . .	2-7
3.	J-2 Engine . . . . .	2-9
a.	General . . . . .	2-9
b.	Development History . . . . .	2-9
c.	Production History . . . . .	2-9
d.	Contractual History . . . . .	2-9



## TABLE OF CONTENTS (CONTINUED)

	Page
4. Space Engines . . . . .	2-9
a. S-IVB Ullage Engines . . . . .	2-9
(1) General . . . . .	2-9
(2) Development History . . . . .	2-10
(3) Production History . . . . .	2-10
(4) Management History . . . . .	2-10
(5) Contractual History . . . . .	2-11
b. C-1 Engine. . . . .	2-11
(1) General . . . . .	2-11
(2) Development History . . . . .	2-11
(3) Production History . . . . .	2-11
(4) Management History . . . . .	2-11
(5) Contractual History . . . . .	2-11
PART III. TECHNICAL PLAN	
A. F-1 Engine . . . . .	3-1
1. Description . . . . .	3-1
a. Development Plan . . . . .	3-1
b. Production Support Plan . . . . .	3-2
c. Reduction in Potential Failure Modes, Increased Utility and Cost Reduction . . . . .	3-5
d. Flight Objectives . . . . .	3-7
e. Existing Engine Component Description . . . . .	3-7
2. Approach . . . . .	3-13
a. Achievement of Project Objectives . . . . .	3-13
b. Elimination of Problem Areas . . . . .	3-14
B. H-1 Engine . . . . .	3-17
1. Description . . . . .	3-17
a. Development Plan . . . . .	3-17
b. Flight Objectives . . . . .	3-23
c. Existing Engine Description . . . . .	3-23
2. Approach . . . . .	3-29
C. J-2 Engine . . . . .	3-29
1. Description . . . . .	3-29
a. Development Plan . . . . .	3-29
b. Flight Objectives . . . . .	3-41
c. Existing Engine Description . . . . .	3-41
2. Approach . . . . .	3-49

## TABLE OF CONTENTS (CONTINUED)

	Page
D. Space Engines . . . . .	3-49
1. S-IVB Ullage Engines . . . . .	3-49
a. Description . . . . .	3-49
b. Gemini Engine Description . . . . .	3-51
c. S-IVB Ullage and Gemini Engine Comparison . . . . .	3-53
2. C-1 Engine . . . . .	3-53
a. Description . . . . .	3-53
b. Technical Approach . . . . .	3-54

### PART IV. RELIABILITY AND QUALITY ASSURANCE PROVISIONS

A. Reliability Program . . . . .	4-1
1. Requirements . . . . .	4-1
2. Plans for Independent Assessment . . . . .	4-2
3. Principal Elements of the Reliability Program . . . . .	4-2
B. Quality Assurance Program . . . . .	4-2
1. Contract Requirements . . . . .	4-2
2. Project Management Decision . . . . .	4-3

### PART V. MANAGEMENT PLAN

A. Introduction . . . . .	5-1
B. Apollo Program Management . . . . .	5-1
C. Engine Program Management . . . . .	5-1
1. MSFC Organization . . . . .	5-1
a. Research and Development Operations . . . . .	5-3
b. Industrial Operations . . . . .	5-3
2. Engine Program Office . . . . .	5-3
a. Program Manager . . . . .	5-3
b. Staff Offices . . . . .	5-4
c. Projects . . . . .	5-5
d. Resident Management Offices . . . . .	5-5
e. Engine Program Relationship . . . . .	5-5
f. Schedules, Analysis, Cost, Configuration Management and Data Management . . . . .	5-6

## TABLE OF CONTENTS (CONTINUED)

Page

### PART VI. MANAGEMENT REPORTING

A.	Introduction . . . . .	6-1
B.	Contractor to MSFC Reporting . . . . .	6-1
C.	MSFC to MSF Reporting . . . . .	6-2

### PART VII. PROCUREMENT ARRANGEMENTS

A.	Identification of Major Project Elements . . . . .	7-1
	1. F-1 Engine . . . . .	7-1
	2. H-1 Engine . . . . .	7-1
	3. J-2 Engine . . . . .	7-1
	4. Space Engines . . . . .	7-1
B.	Responsible Contractors . . . . .	7-2
	1. F-1, H-1, and J-2 Engines . . . . .	7-2
	2. Space Engines . . . . .	7-2
C.	Center Responsibilities . . . . .	7-2
D.	Technical Monitoring and Contract Administration Responsibilities . . . . .	7-2
E.	Schedule of Major Contracting Milestones . . . . .	7-3
	1. F-1 Engine . . . . .	7-3
	2. H-1 Engine . . . . .	7-3
	3. J-2 Engine . . . . .	7-4
	4. Space Engines . . . . .	7-4

### PART VIII. SCHEDULES 8-1

### PART IX. RESOURCE REQUIREMENTS

A.	Manpower . . . . .	9-1
B.	Funds . . . . .	9-1
C.	Facilities . . . . .	9-4
	1. F-1 Engine . . . . .	9-4
	2. H-1 Engine . . . . .	9-4
	3. J-2 Engine . . . . .	9-10
D.	Logistics Support Plan . . . . .	9-11
	1. General . . . . .	9-11
	2. Scope . . . . .	9-11
	3. Responsibilities . . . . .	9-11
	4. Procedure . . . . .	9-12

# LIST OF FIGURES

Figure	Title	Page
	Frontispiece	x
1-1	F-1 Engine Application . . . . .	1-5
1-2	H-1 Engine Application . . . . .	1-6
1-3	J-2 Engine Application . . . . .	1-7
2-1	Launch Vehicle Engine Major Milestone Summary . . . . .	1-10
2-2	F-1 Engine Development . . . . .	2-2
2-3	H-1 Engine Development . . . . .	2-6
2-4	J-2 Engine Development . . . . .	2-8
2-5	C-1 Engine Development . . . . .	2-12
3-1	F-1 Engine Technical Data . . . . .	2-14
3-2	F-1 Engine Components . . . . .	3-8
3-3	H-1 Engine Technical Data . . . . .	3-16
3-4	H-1 Engine Components . . . . .	3-24
3-5	J-2 Engine Technical Data . . . . .	3-28
3-6	J-2 Engine Components . . . . .	3-42
3-7	Gemini Engine for SIVB Application . . . . .	3-50
3-8	C-1 Engine Technical Data . . . . .	3-52
5-1	George C. Marshall Space Flight Center Organization . . . . .	4-4
5-2	Engine Program Office Organization . . . . .	5-2
8-1	Launch Vehicle Engines Delivery Schedule . . . . .	7-6
9-1	F-1 Engine Typical Test Facilities . . . . .	9-2
9-2	F-1 Engine Typical Manufacturing Facilities . . . . .	9-3
9-3	H-1 Engine Typical Test Facilities . . . . .	9-6
9-4	H-1 Engine Typical Manufacturing Facilities . . . . .	9-7
9-5	J-2 Engine Typical Test Facilities . . . . .	9-8
9-6	J-2 Engine Typical Manufacturing Facilities . . . . .	9-9

## PREFACE

This revised edition of the Launch Vehicle Engines Project Development Plan supersedes the issue dated July 1, 1965.

Significant changes which have been made are:

- o Removal of classified data to permit publication as an unclassified document
- o Removal of material applicable to the RL-10 Engine Project which was transferred to the Lewis Research Center effective May 1, 1966
- o Elimination of detailed schedules which quickly become obsolete
- o Punched for maintenance in loose-leaf 3-ring binders and for ease in updating material through issuance of replacement sheets. Binders are not furnished.

The information in this document is current to January 1, 1967.

The Launch Vehicle Engines Project Development Plan is established in accordance with requirements of NASA General Management Instruction 4-1-1, Planning and Implementation of NASA Projects, and OMSF Instruction MP 9320.044, Preparation and Revision of Program/Project Development Plans (PDP's). The Plan, herein referred to as the PDP, has been developed within the scope of current Apollo Projects Approval Documents (PADs) and will be maintained by the Engine Program Manager to identify program requirements, responsibilities, tasks, and resources, and time phasing of major actions required to accomplish the Engine Program. This PDP is the official engine summary document to be used:

1. To delineate the manner in which the objectives of the Engine Program as established by NASA shall be achieved;
2. As the primary decision/approval document of the Engine Program Office;

3. As the basic guidance/directive instrument to participating organizations for implementation of approved engine program changes.

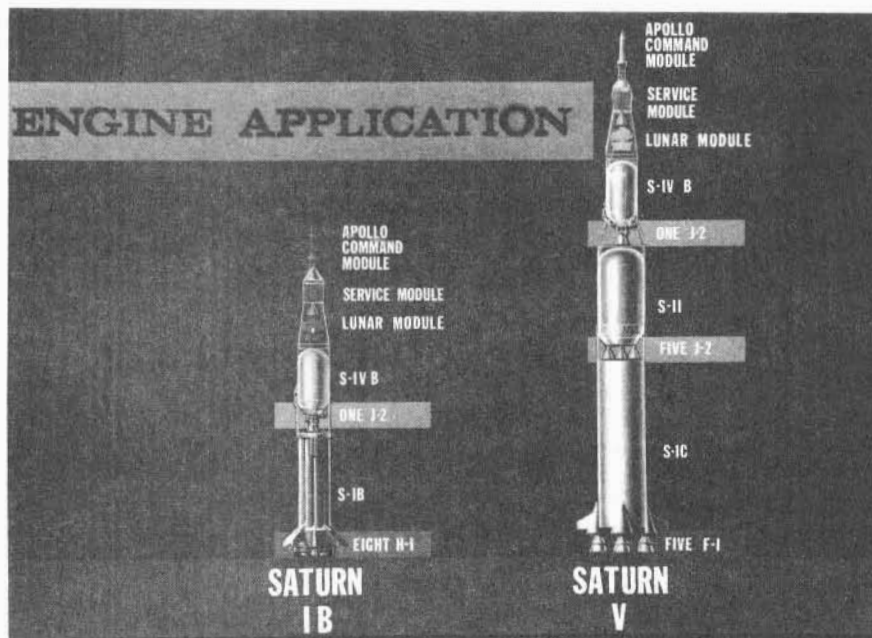
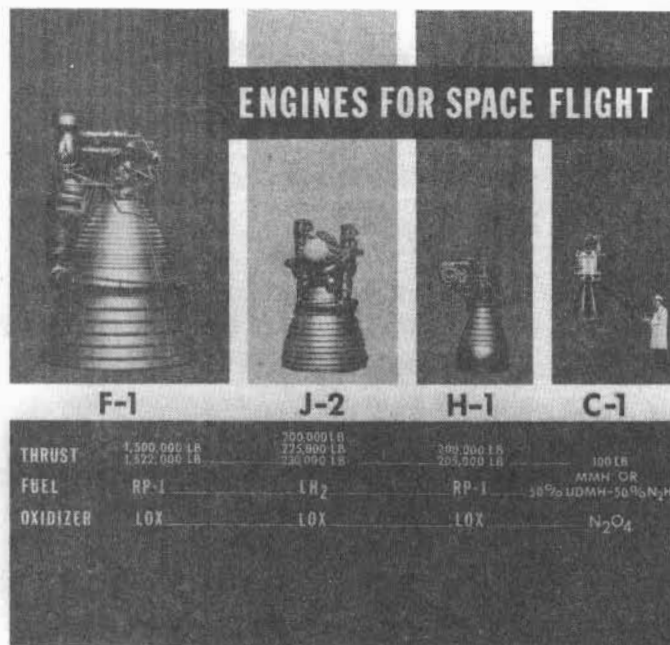
Program planning and implementation by organizations participating in the Engine Program will be responsive to and consistent with this PDP.

This PDP is not intended to provide an exhaustive treatment of each program element. The approach is to make reference to appropriate supporting documents where greater detail may be found. Also, in order to avoid unnecessary frequent updating of this PDP, reliance by reference has been placed on the current approved edition of basic and authoritative NASA, OMSF, Apollo Program, and MSFC documents. Prime examples of these are:

1. The NASA Management Instruction for agency-wide policies, regulations, and procedures;
2. The MSF Program Operating Plan (POP) for budgetary and funding data;
3. The Schedule and Review Procedure (SARP) Charts for Program Schedules and Assessments;
4. The Apollo Flight Mission Assignments Documents for individual mission objectives and configurations;
5. The MSFC Administrative Regulations and Procedures.

#### UPDATING

Revisions to this PDP will be published semiannually (as of January 1 and July 1) in the form of replacement sheets.



## PART I PROJECT SUMMARY

### A. INTRODUCTION

1. In 1958 Congress created the National Aeronautics and Space Administration to direct those aeronautical and space activities sponsored by the United States which are devoted to peaceful purposes for the benefit of mankind. Congress stated that aeronautical and space activities shall be conducted so as to contribute to one or more of the following objectives:

- a. The development of aeronautical and space vehicles,
- b. The scientific investigation of space environment,
- c. The manned exploration of space and the solar system,
- d. The application of space science and technology for peaceful uses,
- e. The application of space science and technology in support of the National Defense.

2. To achieve these objectives, the United States has undertaken a step-by-step program to develop a broad capability for the manned exploration of space that will achieve and maintain United States space leadership. This step-by-step program includes four manned space flight programs:

- a. The Mercury Program - which has adequately established man's ability to perform effectively in the environment of orbital flight and has developed the foundation of a manned space flight technology.
- b. The Gemini Program - which provided opportunity to gain operational proficiency through sustained space flights and which led to the development of new techniques, including space walking and rendezvous.



c. The Apollo Program - with the objective to achieve United States preeminence in space and to develop the ability to explore the moon and return safely to earth before the end of this decade.

d. The Apollo Applications Program - which has two basic objectives: To make unique contributions to practical applications, operational capabilities, science and technology; and at the same time, to place the nation in a position to assess, on the basis of valid scientific experimentation and actual experience, the value and feasibility of future space flight and the interrelated roles of manned and unmanned systems.

3. The Apollo Program began in September 1959 with the Booster Evaluation Committee of the Office of the Secretary of Defense. Following a series of presentations on Saturn, Nova, and Titan C launch vehicles, the Booster Evaluation Committee chose the Saturn system, then being developed by the Army Ballistic Missile Agency under ARPA Order 14-59, as the launch vehicle family that would most feasibly promote NASA objectives of space exploration.

a. Based on recommendations of the Booster Vehicle Evaluation Committee, the NASA Administrator, on December 31, 1959, established a ten-vehicle Saturn I R&D program.

b. On July 1, 1960, the Saturn Program was formally transferred to the George C. Marshall Space Flight Center (MSFC).

c. In January 1962, NASA authorized MSFC to design and develop a large, three-stage launch vehicle, Saturn V, to launch the three-man Apollo spacecraft, under development by MSC Field Center, on circumlunar flights and manned lunar landing missions.

d. On July 11, 1962, NASA announced that an advanced Saturn I vehicle, the Saturn IB, would be developed for manned earth-orbital missions with full-scale Apollo spacecraft. This member of the Saturn family combines the third stage and instrument unit of the Saturn V with an improved version of the first stage of the Saturn I.

4. The Apollo Applications Program (AAP) is planned to make use of Apollo space vehicles and hardware and the complexes that support them.

a. The initial flight missions of the AAP program will utilize those Saturn IB and Saturn V launch vehicles, including the engines for these vehicles, procured within the Apollo program that are not needed to accomplish the Apollo manned lunar landing mission.

b. Follow-on production of Saturn IB and Saturn V launch vehicles for AAP including the engines for these vehicles is planned at the rate of four launches each per year and will proceed in a manner that will avoid any hiatus in the continued development of United States manned flight capability.

c. AAP missions planned include a 10,000-cubic-foot workshop in orbit, a manned astronomical and solar telescope, long duration manned orbital flights allowing for physiological and biological experimentation, manned meteorological and earth resource investigations, and extended lunar exploration and analysis.

5. The Engine Program Office, under the direction of the Director of Industrial Operations, MSFC, and under the cognizance of the Apollo Program Director, is responsible for the research, development, manufacture, test and production support of the family of Launch Vehicle Engines chosen for the Apollo Program and the AAP Program. The Engine Program Manager directs four engine projects, each headed by a project manager, as follows:

a. F-1 Engine Project

b. H-1 Engine Project

c. J-2 Engine Project

d. Space Engines Project

## B. MISSION OBJECTIVES

Primary mission objectives of the engine projects are as follows:

1. F-1 Engine. The primary mission of the F-1 Engine Project is the continued development of a reliable liquid oxygen/RP-1 engine capable of producing 1,522,000 pounds of thrust for the S-IC stage of the Saturn V unmanned and manned vehicles under the Apollo and the Apollo Applications Programs. Figure 1-1 illustrates this application.

2. H-1 Engine. The primary mission of the H-1 Engine Project is to continue development of a reliable engine system as the basic propulsion unit for the S-IB stage of the Saturn IB vehicles under the Apollo and the Apollo Applications Programs. See figure 1-2 for this application.

3. J-2 Engine. The primary mission objective of the J-2 Engine Project is to continue the development and production of a reliable liquid oxygen/liquid hydrogen engine system capable of high-altitude restart, for use on both the Saturn IB and Saturn V vehicles under the Apollo and the Apollo Applications Programs. The S-IVB stage of the Saturn IB vehicle and the S-IVB stage of the Saturn V vehicle will each be equipped with a single J-2 engine. The S-II stage of the Saturn V will use a cluster of five J-2 engines. Figure 1-3 illustrates these applications.

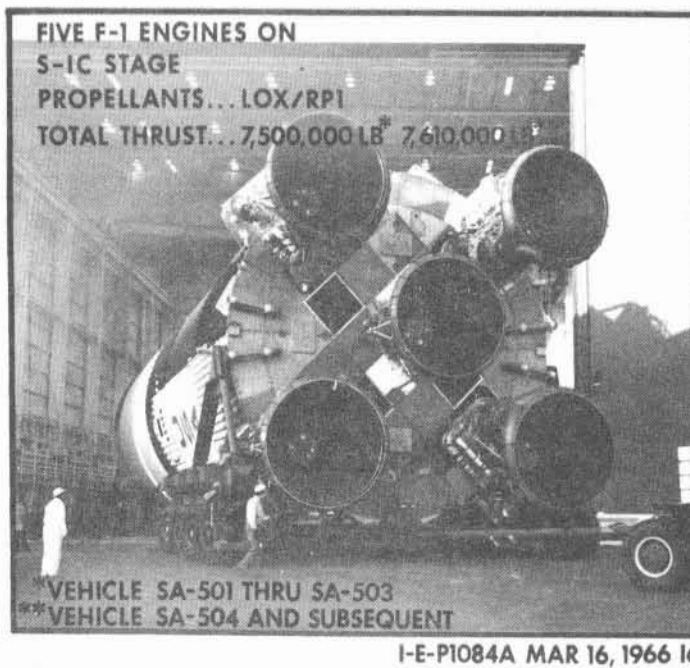
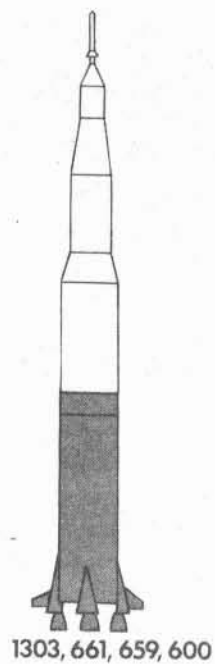
### 4. Space Engines

a. S-IVB Ullage Engine. The primary mission of the S-IVB Ullage Engine Project is to insure the operational capabilities of the standard Gemini spacecraft orbital attitude and maneuvering system (OAMS) engine when exposed to conditions that are unique to the Saturn V/S-IVB stage auxiliary system.

b. C-1 Engine. The mission objective of the C-1 Engine Project is to provide an 80 to 100-pound thrust engine capable of meeting the collective requirements of the following applications:

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## SATURN V, ENGINE/STAGE APPLICATION



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Figure 1-1. F-1 Engine Application

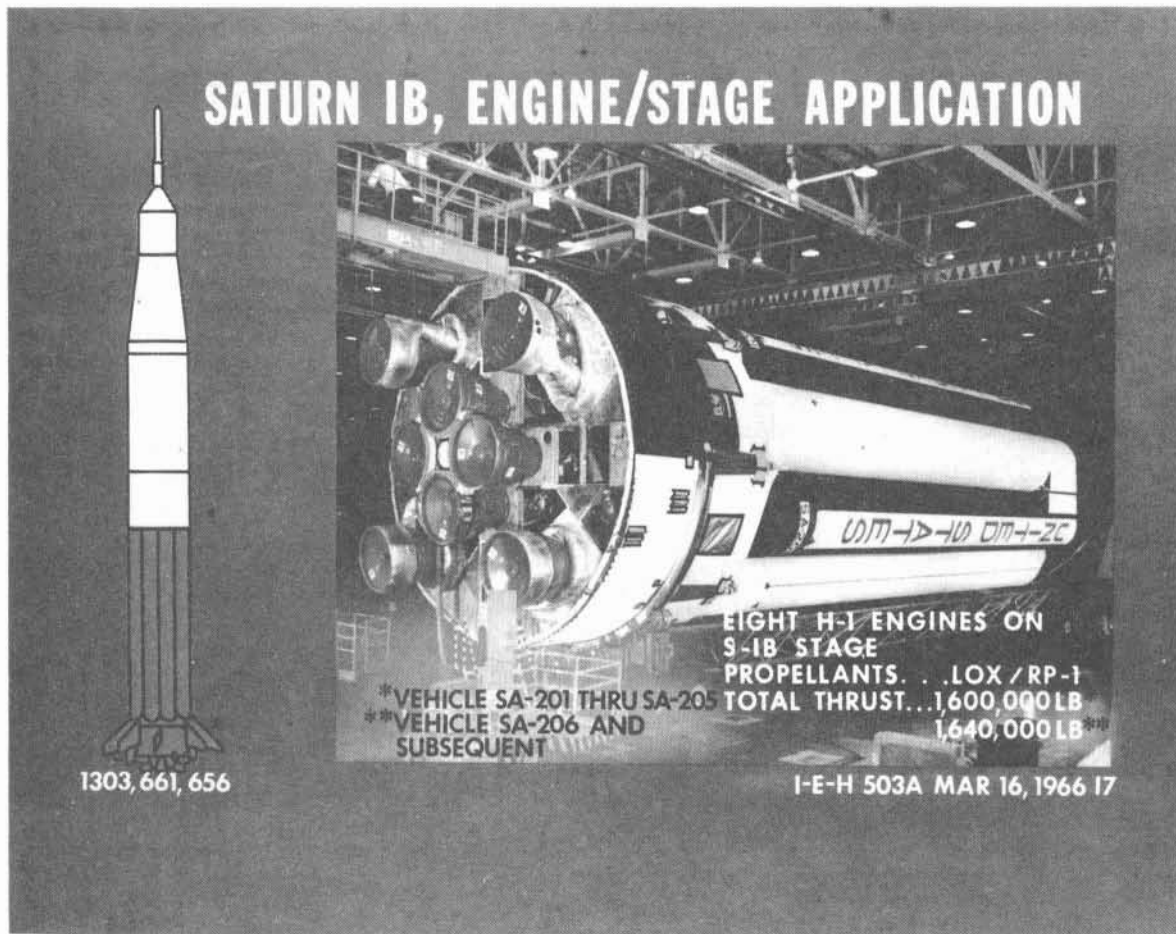


Figure 1-2. H-1 Engine Application

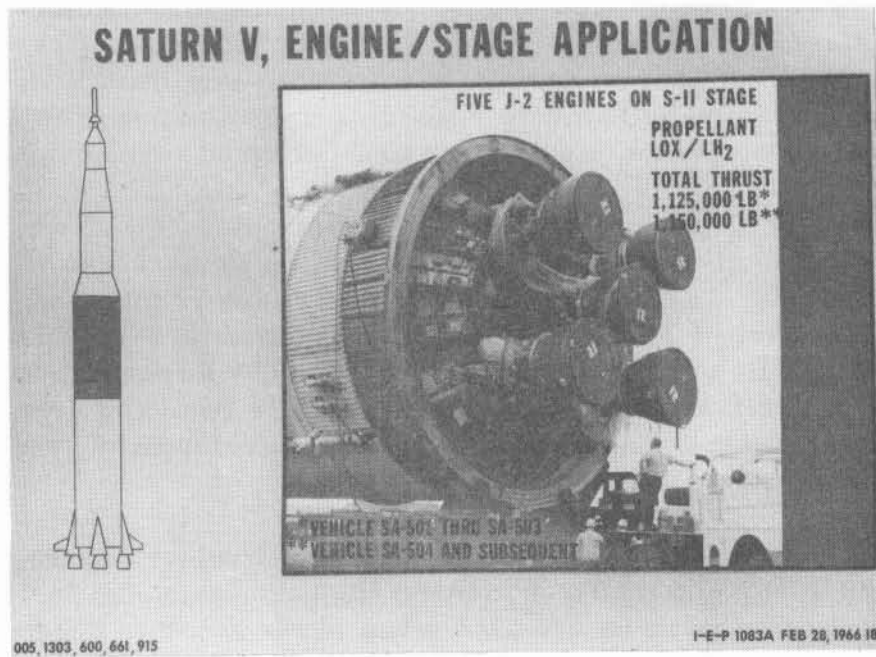
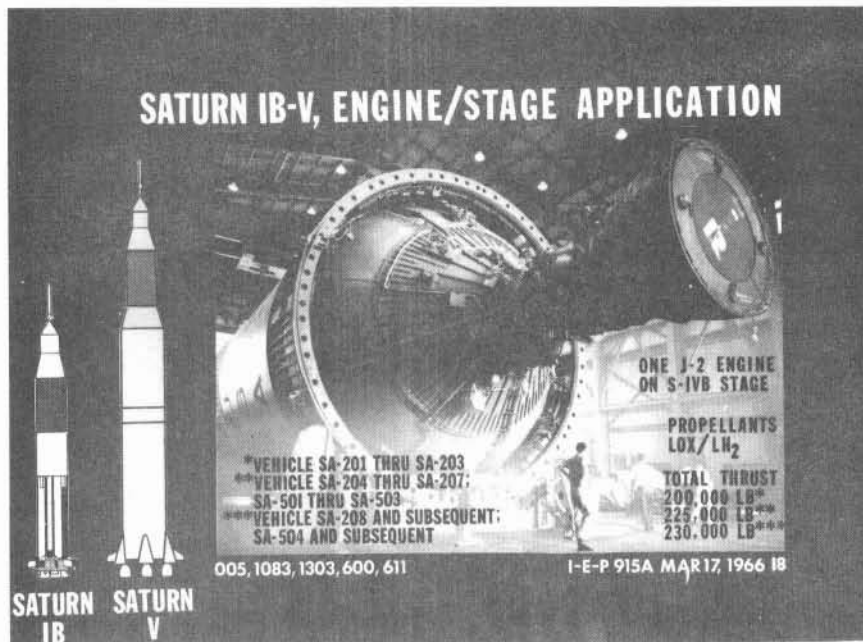


Figure 1-3. J-2 Engine Application

- o Re-entry Control for the Apollo Command Module
- o Ullage settling for the Saturn V/S-IVB stage
- o Reaction control for the Saturn IB and V/S-IVB stage
- o Reaction control for the Apollo Service Module
- o Reaction control for the Apollo Lunar Excursion Module
- o Extended mission requirements of Reaction Control Systems on AAP and post AAP flights.

#### C. COST AND MANPOWER

Cost and manpower requirements are covered in Part IX, Resource Requirements.

#### D. TIME REQUIREMENTS

1. F-1 Engine. The F-1 Engine Project was begun in January 1959 and completed engine qualification in December 1966. Major milestones are given in the Monthly Schedule and Review Procedure (SARP) Report from MSFC to MSF (see Part VIII, Schedules), and specific time requirements regarding contracts, engine and component development, and testing are indicated throughout that report.

2. H-1 Engine. The H-1 Engine Project was initiated September 1958, and the first manned flight is currently scheduled for the first part of 1967. The major milestones are shown in the Monthly Schedule and Review Procedure (SARP) Report from MSFC to MSF (see Part VII, Schedules), and specific time requirements regarding contracts, engine and component development, and testing are indicated throughout that report.

3. J-2 Engine. The J-2 Engine Project was begun in September 1960, and the first manned flight is scheduled in 1967. Major project milestones are also given in the Monthly Schedule and Review Procedure (SARP) Report from MSFC to MSF (see Part VIII, Schedules), and specific time requirements regarding contracts, engine component development, and testing are indicated throughout that report.

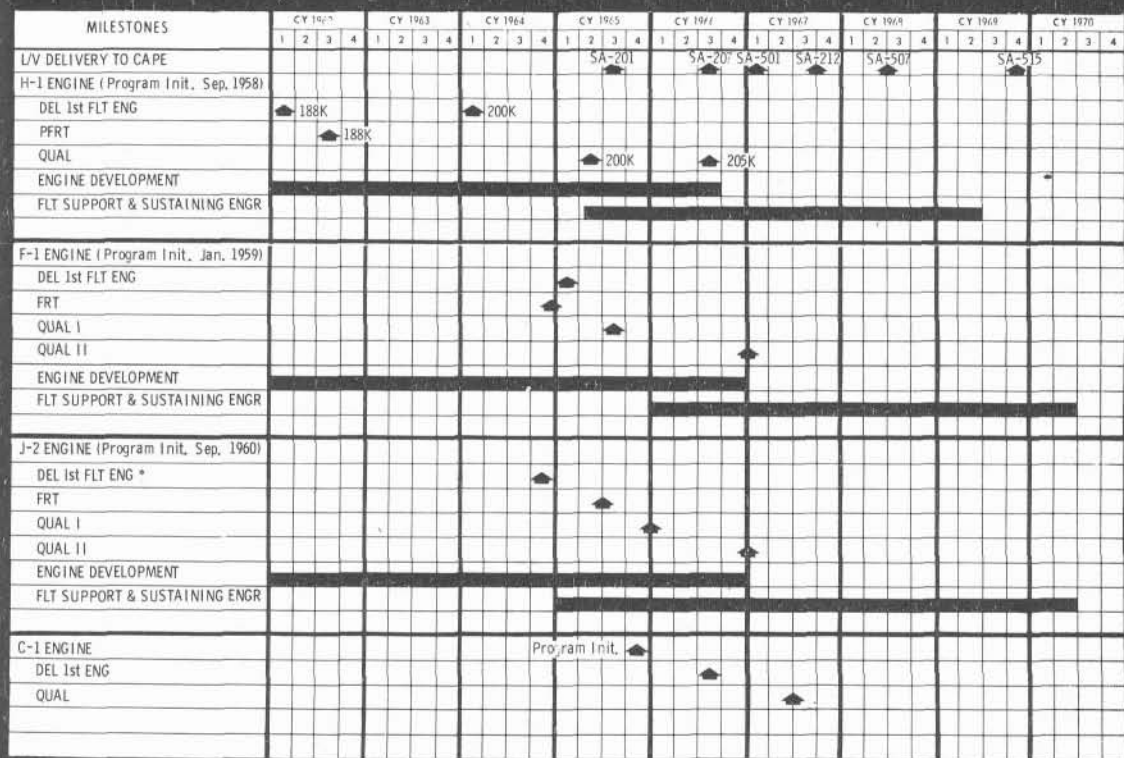
#### 4. Space Engines

a. S-IVB Ullage Engine. The Gemini engine adaptation to the S-IVB stage requirements was initiated March 30, 1964, under the direction of the S-IVB Stage Office. On September 5, 1964, this effort was transferred to the Space Engine Office and engine qualification was completed in August 1965. The initial buy of S-IVB engines for Saturn V vehicles 501 through 506 was completed December 20, 1965. Procurement of engines for vehicles 507 through 515 will be initiated in the first quarter of 1967 with delivery to start in the fourth quarter of 1967 and completed approximately one year later.

b. C-1 Engine. This program was initiated on August 8, 1964. A six-month competitive Definition and Demonstration phase was conducted from March 1965 to September 1965. The Development phase was started in October 1965 and Engine Qualification is scheduled for July 1967.



## ENGINE PRODUCTION, DEVELOPMENT, AND SUSTAINING ENGINEERING



### NOTES

\* J-2 ENGINE DELIVERED NOVEMBER 4 FOR SA-201 WAS COLD-FLOW ONLY

I-E-P 1100A JANUARY 1, 1967

Figure 2-1. Launch Vehicle Engines Major Milestone Summary

## PART II

### JUSTIFICATION, HISTORY AND RELATED WORK

#### A. JUSTIFICATION

1. F-1 Engine. The S-IC stage of the Saturn V Project requires a high-reliability booster rocket engine in the 1,522,000-pound thrust range. The F-1 engine is designed to meet the requirement and will be used in a cluster of five on the S-IC stage to obtain a minimum thrust of 7,610,000 pounds.

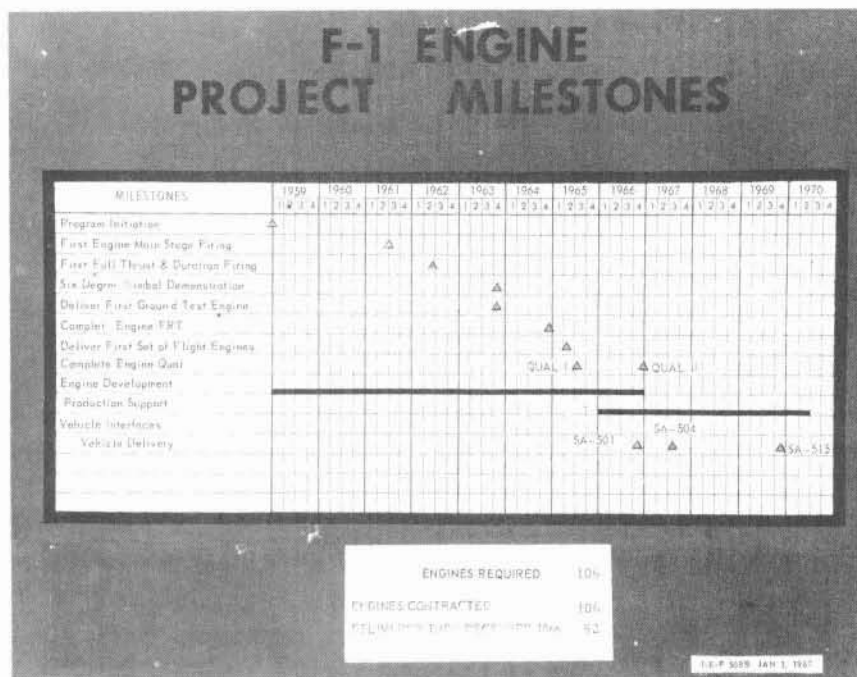
2. H-1 Engine. The Saturn I/IB Project has required high-reliability rocket engines in the 165,000, 188,000, 200,000 and 205,000-pound thrust range for booster application. The engine has been uprated from the 165,000 to the 205,000-pound thrust version to meet all requirements of these vehicles. Saturn I used both the 165,000 and the 188,000-pound thrust engine in clusters of eight engines. Saturn IB used the 200,000-pound thrust version, also in clusters of eight engines, in vehicles SA-201 through SA-205. Vehicle SA-206 and subsequent will use the improved-performance H-1 engine with 205,000-pounds of thrust.

3. J-2 Engine. High-reliability rocket engines, in the 200,000-pound thrust range capable of starting, operating, stopping, and restarting at altitudes in excess of 60,000 feet, are required for the Saturn IB and V Projects. The J-2 engine is designed to meet all vehicle requirements with present plans for qualification of a 205,000/230,000-pound thrust improved-performance engine in April 1967. It is planned to use the improved-performance engine on Saturn IB vehicle SA-208 and subsequent, and Saturn V vehicle SA-504 and subsequent.

A cluster of five J-2 engines will be used on the S-II stage of Saturn V vehicles, and a single engine will be used on the S-IVB stage of Saturn IB and Saturn V vehicles.

#### 4. Space Engines

a. S-IVB Ullage Engine. High-reliability rocket engines in the 100-pound thrust range are required for the Saturn V Project. These engines will be used in accomplishing propellant settlement (ullage) prior to J-2 engine restart. The S-IVB ullage engine is designed to meet these requirements.



### ENGINE PROGRAM OFFICE F-1 ENGINE SYSTEM TEST SUMMARY

NUMBER OF TESTS			NUMBER OF SECONDS		
SINGLE ENGINE	DEC 1966	TOTAL (TO DATE)	SINGLE ENGINE	DEC 1966	TOTAL (TO DATE)
ROCKETDYNE	26	1,895	ROCKETDYNE	3,130	145,848
MSFC	1	131	MSFC	40	8,700
TOTAL	27	2,026	TOTAL	3,170	154,548
CLUSTER (5 ENGINES)			CLUSTER (5 ENGINES)		
MSFC	0	19	MSFC	0	(6,150)
TOTAL	0	19	TOTAL	0	(6,150)
TOTAL NO. OF TESTS	27	2,045	TOTAL NO. OF SECONDS	3,170	160,698

NOTE:

1-4-P 3059 JAN 1, 1967

- NUMBER IN PARENTHESIS IS EQUIVALENT SINGLE ENGINE TESTS/TIME.
- \* THREE OF 19 CLUSTER TESTS WERE SINGLE TESTS FOR A TOTAL OF 22 SECONDS.

Figure 2-2. F-1 Engine Development

b. C-1 Engine. The Apollo Program necessitates high-reliability rocket engines in the 80 to 100 pound thrust range. The C-1 engine has potential use in applications stated under Part I Section B, Mission Objectives.

## B. HISTORY AND RELATED WORK

### 1. F-1 Engine

a. General. Initially, the F-1 engine was a military project. Earliest studies date to 1955, when the U. S. Air Force asked industry for an engine capable of developing 1,000,000 pounds or more of thrust. These studies included comparisons between single and clustered engines in terms of availability and reliability, and detailed analyses of engine systems up to thrust levels of 1,000,000 pounds. Studies culminated in March 1959, with a series of feasibility firings. These firings demonstrated marginal stability at the 1,000,000 pound thrust level for 200 milliseconds, using a solid wall, boiler plate thrust chamber and injector. This series of tests was made with a NASA funding assistance of approximately \$426,000.

(1) Responsibility for development of the high-thrust engine was given to NASA in 1958. When all studies concluded that an engine the size of the F-1 was feasible, a contract was awarded in January 1959, to Rocketdyne, a Division of North American Aviation, Inc., for the engine development. Since vehicle application was not evident at the time, the engine development had to be pursued initially without the advantages of a known use. This necessitated redesign in several areas later because of vehicle interface.

(2) The F-1 engine has an impressive list of accomplishments. A year after the R&D contract was signed, full-scale component testing was in process, and in 27 months complete engine systems testing had begun. Since then, full-thrust and full-duration tests have become routine. The engine has been gimbaled during single engine and clustered engine test firings, and flight rating tests (FRT) were completed in December 1964.

b. Developmental history. Development of the F-1 engine was planned to keep within the bounds of the established state-of-the-art, and was not to be concerned with any substantial technological innovations other than a very considerable scale-up. This did not mean that the development would be problem free, since an enlargement of this magnitude is in itself an innovation. The objective was to limit the project to the bounds of past experience with liquid rocket engines. With the increasing pace of technology, it might be expected that a reliable engine could be developed in a relatively short period of time. However, the following factors entered into the development of the F-1 engine:

(1) Testing of the F-1 engine required the use of large test facilities. This required design and construction of the largest engine test facilities in the United States, and major development of test equipment compatible with test facility size.

(2) Thrust chamber size required new manufacturing techniques for the tube brazing process.

(3) Engine simplification required the use of high-pressure fuel to operate the control system. This eliminated the need for a separate hydraulic system.

(4) Large fuel consumption of the engine and high hardware unit costs required optimum utilization of the test data obtained from all tests conducted.

(5) Manned vehicle application for the engine resulted in additional requirements of quality control and reliability beyond those normally imposed on engines for unmanned vehicles.

The F-1 Engine Project was initiated on an optimistic schedule and with limited funds. However, development milestones have been generally on schedule.

c. Production history. The first F-1 production-type engine was delivered to the George C. Marshall Space Flight Center in October 1963. Engine deliveries are scheduled to satisfy Saturn V requirements. Current delivery schedules are shown in the Monthly Schedule and Review Procedure (SARP) Reports (see Part VIII, Schedules).

d. Management history. The project was initiated under Air Force management, but in 1958 was transferred to NASA. In November 1960, MSFC was given the responsibility for project management.

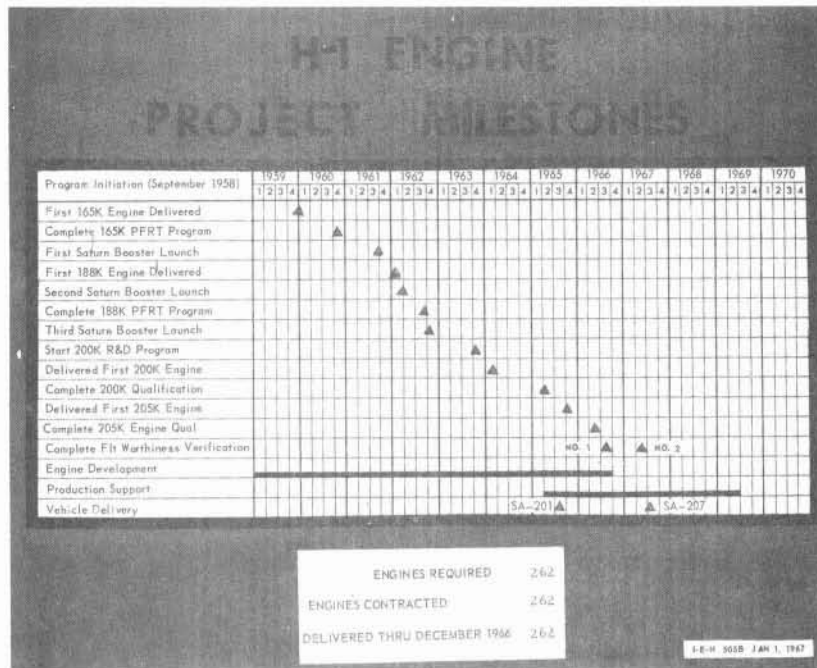
Currently, there is only one application for the developed engine, the Saturn V Program. Because stage and engine project management are located at the same NASA center, operations of this project have proceeded smoothly, and with the same management following the project through to its presently developed state.

e. Technical history. Significant accomplishments in the technical history of this engine are:

- o Accumulated approximately 160,000 seconds of hot firing time during a total of 2,045 tests as of December 31, 1966.
- o Proved and used solid-wall combustion gas generator.
- o Tested engine gimbaling in single and clustered engine firings.
- o Proved through testing gas-cooled thrust chamber extension design.
- o Completed flight rating tests.
- o Completed flight rating tests combustion stability demonstration.
- o Released basic qualification II design.
- o Completed Qualification II testing.

## 2. H-1 Engine

a. General. The H-1 engine system evolved from five different engine-system designs (the Thor, Jupiter, X-1, S-4 and the MA-3) and was specifically designed so that it could be clustered to obtain the desired vehicle thrust level. The basic engine design consisted of four fixed inboard engines and four outboard engines, with gimbaling capabilities for vehicle attitude control. The first engine



### ENGINE PROGRAM OFFICE H-1 ENGINE SYSTEM TEST SUMMARY

NUMBER OF TESTS			NUMBER OF SECONDS		
<u>SINGLE ENGINE</u>	DEC 1966	TOTAL (TO DATE)	<u>SINGLE ENGINE</u>	DEC 1966	TOTAL (TO DATE)
ROCKETDYNE	17	5,482	ROCKETDYNE	1,656	393,604
MSFC	4	424	MSFC	58	31,480
<b>TOTAL</b>	<b>21</b>	<b>5,906</b>	<b>TOTAL</b>	<b>1714</b>	<b>425,084</b>
<u>CLUSTER (8 ENGINES)</u>			<u>CLUSTER (8 ENGINES)</u>		
FLIGHT (SA-1 thru SA-10, AS-201, 203)	0(0)	12(96)	FLIGHT (SA-1 thru SA-10, AS-201, 203)	0	1,702 (13,323)
MSFC	0(0)	86(560)	MSFC	0(0)	5,319 (41,965)
<b>TOTAL</b>	<b>0(0)</b>	<b>98(656)</b>	<b>TOTAL</b>	<b>0</b>	<b>7,021</b>
<u>TOTAL NO. OF TESTS</u>	<b>21</b>	<b>6,562</b>	<u>TOTAL NO. OF SECONDS</u>	<b>1714</b>	<b>480,372</b>

NOTE: <sup>1/8</sup>  
NUMBER IN PARENTHESIS IS EQUIVALENT SINGLE ENGINE TESTS/TIME

S-E-H 5006 JANUARY 1, 1967

Figure 2-3. H-1 Engine Development

was designed to operate at a thrust of 165,000 pounds, and was used in clusters of eight on the early Saturn I vehicles to provide a minimum liftoff thrust of 1,320,000 pounds. Later engines, capable of 188,000-pounds thrust, provided the Saturn I vehicle with a total liftoff capability of 1,504,000 pounds. The first five Saturn IB vehicles will use an uprated engine designed to operate at a thrust level of 200,000 pounds; vehicle SA-206 and subsequent will use an improved 205,000-pound thrust engine. A summary of major milestones in the development of the engine is shown in figure 2-3.

b. Developmental history. In December 1958, the first engine test was conducted utilizing an engine configuration which incorporated the most advantageous design features.

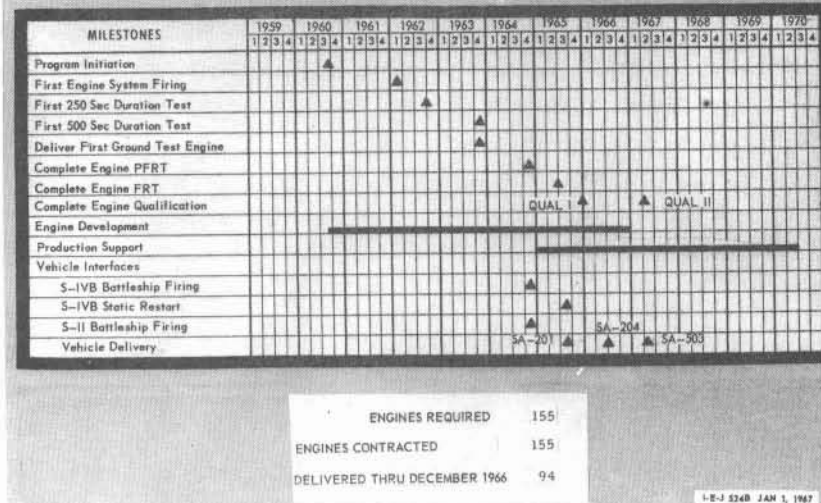
In addition to progressively increasing engine thrust, the following improvements have been made on the H-1 engine:

- o Start and shutdown sequences simplified, resulting in the elimination of numerous subcontrols and electrical sensing devices.
- o A solid-propellant gas generator starter incorporated replacing the two ground-start tanks used with the Jupiter engine.
- o The RP-1 fuel (plus additives) adopted as coolant and lubricant. The Jupiter engine used oil from a 20-gallon tank to cool and lubricate turbopump gears and bearings.

c. Production history. The original production contract was awarded in September 1958, under an Army Ballistic Missile Agency (ABMA) ORD 1387 Contract, and continued on Contracts NAS7-3, NAS7-4, NAS7-162, and Part II NAS7-190. Current delivery schedules are shown in the Monthly Schedule and Review Procedure (SARP) Report from MSFC to MSF (see Part VIII, Schedules).



## J-2 ENGINE PROJECT MILESTONES



### ENGINE PROGRAM OFFICE J-2 ENGINE SYSTEM TEST SUMMARY

NUMBER OF TESTS			NUMBER OF SECONDS		
<u>SINGLE ENGINES</u>	DEC 1966	TOTAL (TO DATE)	<u>SINGLE ENGINE</u>	DEC 1966	TOTAL (TO DATE)
ROCKETDYNE	43	2,450	ROCKETDYNE	6,680	221,129
DAC	0	40	DAC	0	8,219
MSFC	2	40	MSFC	434	6,778
AEDC	5	15	AEDC	90	231
FLIGHT (S-IVB)	0	3	FLIGHT (S-IVB)	0	1,185
<b>TOTAL</b>	<b>50</b>	<b>2,548</b>	<b>TOTAL</b>	<b>7,204</b>	<b>237,542</b>
<u>CLUSTER (5 ENGINES)</u>			<u>CLUSTER (5 ENGINES)</u>		
S&ID (SAT V-S-II)	3(15)	40(200)	S&ID	743(3715)	5971 (29,855)
<b>TOTAL</b>	<b>3(15)</b>	<b>40(200)</b>	<b>TOTAL</b>	<b>743(3715)</b>	<b>5971 (29,855)</b>
<u>TOTAL NO. OF TESTS</u>	<b>65</b>	<b>2,748</b>	<u>TOTAL NO. OF SECONDS</u>	<b>10,919</b>	<b>267,397</b>

NOTE: 706, 715, 719  
NUMBER IN PARENTHESIS IS EQUIVALENT SINGLE ENGINE TESTS/TIME

S-E-J 524B JANUARY 1, 1967

Figure 2-4. J-2 Engine Development

### 3. J-2 Engine

a. General. Prior to October 1958, research by NASA-Lewis Research Center verified the feasibility of using liquid hydrogen as a high-energy rocket engine fuel.

Studies initiated because of increased engine performance requirements of advanced space vehicles indicated the need for an engine using liquid hydrogen and liquid oxygen, capable of obtaining 200,000 pounds of thrust. Consequently, a formal development program for the J-2 engine was initiated with the issuance of contract NAS8-19 to Rocketdyne Division, North American Aviation, Inc., on September 1, 1960.

b. Development history. Pertinent development milestones for the J-2 engine are depicted in figure 2-4.

c. Production history. The J-2 engine production program was initiated and governed by letter contract NAS8-5603 until definization of the contract on June 24, 1964. Current delivery schedules for engines under contract NAS8-5603 are shown in the Monthly Schedule and Review Procedure (SARP) Reports from MSFC to MSF (see Part VIII, Schedules).

d. Contractual history. Research and development/production support contract NAS8-19, and production contract NAS8-5603, constitute the authorization for the J-2 program. These contracts were combined under contract NAS8-19 in July 1966.

### 4. Space Engines

#### a. S-IVB Ullage Engines

(1) General. During early phases of the development of the S-IVB/Saturn V Auxiliary Propulsion System (APS), instability problems were encountered in the storable propellant 1,750-pound thrust engine under development for separation and ullage applications. Subsequent review and program assessment of the APS development problems during a meeting at NASA Headquarters on March 18, 1964, resulted in a decision to redesign the S-IVB/Saturn V Auxiliary Propulsion System. On March 30, 1964, direction (NASA Headquarters TWX M-C MA 3233) was received by MSFC to make the following contractual and design changes in the S-IVB/Saturn V Auxiliary Propulsion System development:

- o Redesign the S-IVB APS for Saturn V to incorporate continuous hydrogen venting to maintain ullage control during vehicle coast. Provide initial settling of propellants and NPSH for recirculation pump during J-2 engine cooldown by two (one per module) standard Gemini OAMS engines with a nominal thrust of 100 pounds each. These to be run at lower-than-standard propellant tank pressure and produce approximately 70 pounds thrust each.
- o Procure the standard Gemini engines through Manned Spacecraft Center and conduct all necessary modification and test programs.
- o Provide S-IVB/Saturn V separation thrust with two existing solid propellant engines of 3,380 pounds thrust each instead of the planned 1,750-pound thrust storable liquid propellant engine. The latter development to be canceled.

(2) Developmental history. The Gemini 100-pound thrust engine was developed and qualified for use in the orbital attitude and maneuvering system (OAMS) of the Gemini spacecraft. Rocketdyne Division, North American Aviation, Inc., designed and developed the engine under subcontract from McDonnell Aircraft Corporation, the Gemini spacecraft prime contractor. Six 100-pound thrust engines are used on the Gemini spacecraft orbital attitude and maneuvering system.

(3) Production history. The first S-IVB ullage production-type engines were delivered for MSFC qualification program in February 1965. The last of the first buy of 29 engines was delivered December 20, 1965. This quantity of engines satisfied needs for MSFC component qualification, Douglas Aircraft Company system testing qualification, and the Saturn V requirement through vehicle SA-506. Procurement of engines for vehicles 507 through 515 will be initiated in the first quarter of 1967.

(4) Management history. The development and qualification of the Gemini 100-pound thrust OAMS engine was managed by NASA Manned Spacecraft Center. The present requirement for engines on the Gemini Program was completed in September 1965.

(5) Contractual history. The first buy of S-IVB ullage engines was by sub-allotment to NASA Manned Spacecraft Center through the McDonnell Company from Rocketdyne Division, North American Aviation, Inc., by amendment to existing MSC Gemini NAS9-170 contract. Future buys are planned from Rocketdyne direct.

b. C-1 Engine

(1) General. Project approval initiating the C-1 Engine Project was released August 8, 1964. This project consists of three phases: Phase I - Definition, Phase II- Development, and Phase III - Production.

Phase I was initiated on March 5, 1965, with two contractors, TRW Systems Group and Reaction Motors Division of the Thiokol Chemical Corporation. This phase was completed in September 1965 and led to the selection of Reaction Motors Division, Thiokol, as the Phase II Development contractor.

(2) Development history. Phase II development was initiated with Reaction Motors Division of Thiokol Chemical Corporation on October 18, 1965. The development program established is to require 21 months through qualification and is designed to keep within the bounds of the established state-of-the-art. The development program is planned to draw heavily on the Phase I definition effort plus experience gained on other engine programs with the same thrust and functional requirements, such as the Rocketdyne Gemini and Command Module engines, the Marquardt Service and Lunar Excursion Module engines, and the RMD Surveyor engine.

(3) Production history. At present, no production is authorized on the C-1 engine.

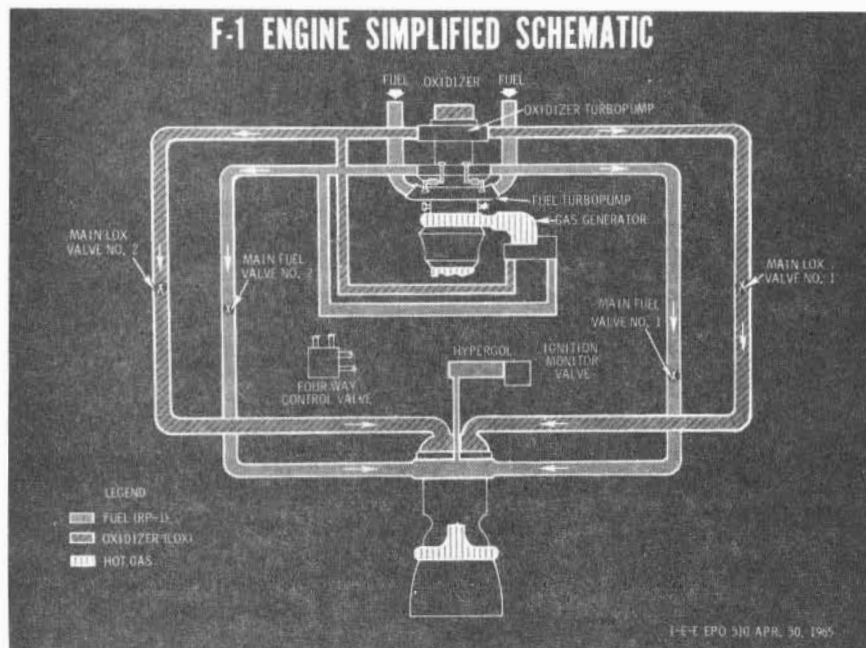
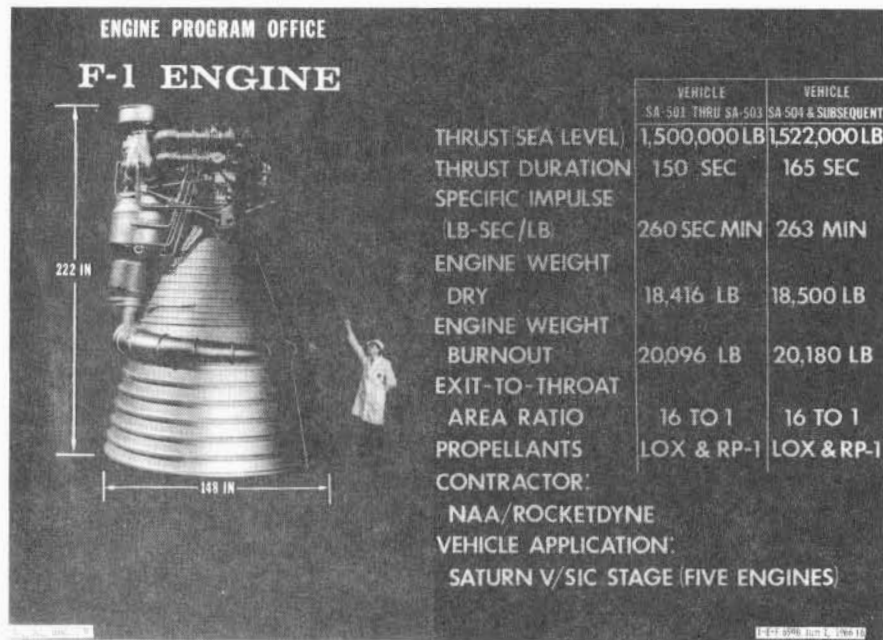
(4) Management history. The project is and has been under MSFC project management since inception. Close coordination is maintained with MSC since three of the four possible applications (CM, SM, and LEM) are managed by MSC.

(5) Contractual history. The C-1 engine contractual history is as follows:



(a) Phase I (Definition) - Phase I was conducted in a competitive atmosphere under fixed price contracts NAS8-14019 valued at \$1,114,132 and NAS8-14022 valued at \$818,078 between TRW and RMD, respectively.

(b) Phase II (Developmental) - Phase II is being conducted under CPIF contract NAS8-15486 with RMD. Target value of this contract is \$16,146,000. No modification has been made to this contract which affects the target value.



## PART III

### TECHNICAL PLAN

#### A. F-1 ENGINE

##### 1. Description

a. Development plan. The F-1 engine development plan prescribes a program for continued development and qualification through the first half of FY 1967 with production support continuing from the qualification of the engine system to the second quarter of 1970. The primary elements of the development plan through engine qualification II was basic development, extended operating limits, combustion stability, performance improvement and demonstration, turbine and pump reliability and efficiency, and flight instrumentation. Production contract NAS8-5604 provides for the procurement of 76 engine systems and associated hardware.

(1) Basic development. Component and engine development effort was directed toward the completion of component and engine qualification in December 1966, and toward the completion of the sustained reliability demonstration series which established the qualification engine configuration at 99% reliability at 75% confidence. Planned development effort was concentrated in the following areas:

- |                           |                             |
|---------------------------|-----------------------------|
| o Turbopump               | o Thrust chamber            |
| o Controls                | Thrust chamber extension    |
| o Interconnect components | Tube braze improvement      |
| o Electrical system       | o Gas generator (GG)        |
| o GG Ignition System      | o Thermal insulation        |
| o Injector                | o Accessories               |
| Combustion Stability      | o Extended operating limits |
| Performance               |                             |



(2) Development plan milestones for the engine system are presented in the Monthly Schedule and Review Procedure (SARP) Reports (see Part VIII, Schedules).

b. Production support plan. Contract NAS8-18734 provides for the delivery of 30 additional engine systems and associated hardware and for production support to all delivered engine systems. The production support effort will make available the capability to provide solutions to F-1 engine problems so that the impact of any such problems on the Apollo Program will be minimized. At the same time it will provide for vehicle and stage related support, for a continued assessment and demonstration of engine system reliability and flight worthiness, and for the accomplishment of select improvement tasks which will insure the maintenance of a high level of proficiency in the production support team by fully utilizing its capabilities during those periods when such capabilities will not otherwise be fully utilized. Reduction in potential failure modes, increased utility, cost reduction, and increased engine flexibility and simplification will be pursued when the full effort of the program is not needed to solve flight related problems. Planned production support effort will be concentrated in the following task areas:

(1) Task A1 - Manufacturing, Ground Test, and Manned Flight Support

Provides the capability, including engineering personnel, test facilities, and hardware as necessary to accomplish expeditious solutions, or make recommendations concerning operational support problems encountered during manufacture, acceptance, or field utilization of the F-1 engine system and accessories. Major areas of effort include the following:

o Definition and Solution of Engine Manufacturing, Checkout, and Acceptance Problems

Problems that are encountered during engine manufacture, inspection, checkout and acceptance testing which directly impact engine delivery. This effort supplements engine deliveries in that problems or unsatisfactory conditions that are applicable to more than one engine are resolved as part of this task.

- o Definition and Solution of Field Problems

Engine problems encountered after the government has accepted delivery of the engine.

Surveillance will be maintained over engine system integration with the stage and ground service equipment (GSE), including stress and other technical analyses and periodic reviews of customer connect points and requirements, and applicable stage contractor documents.

- o Review and Analysis of Ground Test Data

Performance data obtained from single engine and cluster ground tests for trends, deviations, and biases that could affect the flight program.

- o Review and Analysis of Flight Test Data

To define propulsion system operating characteristics during launch and flight as part of the overall Apollo requirement to determine, investigate, and explain problems and malfunctions encountered during launch and flight.

- o Data Evaluation Program

The program began December 1, 1957, and will be continued through June 30, 1970. The program provides data reduction digital methods and evaluation of test data from the data reduction methods.

- o Procedure Simplification and Improvement

Surveillance of procedures presented in specifications and handbooks will be maintained to detect problem areas and marginal methods.

- o Review of Stage Contractor ECP's, Engine Add-Ons, etc., for Engine Impact

From November 11, 1967 through June 30, 1970, engineering support will be required for the review of S-IC Stage Contractor engineering drawings and engineering change proposals for additions to or changes in designed hardware configurations proposed for installation on the engine system.

(2) Task A2 - Manned Reliability Assessment

Continued assessment and surveillance is provided for engine reliability, making use of production support engines and deliverable engines and hardware. Major areas of effort include the following:

- o Reliability Assessment

Reliability assessment of production support and deliverable engines in accordance with Reliability Assessment Procedure, R-6677, dated June 30, 1966.

- o Stability Sampling

Periodically demonstrate that deliverable engine stability characteristics as defined by paragraph 3.3.2 of the Model Specifications R-1420eS, dated May 3, 1965, are being maintained in production.

- o Flight Worthiness Verification

A test program will be conducted from about mid CY 1968 to verify that engine reliability and workmanship has in no way deteriorated.

Improvement (3) Task A3 - Critical Component and Subsystem

Provides for improved back-up designs for those components and subsystems which are extremely critical to mission success and which have long development and/or procurement lead times. Selection of those long lead components and/or subsystems which are to be investigated under this task will be based primarily on development history, criticality, and failure effects.

c. Reduction in Potential Failure Modes, Increased Utility and Cost Reduction. The effort under each task of the following categories is planned on the basis that it leads to submission of an ECP or SCN.

(1) Task B1 - Reduction in Potential Failure Modes, Improved Engine Maintenance and Increased Operational Flexibility. Major areas of effort include the following:

- o Elimination of Thrust Chamber to Nozzle Extension Mating Flange Hot Gas Leakage
- o Static Seal Improvement
- o Improved Gas Generator Chamber Pressure Transfer Tube
- o Turbopump Intermediate Seal
- o Improvement of Hydraulic Control Lines
- o Boss Improvement
- o Improvement of Gas Generator Ball Valve
- o Turbopump Shaft Balance
- o 35-inch Turbine Manifold Nozzle Improvement
- o Instant Release Capability
- o Baffle Bulging

- o Improved Specific Impulse
- o Thrust Chamber External Tube Leaks
- o Reduction in Operational Restrictions

(2) Task B2 - Cost Reduction, Simplification, and Increased Engine Flexibility. Provides for material, personnel, engineering, test facilities, support and other related activities in a program directed toward engine system cost reduction simplification and increased flexibility. The primary effort under this task is directed toward areas which will result in a lower engine system unit cost to the government through design simplification and increased engine system flexibility. Major areas of effort include the following:

- o Cost Reduction

Effort is to be expended to reduce engine hardware costs through analysis and redesign of components which historically have been difficult to manufacture, by extending useful service life and by reclamation of high cost items. Areas to be emphasized are:

Improved Producibility

Reclaiming Used Hardware

Development of Reclaiming Procedure  
for Injector Bodies

- o Design Simplification

- o Increased Engine System Flexibility

A program to evaluate and demonstrate an engine system with increased flexibility. The objectives of this effort are the removal of certain inherent engine system limitations thereby improving vehicle mission flexibility, and the evaluation of thrust limiting and/or controlling devices to make maximum utilization of the inflight performance increase.

o Materials Investigation

Covers analyses and tests of components, materials and processes and investigation of the use of improved materials and processes having application in the F-1 engine system. The primary goals of this effort are reduction of engine system cost, increased service life, and improved reliability.

(3) Task B3 - Combustion Stability Investigation.

Provides for maintenance of the capability to solve and take appropriate action should a combustion stability problem occur.

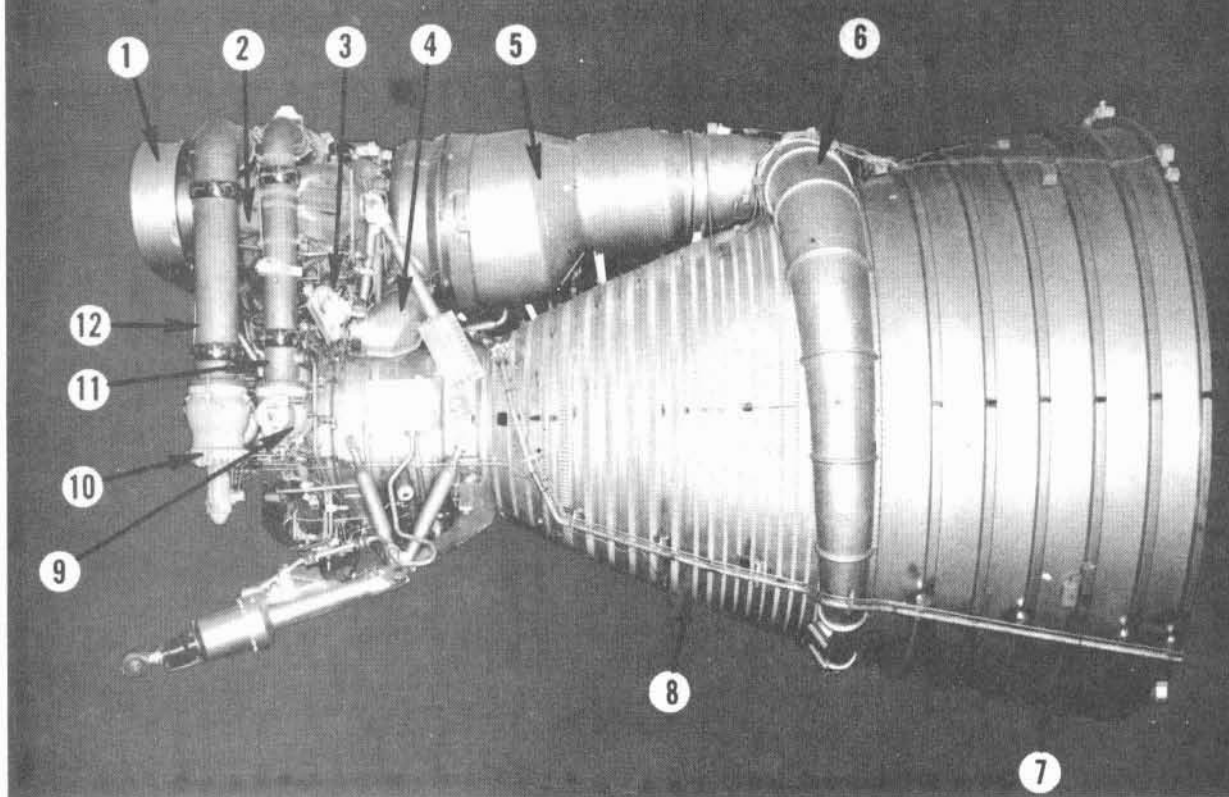
o Relationship of Specific Impulse to Combustion Stability

Involves investigation of the relationship of specific impulse to combustion stability and their effect both singularly and combined, on the injector or thrust chamber.

d. Flight Objectives. Used in a five-engine cluster on the S-IC stage, F-1 engines will launch Saturn V vehicles on pre-planned trajectories. The five-engine cluster, one stationary inboard and four gimballing outboard engines, will produce a total nominal thrust of 7,610,000 pounds at sea level and at lift-off. Figure 3-1 reflects engine characteristics.

e. Existing engine component description, major design parameters. The F-1 engine is a single-start, fixed-thrust, gimbaled bipropellant system which uses liquid oxygen (LOX) as the oxidizer. RP-1 is used as the fuel, the turbopump bearing lubricant, and the control system fluid. The engine has a single, regenerative fuel-cooled thrust chamber with a turbine exhaust gas-cooled extension. Propellants are supplied to the thrust chamber by a direct-drive turbopump driven by exhaust gases from a gas generator which uses the same propellant (but different mixture ratio) as the thrust chamber. Descriptions of major components may be found in the following paragraphs and figure 3-2 illustrates major components.

# F-1 ENGINE MAJOR COMPONENTS



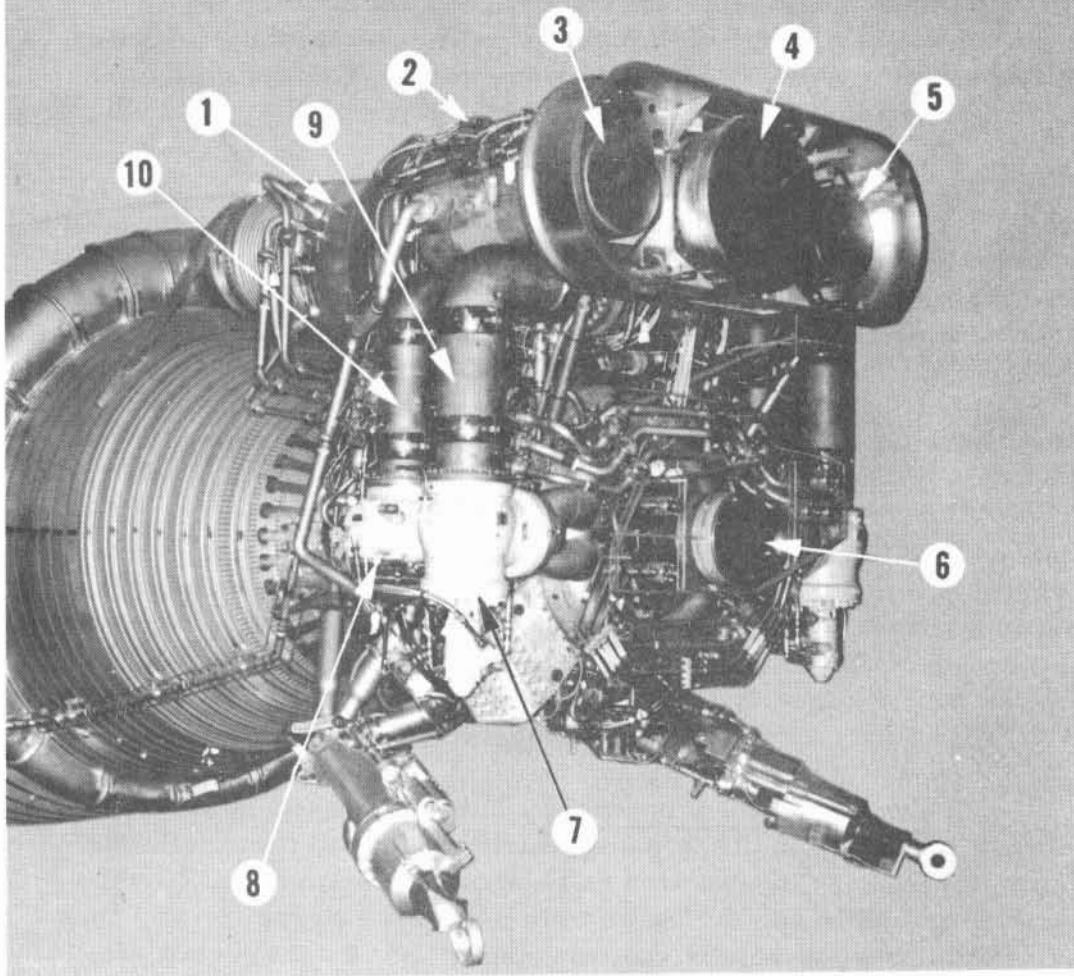
- |   |                          |    |                               |
|---|--------------------------|----|-------------------------------|
| 1 | INTERFACE PANEL          | 7  | THRUST CHAMBER EXTENSION      |
| 2 | TURBOPUMP                | 8  | THRUST CHAMBER                |
| 3 | GAS GENERATOR BALL VALVE | 9  | NO. 1 MAIN FUEL VALVE         |
| 4 | GAS GENERATOR            | 10 | NO. 1 MAIN LOX VALVE          |
| 5 | HEAT EXCHANGER           | 11 | NO. 1 HIGH-PRESSURE FUEL DUCT |
| 6 | TURBINE EXHAUST MANIFOLD | 12 | NO. 1 HIGH PRESSURE LOX DUCT  |

I-E-P 823 AUG 28, 1965 16

Figure 3-2. F-1 Engine Components (Sheet 1 of 2)



## F-1 ENGINE MAJOR COMPONENTS



- 1 HEAT EXCHANGER
- 2 TURBOPUMP
- 3 NO. 2 FUEL INLET
- 4 LOX INLET
- 5 NO. 1 FUEL INLET

- 6 GIMBAL BLOCK
- 7 NO. 2 MAIN LOX VALVE
- 8 NO. 2 MAIN FUEL VALVE
- 9 NO. 2 HIGH-PRESSURE LOX DUCT
- 10 NO. 2 HIGH-PRESSURE FUEL DUCT

I-E-P 824 AUG 28, 1965 16

Figure 3-2. F-1 Engine Components (Sheet 2 of 2)



(1) Thrust chamber. The thrust chamber consists of an oxidizer dome, an injector, and a tubular fuel-cooled body. The thrust chamber receives propellants under pressure from the turbopump, and the injector evenly injects high-velocity propellants into the chamber combustion zone. The combustion gases resulting from burned propellants are expelled at high velocity, thus producing thrust.

The oxidizer dome is a dual-inlet manifold. Inlets are 180 degrees opposed, providing even distribution of LOX to the injector.

The thrust chamber injector is a baffled multi-orificed injector that directs RP-1 and LOX into the thrust chamber in a pattern that will ensure satisfactory combustion.

The thrust chamber body, a brazed assembly, is a tubular walled, regeneratively fuel-cooled, nozzle-type chamber incorporating four outrigger arms. Two outrigger arms support the turbopump assembly and two are used as actuator attachments for thrust vector control. Approximately 30 percent of the fuel is routed directly to the injector while about 70 percent fuel flows through the body tubes, providing cooling during engine operation.

(2) Turbopump. The turbopump is a direct-drive unit consisting of an oxidizer pump, fuel pump, and turbine mounted on a common shaft. Its function is to propel RP-1 and LOX to the gas generator and to the thrust chamber at rated pressure and flow rates. Liquid oxygen enters the turbopump axially through a single outlet in line with the shaft and is discharged radially through dual outlets. Fuel enters the turbopump radially through dual outlets and is discharged radially through dual outlets. The dual inlet and outlet design provides a balance of radial loads in the pump and also minimizes the required pump diameter.

The oxidizer pump is the portion of the turbopump housed inside the oxidizer volute. The pump impeller pressurizes LOX and directs flow to the oxidizer volute dual outlets which in turn direct LOX to the thrust chamber and the gas generator.

Housed inside the fuel volute and the fuel inlet is the fuel pump. RP-1 is driven into the fuel volute by the pump impeller. From the fuel volute RP-1 is directed through dual outlets to the thrust chamber and the gas generator.

The turbine drives RP-1 and LOX pumps by flow of hot gas through the turbine. Gas flow rotates a common shaft, driving the pumps.

(3) Gas generator. The gas generator consists of a ball valve, injector fuel inlet housing tee, injector, combustion chamber, and associated seals.

The gas generator ball valve is a hydraulically operated valve incorporating two hollow balls connected to a single actuator. This valve controls and sequences entry of propellants into the gas generator.

The gas generator fuel inlet housing tee provides a flexible manifold for attaching the ball-valve fuel-outlet port to the gas generator injector plate fuel-inlet port.

The gas generator injector mounts on the combustion chamber and is a flat-faced, multi-orificed type injector. Its function is to direct RP-1 and LOX into the combustion chamber in a pattern that will support efficient combustion.

The combustion chamber consists of a solid-wall chamber, which provides a zone for burning propellants, and a manifold for exhausting the gases from the burning propellants into the turbine.

(4) Main oxidizer valve. The oxidizer valve is a hydraulically actuated, balanced poppet-type valve containing a mechanically-actuated sequence valve and a position indicator. The position indicator contains switches for indicating extreme poppet positions and a potentiometer for recording valve-poppet movements. Two oxidizer valves in the engine system control flow of LOX to the thrust chamber and sequence the opening hydraulic fuel pressure to the gas generator ball valve.

(5) Main fuel valve. The fuel valve is a balanced poppet-type valve incorporating position indicator containing switches for extreme poppet position and a potentiometer to record the valve poppet movement. The switch provides relay logic in the engine electrical control circuit, and the potentiometer provides the instrument pickup for monitoring the valve poppet movement. Two fuel valves in the engine system control the flow of RP-1 to the thrust chamber.

(6) Hydraulic filter and four-way solenoid valve manifold. The hydraulic filter and four-way solenoid valve manifold (engine control valve) contains three filters. One filter is in the supply system and one each is in the opening and closing pressure systems. These filters prevent foreign matter entry into the control system. A start solenoid and stop solenoid with associated pistons and poppets enable the valve manifold to control starting and stopping of the engine by directing control fluid to open or close propellant valves.

(7) Checkout valve. The checkout valve consists of three basic components: a ball, a poppet, and an actuator. Valve functions are to direct ground supplied control fluid back to ground during engine checkout and initial start sequence.

(8) Hypergol manifold. The hypergol manifold consists of a hypergol container, ignition monitor valve, position switch, and igniter fuel valve. A hypergol check valve is installed in the igniter fuel valve. The spring-loaded cam-lock mechanism in the hypergol manifold prevents actuation of the ignition monitor valve until the hypergol cartridge diaphragm bursts. This mechanism also actuates a position switch indicating when the hypergol cartridge is installed. Essentially, the igniter fuel valve is a spring-loaded cracking check valve that allows flow when pressure applied to the fuel in port is  $375 + 30$  psig. The combination of this pressure and increasing pressure supplied by turbopump discharge is then applied to the hypergol cartridge diaphragm when installed. The igniter fuel valve meters fuel to the thrust chamber igniter fuel system.

(9) Bearing coolant-control valve. The bearing coolant-control valve is a dual-poppet cracking valve with three inlets (two are common), three 40-micron filters, and two common outlet ports.

Functions performed are to control the supply of coolant-lubricant fuel to the turbopump bearings and serve as a means of preserving the turbopump bearings between static firings or during engine storage.

(10) Dual gas heat exchanger. Consisting of two separate coil elements in a shell, the heat exchanger utilizes turbine exhaust gas to superheat LOX and cold gaseous helium transforming them to LOX and hot gaseous helium to pressurize the vehicle propellant tanks. Turbine exhaust gases passing through the heat exchanger shell and over the coils super-heat the LOX and liquid helium.

(11) Thermal insulation. Thermal insulation consists of a Refrasil batt between Inconel foil and covers the engine from exit plane to gimbal block. Insulation is to protect components, electrical and control systems and structural parts of the engine from radiant heat from the exhaust plume.

2. Approach. Technical and economic aspects of the plans for the continued project development can be defined best by consideration of the achievement of project objectives and elimination of problem areas.

a. Achievement of project objectives. Required effort to meet objectives of the project will be implemented through the development plan indicated previously in paragraph 1.a.

Project time requirements and large development costs require that extensive efforts be made to obtain maximum data from engine tests and associated analyses. Minimization of tests for demonstration of basic program objectives and exploration of potential problem areas will be a major effort. This planning is reflected in testing efforts illustrated in figure 8-2.

Optimum project efficiency will be accomplished by combining variables which are common to both the exploration into prevalent problem areas and the fulfillment of basic project objectives.

Close monitoring of the contractor will be continued, with appropriate coordination maintained between contractor development efforts and Marshall Space Flight Center. This will ensure the minimum

effort to produce maximum results, while retaining the capability of rapid response to unforeseen problems.

b. Elimination of problem areas. Current engine development presents design problems that have been common to prior high-thrust engines. Due to the scale-up involved in engine design, problem areas are apparent; however, they remain within the state-of-the-art and will be resolved by further development effort. Planned technical approach for the specific problem areas, prevalent within each subdivision of the development plan, follows:

(1) Combustion instability. Evaluation of injector configuration using the explosive pulse stability rating technique and necessary redesign will be continued. Injectors will continue to be investigated to provide a system that will satisfy performance ISP and stability requirements by qualification.

(2) Turbopump testing. Turbopump testing will be performed to determine the cause and means to eliminate turbopump oscillations and to prove turbopump structural and operational integrity.

(3) Nozzle extension erosion and structural integrity. Design modifications, based on test results to improve flow distribution will be continued.

(4) Heat exchanger. Analysis and modifications to stabilize and improve performance will continue.

(5) Other minor problem areas. Continued analyses, testing, and redesign where necessary will be accomplished to resolve minor problems.



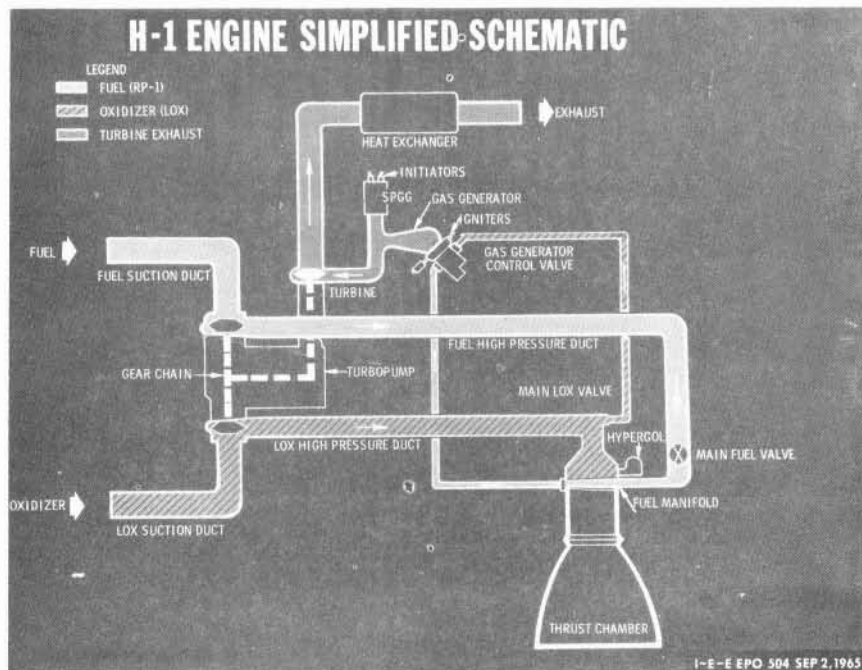
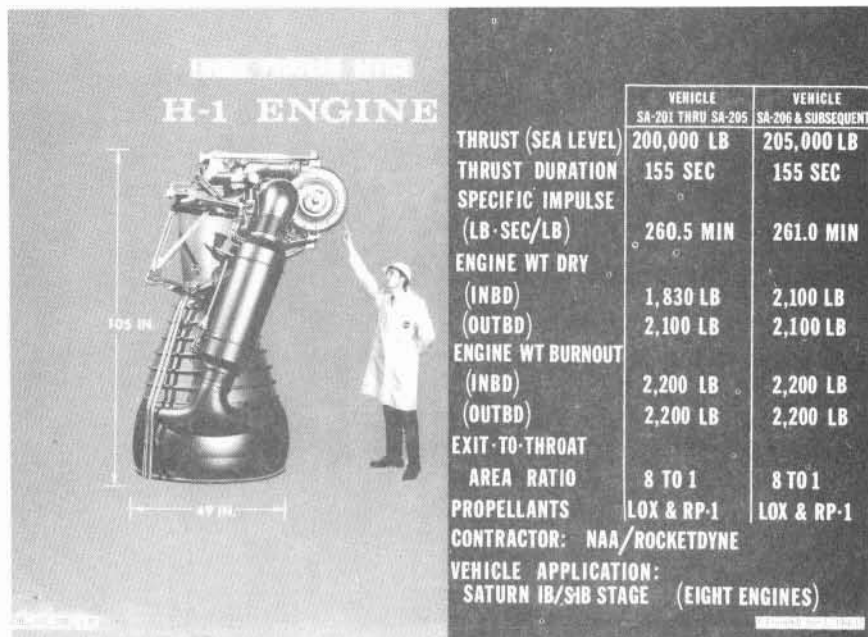


Figure 3-3. H-1 Engine Technical Data

## B. H-1 ENGINE

### 1. Description

a. The H-1 Engine effort is to be expended in direct support of (1) production problems requiring engineering studies, engine and/or component tests, (2) vehicle static tests, and (3) flight, to provide answers in a timely manner. This effort, in support of (1) above, includes studies and tests necessary for the improvement of H-1 engine quality, integrity, and reliability. The effort is inclusive of the following:

- o Manufacturing, Ground Test and Flight Support
- o Flight Worthiness Verification
- o Data Analysis
- o Stability Sampling
- o Sustaining Reliability
- o Special Studies

(1) Manufacturing, ground test and flight support. Capability will be provided, which includes engineering personnel, test facilities and hardware, to resolve engine and GSE problems encountered during production and field utilization of the H-1 engine. This includes the developmental and test effort required to investigate and recommend design changes, Specification Change Notices, Engineering Change Requests, or Engine Field Inspection Requests, and to evaluate stage contractor's Engineering Change Proposals for engine impact.

If problems exist in the field during engine checkout, static test and flight, the definition and evaluation of the problems and recommendations for the solutions to the problems will be accomplished.



Investigations, system analysis, laboratory tests, redesign, procurement or fabrication of test hardware, component tests, and engine tests will be conducted as required to evaluate these problems. This effort includes maintaining surveillance of engine integration with the vehicle, establishment of customer connect points, and definition of the vehicle interface. As new design changes become effective, the coordination of engine changes with the vehicle (contractor) will be performed. The procedures employed by the vehicle (contractor) for engine checkouts in the vehicle and during static firing will be reviewed for concurrence and maintained current with applicable engine specifications.

An average of 700 seconds per month for a total of 33,000 seconds will be accumulated in turbopump component pit testing.

Effort will be directed toward Turbopump Operational support of production, static test and flight. Capability will be provided, which includes engineering personnel, test facilities and hardware to resolve turbopump problems encountered during manufacture, acceptance and field utilization of the H-1 engine, requiring effort beyond the scope of normal Maintenance Engineering.

If problems arise in the field during checkout, static test, and flight, the definition and evaluation of the problems and recommendation for the solutions to the problem will be accomplished.

To the extent that turbopump test capability is not utilized in accomplishing the objectives for Turbopump Operational Support, effort will be applied to the objectives for Turbopump Improvement and Second Source Evaluation.

The objectives of the Turbopump Improvement and Second Source Evaluation Component Pit Test Program are to evaluate test hardware procured from second source suppliers and to evaluate design and operational improvements. The following programs are scheduled to accomplish the objectives:

(a) Turbocast first stage turbine wheel blades. A redesigned first stage turbine wheel blade is being made which will be Reliability Verification Tested when assembled into wheels. Three wheels will be tested. Laboratory vibration tests will also be accomplished. Successful completion of this program will provide a second source for the first stage wheel blades.

(b) Haynes second stage turbine wheel blades. The Haynes second stage turbine wheel will be Reliability Verification Tested. The turbine blades will be fabricated using the shell mold process. Three wheels will be tested.

(c) Turbine manifold. Another supply source will be acquired for turbine manifold. Three manifolds, obtained from the new source, will be Reliability Verification Tested.

(d) Turbopump main shaft. A second source will be evaluated to supply the turbopump main shaft. The present method used to weld the shaft together is a pressure weld. This method will probably be changed to a more widely used technique. Three shafts will be Reliability Verification Tested.

(e) K-Monel LOX inducer. A LOX inducer material change to K-Monel will be evaluated. This change is intended to eliminate the possibility of stress corrosion. Three inducers will be tested to establish satisfactory operation.

(f) Kel-F liner. An operating life limit is presently imposed on the oxidizer pump Kel-F liner because of cracking which has occurred. A possible redesign of the liner will be evaluated to eliminate the cracking tendency. If a satisfactory design is determined, liners will be tested to establish satisfactory operation.

(g) Improved second stage turbine wheel. An improved second stage turbine wheel, which has been designed to reduce the axial load on the number 7 bearing, will be tested. The blades will be machined as an integral part of the wheel. Three wheels will be tested to establish satisfactory operation.

(h) Turbine installation. A study will be conducted to find methods of reducing problems associated with the installation and removal of the turbine assembly in the turbopump. To reduce these assembly problems, minor design changes and/or design and fabrication of installation and removal tools will be evaluated.

(i) No. 1 bearing clamp ring lock. Designs will be evaluated to provide a positive retention of the Number 1 bearing clamp ring which will prevent recurrence of problems associated with tightening of the ring during turbopump operation.

(j) No. 1 bearing heater simplification. Replacement of the bearing heaters with one heater having an equal or greater power rating and relocated to the outboard side of the bearing will be evaluated. This will result in system simplification. An investigation also will be directed toward eliminating the No. 1 bearing temperature redline for launch.

(2) Flight worthiness verification. A test program will be conducted to verify the integrity of the flight engine after a long-term storage by testing five GFP engines. The engines will be of the 205,000-pound thrust configuration and all engine hardware will be provided to test the engines in the contractor's test stands. The engines will be compatible in actual configuration with the engine log book and will have all applicable kit changes installed prior to receipt by the contractor. The applicable engine specifications, modified for each engine, will be used. The engine shall be subjected to a test program which will accumulate sufficient tests and seconds to complete engine service life of 15 starts and 2025 seconds followed by a modified post acceptance checkout. The 15 starts and 2025 seconds includes all test time accumulated on the engines when provided as GFP for this task. After hot-fire tests and checkout are complete, the engine will be disassembled and inspected for abnormal conditions and discrepancies.

A flash report will be required immediately after the occurrence of any significant discrepancy and after completion of hot-fire tests. A formal report summarizing the testing and teardown inspection will be required on each engine.

(3) Data analysis. The existing digital data reduction methods used for engine acceptance will be made available in a form convenient for converting into other digital systems. Supporting data and materials will be provided to MSFC. A manual will be provided for the purpose of instruction in the operation of the data reduction program.

General analysis of engine performance data will be summarized for presentation in a report. The report will include the primary values found in the data reduction printout.

Special data reviews and analysis of flight oriented engine data will be conducted. These reviews and analyses require detailed evaluation of the test program performed on the engine.

Evaluation of test stand instrumentation precision and engine performance repeatability will also be performed. This effort includes data analysis on all production engine tests which have an abnormal and unexplained occurrence. An example of an abnormal occurrence would be a performance shift of 10 psi or greater in the site chamber pressure and/or fuel injector manifold pressure, or a shift in thrust of 2500 pounds or greater within a period of less than 2 seconds. The purpose of the analysis will be to determine the origin and significance of the occurrence. A statement for each analysis summarizing the findings, conclusions, and necessary corrective action will be included in the Bi-monthly Informal Technical Progress Report.

(4) Stability sampling. The stability characteristics of a deliverable injector will be periodically demonstrated to verify that they are within limits of the Model Specification. This demonstration will be conducted on eight GFP injectors. Each injector will be assembled into an engine system of essentially the current production engine configuration. The engine will be subjected to a combustion disturbance which will be induced in the main chamber by detonating a 50 grain bomb located in an outer compartment of the injector. Thrust limits of the stability tests taken at the standard data interval shall be within the current Model Specification limits. Each injector will be tested to accumulate approximately 600 seconds before it is subjected to a stability test. One test with thrust induced combustion disturbance, and damp time within the limits of the Model Specification will be sufficient to demonstrate adequate stability characteristics.

(5) Sustaining reliability

(a) Reliability test. A reliability demonstration program for the H-1 engine is described below:

1. Reliability category B - Tests will be declared within this category during the production support program to continue the demonstration of 99% reliability and a confidence level of 50% or greater while operating at or above 200,000 pounds thrust. The confidence level computed will include tests used in category B during the H-1 sustaining engineering program (April 1, 1965 through June 30, 1967). The objective of the program is to establish the highest possible confidence at 99% reliability. It is estimated that approximately 100 equivalent full-duration tests will be accumulated during the production support program.

2. A test can not be declared for category B reliability which excludes a component which has experienced a hardware or procedural failure in either production support or production testing until the mode of the failure has been determined and corrected. When such a failure is judged a hardware failure, then two components must successfully complete testing to qualification life to prove that the mode has been corrected.

3. Reliability category C - Tests will be declared within this category to determine the reliability at 50% confidence while operating at or above 207,000 pounds thrust and/or operating with hardware which has exceeded engine service life. The objectives of this category is to establish a reliability value from tests that would normally be excluded from category B because of excessive thrust level or hardware which has exceeded engine service life. The reliability computed will include tests used in category C during the H-1 sustaining engineering program (April 1, 1965 through June 30, 1967). Tests declared in this category will not be used in category B.

(b) Malfunction analysis. Operation and malfunction data will be maintained. Reports of failures and/or unsatisfactory condition and failure analysis reports will be documented. An unsatisfactory condition report will be required for each problem of non-conformance to drawings, specifications, or operational requirements.

(6) Special studies. Special studies associated with the H-1 engine will be conducted during the period of performance. Examples of effort that might be conducted are studies to increase performance of the H-1 engine, studies on engine system and component reliability, studies necessary to further define design, functional and performance characteristics of any engine or component and stage-peculiar problems.

b. Flight Objectives. Clustered in a group of eight, the H-1 engine forms the most powerful liquid propulsion system launched in the free world. Primary objectives of this system follow:

(1) Utilize the eight-engine cluster to provide the S-IB stage of the Saturn IB vehicle with a thrust of 1,600,000 pounds for vehicles SA-201 to 205 and to provide 1,640,000 pounds thrust for S-IB stages effective vehicle SA-206.

(2) Utilize H-1 engines on the S-IB stage to launch Saturn IB vehicles on planned trajectories.

c. Existing engine description

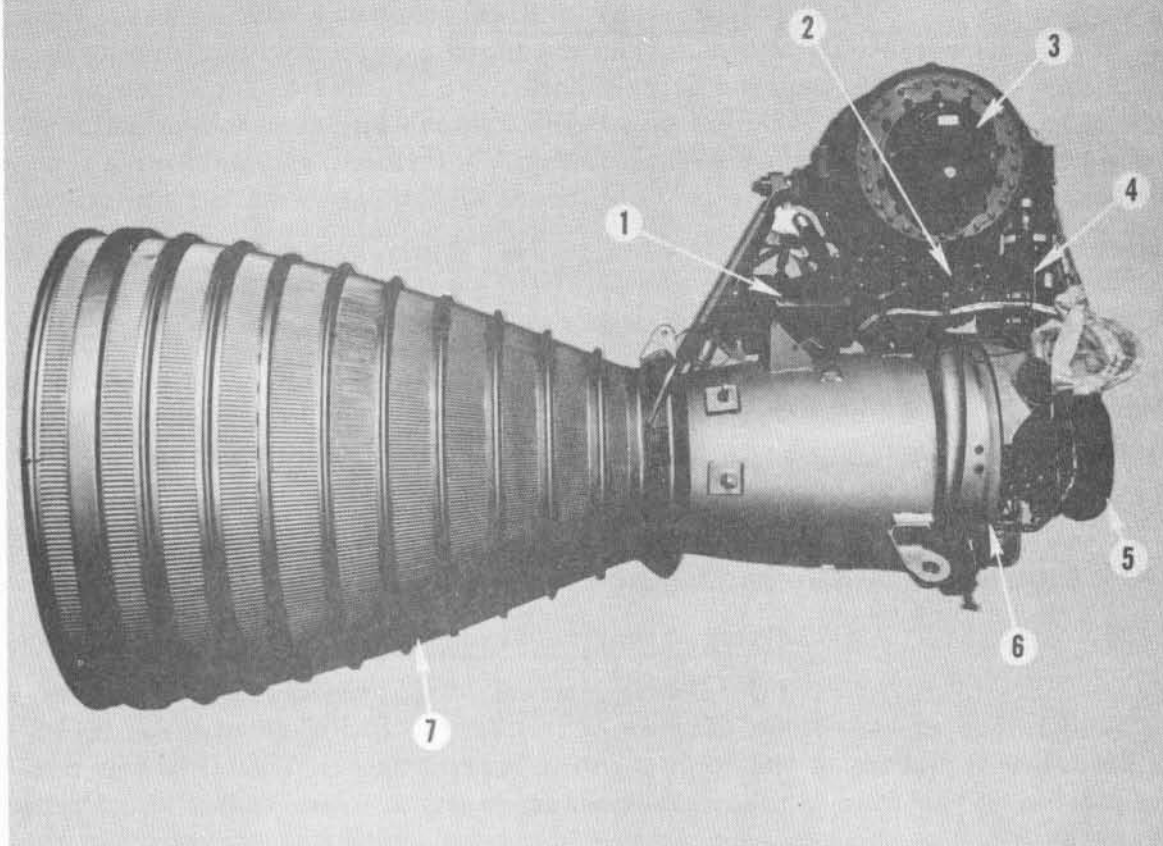
(1) Configuration. Two models of the H-1 engine are used in the eight-engine cluster of the Saturn IB, S-IB stage. H-1C is the model designation of the four-fixed inboard engines; H-1D is the model designation of the four-gimbaled outboard engines. Basically, the physical characteristics of the two models are identical, with the exception of the exhaust system and vehicle-attach hardware. The H-1C engine is delivered with a partial aspirator and the H-1D engine is delivered with full aspirators for exhaust gas flow control.

Each engine is attached to the vehicle structure by a gimbal assembly. The inboard engines are stabilized in their positions by struts attached to the stabilizing lugs. The outboard engines have gimbal actuators attached to the gimbal outriggers, permitting the outboard engines to gimbal a 10-degree square pattern for vehicle directional control.

(2) Description. The engine is a calibrated fixed-thrust, bipropellant rocket engine with a nominal sea-level rating of 205,000 pounds thrust. The engine employs a gimbal mounted, regeneratively fuel-cooled single thrust chamber with an exhaust nozzle expansion ratio of 8 to 1. The propellants (LOX and RP-1) are supplied to the thrust chamber by a turbopump. A gas generator using the same propellants as the thrust chamber powers the turbopump.



## H-1 ENGINE MAJOR COMPONENTS



1 FUEL ADDITIVE BLENDER UNIT

2 TURBOPUMP GEAR CASE

3 LOX PUMP

4 LOX HIGH PRESSURE DUCT

5 GIMBAL ASSEMBLY

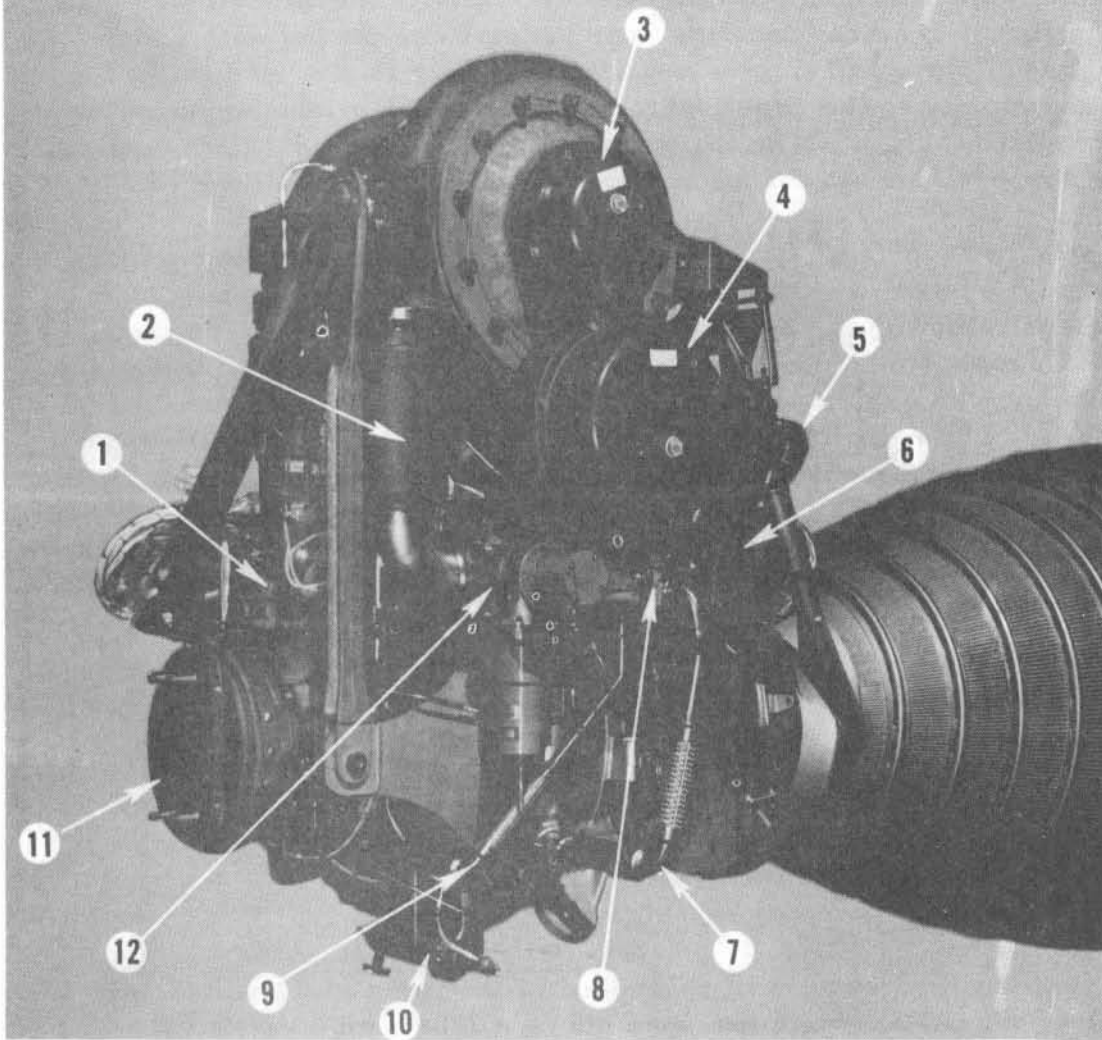
6 LOX DOME

7 THRUST CHAMBER

I-E-P 821 AUG 28, 1966 17

Figure 3-4. H-1 Engine Components (Sheet 1 of 2)

## H-1 ENGINE MAJOR COMPONENTS



- |   |                               |
|---|-------------------------------|
| 1 MAIN LOX VALVE                                  | 7 FUEL BOOTSTRAP LINE         |
| 2 FUEL HIGH-PRESSURE DUCT                         | 8 GAS GENERATOR CONTROL VALVE |
| 3 FUEL PUMP                                       | 9 LOX BOOTSTRAP LINE          |
| 4 TURBINE ASSEMBLY                                | 10 HYPERGOL CONTAINER         |
| 5 SOLID PROPELLANT GAS GENERATOR ATTACHMENT POINT | 11 GIMBAL ASSEMBLY            |
| 6 GAS GENERATOR COMBUSTOR BODY                    | 12 MAIN FUEL VALVE            |

I-E-P EPO 822 AUG. 28, 1965

Figure 3-4. H-1 Engine Components (Sheet 2 of 2)



(a) Thrust chamber and gimbal.

The thrust chamber and gimbal assembly include a gimbal, LOX dome, injector and hypergol container, and a thrust chamber body. The thrust chamber function is to receive the propellants under turbopump pressure, mix and burn the propellants, and impart a high velocity to the expelled combustion gases producing vehicle propulsion thrust. The thrust chamber also serves as a mounting, or support, for all engine and certain vehicle components.

(b) Exhaust system. The engine exhaust system on the model H-1D engines consists of a turbine exhaust elbow duct, heat exchanger, heat shield, and heat exchanger LOX supply line. The thrust chambers on all model H-1D engines also have an aspirator installed to distribute the exit flow of exhaust gases. The exhaust system for the model H-1C engine differs in that its design incorporates a partial aspirator.

(c) Gas generator and control system. The gas generator and control system consists of the liquid propellant gas generator, ignition monitor valve, purge check valve, orifices, boot strap lines, and the hose and line assemblies which make up the series control line.

(d) System check valves and coupling. Check valves on the engine are used to limit the flow of fluids to one direction. Quick disconnect couplings are used on system fill ports and for system drains.

(e) Propellant feed system. The propellant feed system is composed of the main fuel valve, main LOX valve, propellant high pressure ducts, turbopump, check valves, and orifices. The purpose of the propellant feed system is to supply propellants at the pressures and in the quantities required for engine ignition, transition, and mainstage operation.

(f) Turbopump assembly. The turbopump is a turbine driven, dual-lumping unit consisting of an oxidizer pump, fuel pump, reduction gearbox, accessory drive adapter, and turbine. To simplify the engine system high-pressure plumbing, the turbopump is mounted on the side of the thrust chamber, with the main shaft at right angles to the thrust vector. This mounting

provides a high-pressure duct routing with minimum pressure drop, reducing the requirements for development of high-pump outlet pressures. The outlets of the oxidizer pump and the fuel pump are integral parts of the respective pump volutes. These outlets are attached to the main-propellant ducting. During engine operation, the turbopump supplies oxidizer and fuel to the thrust chamber at the required pressures and flow rates. The turbopump also supplies the liquid propellant gas generator with the required flow of oxidizer and fuel. Engines are equipped with the Mark III H or Mark III turbopump. The Mark III H is a more refined turbopump incorporating increased volute strength, integral-diffuser vanes, high-strength bolting arrangements, and tapered-inducer vanes.

(g) Pneumatic lubrication system. The pneumatic and lubrication system includes: purge lines and check valves, pressurizing lines and check valves, vent lines, drain lines, filters, screens, lube lines, and the fuel additive blender unit. The purge lines and check valves serve as connect points for gaseous-nitrogen purges required during pretest, test, post-test, and certain maintenance procedures. The check valves prevent flow reversal at connect points. The fuel additive blender unit blends fuel and a high-pressure lubricant additive for turbopump gearcase lubrication.

(h) Electrical system. The engine electrical system consists of harnesses and heaters, a ground box, and an engine simulator. The purpose of the engine electrical system is to condition the engine, checkout the electrical system and the engine, and control engine start and cutoff.

(i) Instrumentation system. The standard instrumentation system consists of instrumentation taps located at various points throughout the engine. The taps are provided for installation of sensing devices which monitor the performance of engine components and subsystems during engine operation.

(3) Major design parameters and physical characteristics. Figure 3-3 shows the major design parameters and physical characteristics and figure 3-4 illustrates major components.

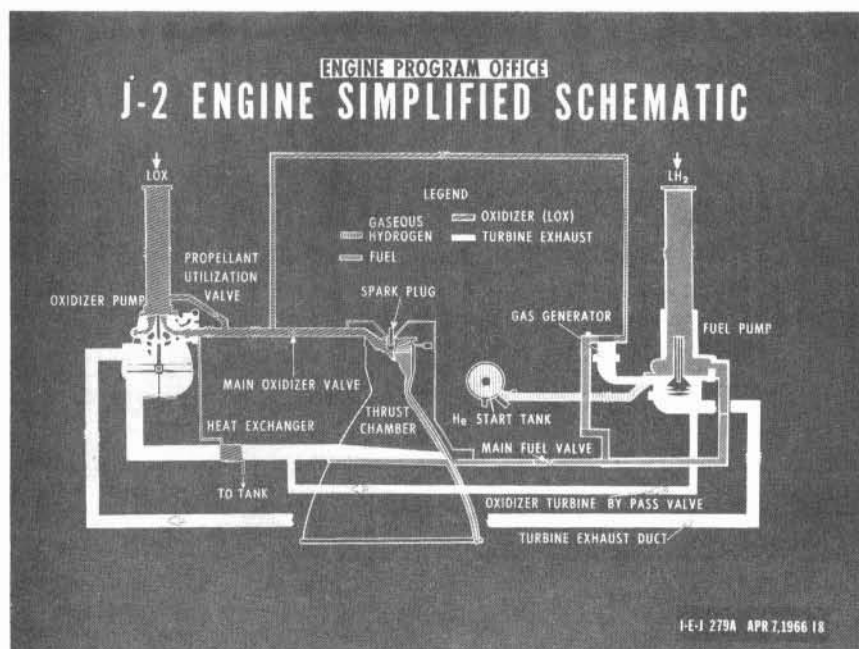
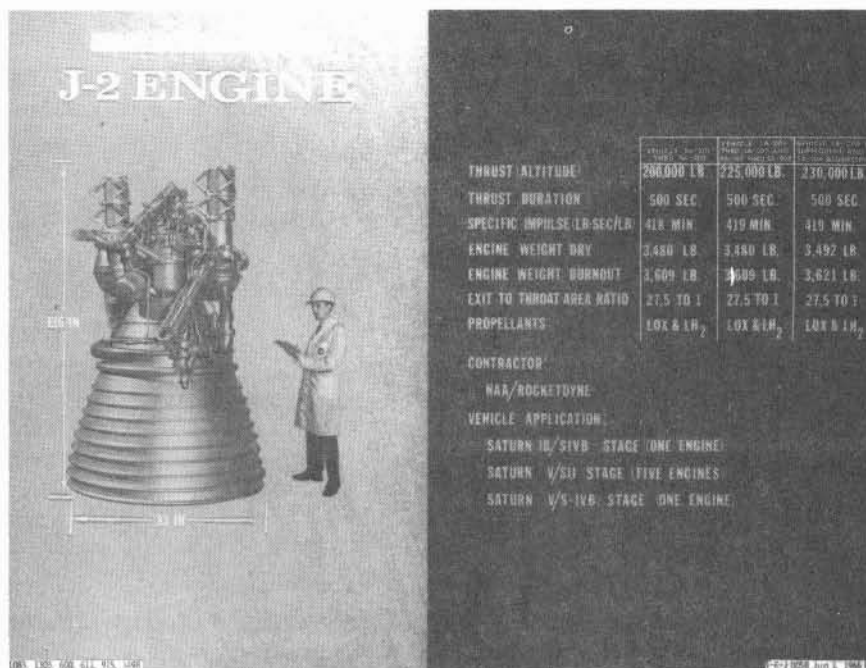


Figure 3-5 J-2 Engine Technical Data

2. Approach. The primary effort is improving the H-1 engine, increasing the present reliability, and investigating means of preventing malfunctions that could delay launch or cause vehicle damage. It is intended that the engine be maintained easily at minimum cost and manpower. This effort will consist of tests and analyses, and redesign where necessary. To enable any weaknesses found to be traced directly through the production system, only production-type hardware will be used. All engine rebuilding will be performed at MSFC, using production line hardware.

Test stand utilization will be adjusted as required to provide the facilities necessary for program support. This adjustment will shorten calendar time required for hardware testing by increasing facility capability when needed. During this period, design deficiencies will be corrected and a formal qualification demonstration program will be conducted. Production engines incorporating the latest features will be used.

### C. J-2 ENGINE

#### 1. Description

a. Development plan. Presently, the engine development program has progressed through completion of preliminary flight rating tests, the flight rating tests, qualification of the 200,000-pound thrust engine and the qualification test series of the 205/230,000-pound thrust engine. Completion of the qualification requirements for the 205/230,000-pound thrust engine is scheduled for April 1967. This plan presents the development program to qualify the uprated 205,000-pounds thrust at a 5.0 mixture ratio with 99 percent reliability at a 50 percent confidence. Effort will also be directed toward demonstration of increased specific impulse and thrust over that of the 205/230,000-pound thrust engine. A production support program is designed to furnish vehicle flight support. Production support time will be utilized between peaks to make needed and desirable engine system improvements and to effect simplifications of direct benefit to the Apollo Program. This effort will bring about simplified static test and launch procedures and increased operational and performance capabilities such as:

- o Reduction of redline and operational restraints
- o Elimination or reduction of engine propellant and thrust chamber conditioning requirements
- o Improvement in engine start characteristics and side load reductions

Additionally, the program will provide for the investigation and conduct of feasibility tests in a number of areas to provide a more versatile J-2 propulsion capability. Concepts to be investigated are:

- o Self-ullaging idle mode of operation with attendant elimination of the present S-IVB stage propellant ullaging and LOX recirculation system
- o Tank head start
- o A pneumatic logic control system in lieu of the present electrical system
- o Propellant utilization mixture ratio control system that causes less thrust variation than the present oxidizer propellant recycle system
- o In-flight deployable nozzle extension systems usable with the existing S-IVB stage envelope
- o Turbomachinery to further minimize propellant pump inlet requirements and vehicle propellant-conditioning systems
- o Engine performance limits of turbomachinery and other engine system hardware

Sea level launch operation, injector performance, thrust chamber performance, heat transfer, stability, ignition, aerodynamics, and fluid dynamic coupling characteristics will also be investigated.

(1) Engine systems. Engine systems development effort through 1968 will be expended on the 225K engine and the 230K engine, and on production support effort for the two engines. The production support effort is directed toward support of the vehicle flight and static test programs and the investigation of engine improvements which will provide major vehicle and operational simplification and additional mission capability.

The 225K engine, which has been under development, has now completed the PFRT, the FRT, and the Qualification programs.

Engine system development effort was started on the 230K engine in the second quarter of 1965, and will continue into 1967. Current test effort is oriented toward verifying Qualification II (230K) readiness. The formal Qualification II test series was completed on August 22, 1966, in 30 tests for 3807 seconds without engine or test facility malfunction. Completion of Qualification II requirements is scheduled for April 30, 1967.

The production support program plan is designed to provide engineering support for the J-2 engine in the field, and based upon development and operational experience, to investigate improved J-2 engine features for major vehicle and operational simplification and for increased vehicle mission capabilities.

As field problems arise during the checkouts, static tests, and flights, the problems will be defined and evaluated and followed by firm recommendations for resolution. Investigations, systems analyses, laboratory tests, redesign, procurement or fabrication of prototype hardware, component tests, and engine tests will be conducted as required to evaluate these problems. As new design changes become effective, coordination of engine changes with the vehicle contractors (S&ID and DAC) will be performed. Procedures employed by the vehicle contractor for engine checkout of the vehicle and during static firing will be reviewed for simplification.

Flight data evaluation will be performed to determine propulsion system operating characteristics during flight and to support the vehicle contractor in the Flight Evaluation Working Group (FEWG). A permanent member of the FEWG will be maintained,

and the member will participate in all FEWG meetings. The evaluation will include engine or component tests necessary to support the FEWG final report, and to substantiate recommendations for subsequent vehicle flights.

In mid-1964 the J-2 Experimental Engine Program was initiated to simplify the J-2 engine system by using the principle of tapping combustion products from the thrust chamber to drive the oxidizer and fuel turbopumps, thus relieving the gas generator and all of its associated controls. This engine feature has been successfully demonstrated on a full-scale J-2 engine by means of engine system testing. This effort was subsequently directed toward investigation of additional features which would provide more benefits to the vehicle and vehicle operational procedures. The following engine system features have been identified as being the most significant and beneficial for further investigation:

(a) Engine idle-mode operation which could be utilized to settle propellants in the vehicle prior to restart and provide for the propellant and hardware conditioning necessary to achieve a satisfactory self-ullaging engine restart.

(b) A tapoff turbine drive system which provides for engine system and accessory simplifications and reduced engine sensitivity to the wide range of propellant conditions experienced during a self-ullaging engine start and restart.

(c) A thrust chamber configuration which would enable a sea level launch capability without the use of side-load restrainers and diffusers.

(d) Use of a solid-propellant turbine spinner in lieu of a start tank.

These engine system features will be investigated further by means of engine system tests to demonstrate their practicality as a portion of the production support program.

The altitude facility at Arnold Engineering Development Center, Tullahoma, Tennessee (AEDC), was activated in August 1966 to serve as the final verification of engine performance characteristics at altitude and for simulated flight environmental conditions. The present test program is designed to solve problems indicated from data from previous flights.



The single-engine J-2 test stand at MSFC will also be used to the maximum extent possible in the development of the J-2 engine/vehicle system. This test stand will serve as an ideal test bed for confirmation testing of all engine starting and operating conditions in conjunction with stage limit conditions.

(2) Thrust chamber assembly. Effort will be directed toward product development, support of the 225K and the 230K engines, and the flight support program. The objectives will be to support the overall engine development program with suitable hardware; make design changes required for development and application of the engine at targeted thrust and specific impulse levels; and demonstrate conclusively from data obtained during testing that the thrust chamber assemblies meet model specification requirements.

Injector design changes will be evaluated to further increase the specific impulse. Thrust chamber changes to be evaluated are those needed to retain thrust chamber reliability and durability under the higher specific impulse and thrust conditions.

(a) Thrust chamber development. The thrust chamber development program will be primarily oriented toward solving problems caused by uprating. In addition, those structural changes required by the uprating program will be incorporated into the chamber.

Thrust chamber problem areas concern degradation of the tubes in the combustion zone by tube splits as a result of engine stalls or injector streaking. To correct this, the following measure is being taken: An R&D chamber will be fired with thermocouples installed to measure the wall temperature of the tubes and, in addition, with sufficient additional pressure taps to determine the distribution of pressure drop in the chamber. This effort will furnish fundamental information on the operation of the cooling circuit and aid in resolving reliability problems.

(b) Injector development. The injector will be refined to meet conditions as discussed below:



An evaluation is being made of the performance of candidate injector patterns, including the effects of variations of film-coolant quantity and distribution. All candidate injectors will include a turning vane at the injector inlet to reduce pressure drop, a gap between the injector and chamber to prevent faceplate shrinkage, and modified chamber pressure tap purge arrangements to reduce chamber pressure measurement deviations.

An injector will be evaluated with the foregoing modifications at uprated thrust levels in several R&D engines. On the basis of these R&D engine test results, it will be determined whether the film-cooling modified injector will satisfactorily meet the requirements.

An engine stability rating technique will be evaluated to test the stability of the injector system against disturbances created by detonation of explosive charges in the combustion chamber. This technique may then be used to demonstrate the inherent stability of the injection system, and to compare the stability of the candidate injection systems.

(3) Gas generator. Development effort is considered complete on the gas generator. Hardware inspection and data monitoring will be continued on all gas generators. Fabrication of R&D gas generator hardware to support turbopump component and engine R&D programs will be accomplished. Process specifications will be monitored to verify those critical processes required to produce consistently acceptable products.

(4) Fuel turbopump. The major effort remaining in the fuel turbopump program is in the flight support program.

Backup turbine seal configurations will be tested on flight support engines in those instances in which the flight support test objectives are not compromised. A controlled-gap carbon turbine seal is presently being considered for evaluation.

Turbopumps scheduled for flight support engines will be green-run tested in the component facility.

The basic development program was concluded upon completion of the last fuel turbopump milestones.

(5) Oxidizer turbopump. Effort will be expended in assembling, green-run testing, and preparing turbopump assemblies for engine flight support testing.

Effort will also be expended, as required, to resolve oxidizer turbopump problems arising during flight testing of the J-2 engine system.

Analyses and test data indicate that the thin first-row turbine wheel encounters a critical axial vibration when operating at the increased power level. An investigation is being conducted to identify the vibration mode. Strain gages and thermocouples have been attached to thin and thick first-row wheels. Testing has commenced, utilizing a slip-ring assembly, to obtain the operating stress levels and temperature gradients. Data from testing the thin-wheel configuration are being evaluated. Subsequent testing will be conducted on a thick-wheel assembly, with and without the stator gas seals.

Inspection of accessory drive quill shafts used in the field revealed rusting and minor pitting on the splines. Bench tests have been conducted on a standard and chrome-plated shaft. Results revealed the latter had a substantial increase in resistance to corrosion over the standard shaft. Wear characteristics also were improved. The possibility of conducting additional testing on an engine is being considered. If this additional testing corroborates the results obtained during the bench tests, the chrome-plated shaft will be considered for production as a Class II change.

(6) Control components. Structural, vibrational and laboratory flow testing will be conducted to determine the operating characteristics of the controls hardware over the full range of operational conditions with verification tests in component pits and on the engine. This testing will serve to demonstrate that the hardware meets all requirements, will define the operating margins, and will permit the searching for and identification of problem areas. Areas which are included in this task are:

(a) Development techniques employing engineering logic, computers, or simulated systems to assist in defining, duplicating, and resolving the conditions occurring on engine control systems.

(b) Study problem areas and proposed solutions to specific engine control problems that can be negotiated into the engine and assembly at proper change points.

(c) Complete sufficient engine testing of redesigned helium high-pressure relief valve to substantiate presentation of an ECP by January 1967. The new valve has been developed to provide protection from atmospheric moisture and will also decrease the vibration sensitivity of the valve.

(d) Complete design study of an improved start tank vent and relief valve incorporating a one-piece guide and bolt by January 1967.

(e) The design study has been prepared for a thermostatic orifice for MOV closing control to reduce variations in cutoff impulse. The previous study revealed that restrictions within the closing control system are of such magnitude as to preclude the use of a thermostatic orifice.

The following items of control hardware are within the Component Qualification Program:

- o \*Main fuel valve
- o \*Fuel bleed valve
- o \*Pressure-actuated purge control valve
- o \*ASI oxidizer valve
- o \*GG propellant control valve
- o \*Fuel pump drain check valve

\*These components have completed Component Qualification test.

- o \*Main oxidizer valve
- o \*Start tank fill and refill package
- o \*Propellant utilization valve
- o \*Heat exchanger antiflow check valve
- o \*GG fuel purge check valve
- o Start tank discharge valve
- o \*Oxidizer turbine bypass valve
- o \*Oxidizer injector purge check valve
- o \*Mainstage pressure switch
- o \*Start tank refill check valve
- o \*Pressure-actuated shutoff valve
- o Pneumatic control package
- o \*Restrictor check valve (two types)
- o Start tank vent and relief valve
- o \*Oxidizer bleed valve
- o \*GG oxidizer purge check valve
- o \*Pump purge check valve
- o \*Oxidizer pump intermediate seal check valve
- o \*Four-way solenoid valve
- o \*Start tank

\*These components have completed Component Qualification test.

(7) Interconnect components. The objective of the interconnect components effort is to develop components that comply with the requirements of the J-2 Model Specification. This product development effort will continue through the production support program.

Test programs will be designed to permit the isolation of operational deficiencies and problem areas. Configuration changes required by fabrication problems, for the correction of operational deficiencies, by the customer, or by other engine needs, will be designed, developed, and incorporated into the qualification configuration in accordance with standard procedures. Hardware produced from drawings and process specifications will be proven by laboratory and manufacturing effort to meet qualification requirements.

Process specifications will be developed to define critical processes requiring strict control to produce consistently acceptable end products. Inspection and dissection of various components will be performed, and fabrication processes will be reviewed for compliance with drawings and specifications.

Engine test support effort will include inspection, review, and disposition of engine hardware and analysis of engine test results which affect interconnect components hardware.

(8) Electrical. A program of engine firings and component evaluation testing including structural, vibrational, and laboratory checkout testing will be conducted to verify the operating characteristics of the electrical control assembly (ECA) under operational conditions with incorporated ECP improvements. This testing will serve to demonstrate that the ECA meets all requirements, will define operational margins, and will permit the isolation, identification, and development of designs to solve operational deficiencies.

Effort will be directed toward (a) investigating the environmental effects of an increased-performance engine on the engine electrical system, and (b) performing intensive testing to demonstrate adequate confidence for the life requirement of the engine.

The following electrical items are within the Component Qualification Program and have successfully completed the test series:

- (a) Electrical controls assembly
- (b) Electrical harness assembly
- (c) Ignition-detection probe

(9) Flight instrumentation. A program of engine and laboratory testing will be conducted for the improved pressure transducers and the hot-gas temperature transducers. The parameters which must be met in this program are established by the model specification and supplemental requirements established by the Design Requirements Specification. This testing will serve to demonstrate that these components meet all requirements, define operating margins, aid in the searching out and identification of operational deficiencies, and verify redesigns for these conditions.

(a) The following test requirements exist for each of the above-mentioned components:

1. Pressure transducers. Conduct engine tests and evaluate the high-reliability pressure transducers for extended-life capability.

2. Temperature transducer. Evaluate replacement of fine-gage wire in hot-gas temperature transducer for increased physical strength and faster time response. An R&D test program has been initiated to improve the reliability of this unit.

(b) The following flight instrumentation items are within the Component Qualification Program and have successfully completed the test series:

- 1. Primary flight instrumentation package
- 2. Auxiliary flight instrumentation package

3. Fuel flowmeter
4. Oxidizer flowmeter
5. Surface temperature transducer
6. Hot-gas temperature transducer
7. Fuel temperature transducer

(10) Ground support equipment. Engine ground support equipment (GSE) is government furnished to stage contractors utilizing the J-2 engine system and to engine maintenance field service personnel.

Engine GSE is divided into three main categories: engine checkout equipment, engine handling equipment, and engine maintenance equipment:

(a) Engine checkout equipment. This equipment consists of items such as the Electrical Checkout Console Assembly (P/N G1037), and the Bypass Valve Actuation Plate Kit, (P/N 9016723). Checkout equipment is used for receiving inspection of the engine and for separate engine system or component checkout.

(b) Engine handling equipment. Consists of items such as the Engine Vertical Installer Assembly, (P/N G4035), Engine Handler Assembly (P/N G4046). This equipment is used for engine stage installation, engine handling, and engine component handling.

(c) Engine maintenance equipment. This equipment consists of items such as the Automatic Arc Welding Set, (P/N G3128), and the Main Propellant Valves Maintenance Set (P/N 902097), and is used by Rocketdyne field service personnel for engine maintenance.

Ground support equipment is outlined in Rocketdyne/Report R-5334, J-2 Engine GSE Support Plan.

b. Flight Objectives

(1) Saturn IB/S-IVB stage. The primary objective of the J-2 engine on the Saturn IB vehicle flights is to provide thrust necessary for the S-IVB stage and attached payload to simulate lunar return and re-entry conditions.

(2) Saturn V/S-IVB stage. Primary engine objectives on Saturn V vehicle flights are to provide the necessary thrust for the S-IVB stage and attached payload to accomplish desired earth parking orbit, to restart the engine in that orbit, and to provide the thrust required for lunar trajectory.

(3) Saturn V/S-II stage. The primary J-2 engine objective on the S-II stage flights is to provide the thrust needed to assist the S-IVB stage and payload into earth orbit.

c. Existing engine description. The J-2 rocket engine is an advanced, high-performance, multiple restart engine utilizing liquid oxygen and liquid hydrogen as propellants. It is designed to be used in cluster or singly.

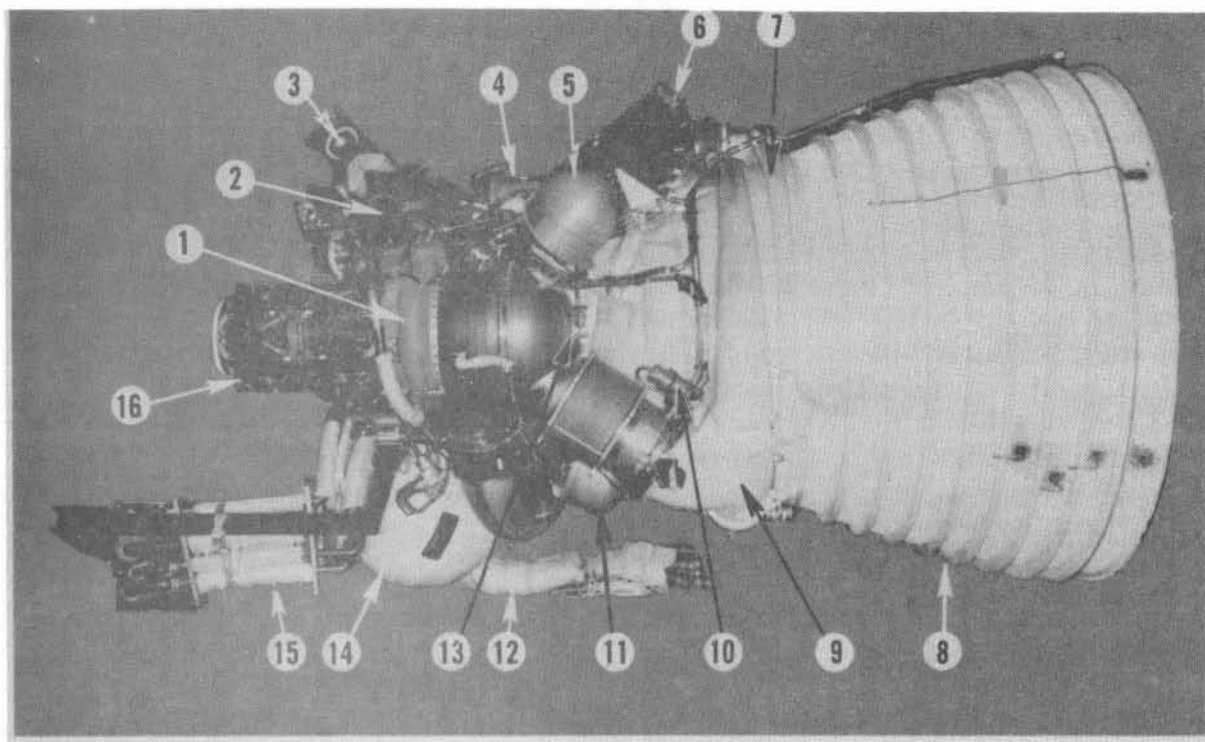
Design features incorporate a single-tubular-wall, non-optimum bell-shaped thrust chamber, and independently driven direct-drive turbopumps for liquid oxygen and liquid hydrogen. A single gas generator utilizing the same propellants as the main thrust chamber powers both turbopumps. The exhaust gases from the gas generator are directed to the inlet of the fuel turbopump turbine and the exhaust gases of the fuel turbopump turbine are ducted to the inlet of the oxidizer turbopump turbine, thus creating a power series that allows each turbopump to operate at its most favorable speed.

Liquid hydrogen, liquid oxygen, and helium are the only fluids used. No lubricants or other fluids which could freeze at the extremely low operating temperatures are used in this engine.

An electrical control system which contains solid-state logic elements is used to sequence the start and shutdown operations of the engine.

Flexible inlet bellows are provided for engine system gimbaling. A gimbal block is installed at the center of the thrust chamber dome, and gimbal actuator attach points are incorporated into engine design.

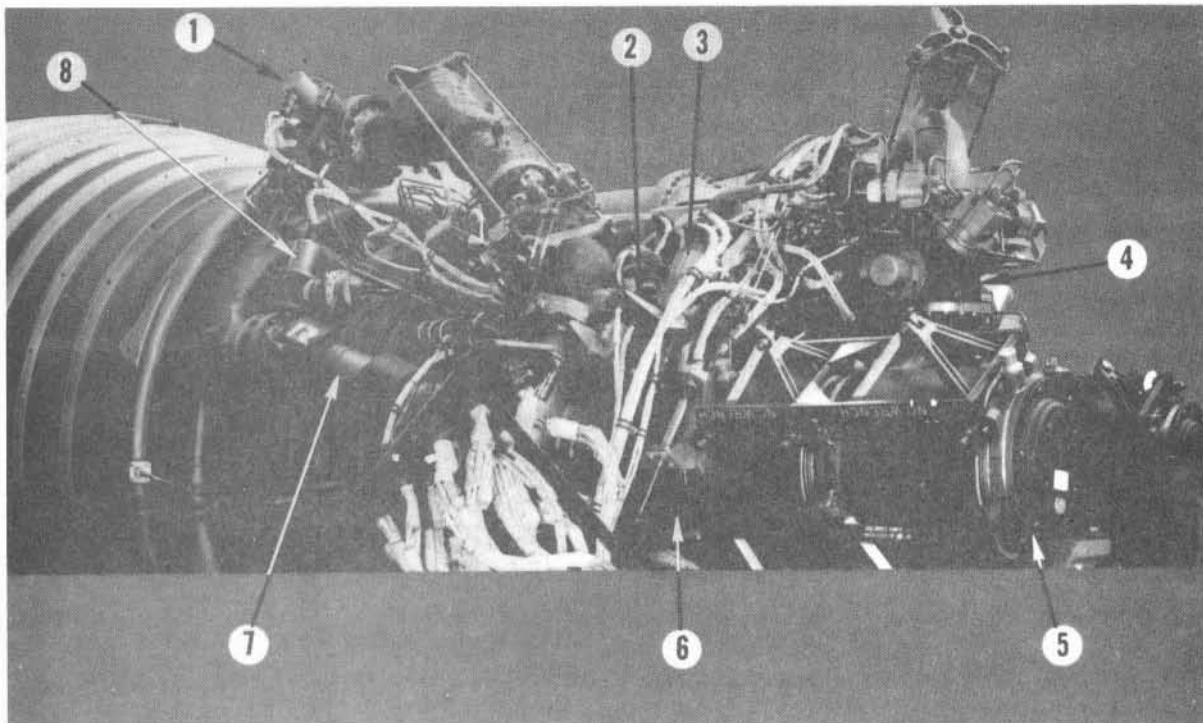




- |  |   |
|--|---|
| 1 OXIDIZER TURBOPUMP                     | 9 EXHAUST MANIFOLD                          |
| 2 PROPELLANT UTILIZATION VALVE           | 10 ANTI-FLOOD CHECK VALVE                   |
| 3 HIGH-PRESSURE OXIDIZER DUCT            | 11 AUXILIARY FLIGHT INSTRUMENTATION PACKAGE |
| 4 ELECTRICAL CONTROL PACKAGE             | 12 CUSTOMER CONNECT LINES (ELECTRICAL)      |
| 5 PRIMARY FLIGHT INSTRUMENTATION PACKAGE | 13 ACCESSORY DRIVE PAD                      |
| 6 HIGH-PRESSURE FUEL DUCT                | 14 GH <sub>2</sub> START BOTTLE             |
| 7 FUEL MANIFOLD                          | 15 CUSTOMER CONNECT LINES (PNEUMATIC)       |
| 8 THRUST CHAMBER                         | 16 OXIDIZER INLET DUCT                      |

I-E-P 825A Jun 1, 1966 18

Figure 3-6. J-2 Engine Components (Sheet 1 of 2)



- |                       |                                 |
|-----------------------|---------------------------------|
| 1 MAIN FUEL VALVE     | 5 FUEL INLEX DUCT               |
| 2 GAS GENERATOR       | 6 FUEL TURBOPUMP                |
| 3 FUEL BLEED VALVE    | 7 TURBINE BYPASS DUCT           |
| 4 MAIN OXIDIZER VALVE | 8 OXIDIZER TURBINE BYPASS VALVE |

I-E-P EPO 826 AUG 28, 1965

Figure 3-6. J-2 Engine Components (Sheet 2 of 2)

A high-speed, direct-drive power takeoff is provided at the liquid oxygen turbine for accessory operations.

Propellant utilization is accomplished by bypassing liquid oxygen from the discharge side of the pump to the inlet side through a valve controlled by a small servometer.

A heat exchanger, located in the oxidizer pump turbine exhaust duct, provides for pressurization of the vehicle oxidizer tank. Vehicle supplied helium or oxygen tapped from the high-pressure duct, may be used for oxidizer tank pressurization. Gaseous hydrogen from the thrust chamber fuel manifold is used for fuel tank pressurization.

Welded joints are used to minimize leaks to improve reliability. Dual seals incorporated on intermediate bleed from the low-pressure side, are utilized where seals are necessary.

Flight instrumentation packages are mounted on the engine to monitor operation and supply vehicle data through customer connections.

Major component assemblies composing the J-2 engine are given in the following paragraphs. Figure 3-5 outlines engine data and figure 3-6 illustrates component locations.

(1) Thrust chamber. The thrust chamber includes a body and an injector. The purpose of the thrust chamber is to receive liquid propellants under turbopump pressure, convert them to a gaseous state, mix and burn them, and impart a high velocity to the expelled combustion gases to produce thrust. Subassemblies of the thrust chamber are the thrust chamber body and the injector.

The thrust chamber body is a tubular-wall, non-optimum, bell-shaped thrust chamber, consisting of a cylindrical section where combustion occurs, a narrowing throat section, and an expansion section.

The thrust chamber injector is a concentric orifice, a porous-faced injector manufactured from a rough-die forging.

(2) Gimbal. The gimbal is essentially a universal joint consisting of a spherical socket-type bearing with a Teflon-Fiberglas composition coating that provides a dry-low-friction bearing surface. Gimbaling is 7-degrees limit without snubbing; 7-degree square pattern with snubbing, and 10-degrees approximately in corners.

(3) Augmented spark igniter. The augmented spark igniter is chamber mounted in the injector. It receives initial flow of oxidizer and fuel which are ignited by means of two spark plugs side-mounted in the igniter chamber.

(4) Augmented spark igniter oxidizer valve. The augmented spark igniter oxidizer valve is a normally closed, pneumatic operated, poppet valve. The valve is designed to control oxidizer flow to the spark igniter and is main oxidizer valve mounted.

(5) Augmented spark igniter ignition monitor. The augmented spark igniter ignition monitor is a link-type detector unit installed in the augmented spark igniter. It is used to detect ignition in the augmented spark igniter combustion zone.

(6) Oxidizer turbopump. The oxidizer turbopump is a single stage centrifugal pump with direct turbine drive. It is self-lubricated, self-cooled, and designed to increase the pressure and propel the liquid oxygen through high-pressure ducts to the thrust chamber.

(7) Fuel turbopump. The fuel turbopump is a turbine-driven, axial-flow, pumping unit consisting of an inducer, a seven-stage rotor and a stator assembly. It is a self-lubricated, high-speed pump and is designed to increase hydrogen pressure and propel the fluid through high-pressure ducting to the thrust chamber.

(8) Main oxidizer valve. The main oxidizer valve is a gate-type valve, spring loaded to the closed position, and is pneumatically operated to the open and closed position. The main oxidizer valve function is to control flow to the thrust chamber.

(9) Main oxidizer pressure-actuated control valve. The main oxidizer pressure-actuated control valve is a multiported valve requiring a pressure source for actuation. Outlet ports are spring loaded in the closed position. The purpose of the valve is to supply control pressures for opening or closing engine system valves.

(10) Main fuel valve. The main fuel valve is a gate-type valve, spring loaded to the closed position, and pneumatically operated to the open and closed positions. The purpose of the main fuel valve is to control fuel flow to the thrust chamber assembly.

(11) Oxidizer dome purge check valve. The oxidizer dome purge check valve is a spring loaded, normally closed, poppet check valve and is located on the main oxidizer valve. The purpose of the valve is to prevent oxidizer from flowing to the helium regulator.

(12) Gas generator assembly. The gas generator consisting of a combustor body, injector, and a control valve containing oxidizer and fuel poppets and two spare igniters, produces the hot gas to drive the fuel turbine which, in turn, supplies propellant pumps operating power.

(13) Gas generator control valve. The gas generator control valve is a pneumatically operated, spring loaded to the closed position, poppet valve. The oxidizer and fuel poppets are mechanically linked by an actuator. The purpose of the gas generator control valve is to control the flow of propellants through the gas generator.

(14) Heat exchanger. The heat exchanger is a shell assembly, consisting of a duct, bellows, flanges, and coils. The heat exchanger is mounted in the turbine exhaust duct between the oxidizer turbopump and the thrust chamber. Its function is to heat and expand helium gas or to convert liquid oxygen to gaseous oxygen for maintaining vehicle oxidizer tank pressurization.

(15) Oxidizer turbine bypass valve. The oxidizer turbine bypass valve is a normally open, spring loaded gate valve. It is mounted in the oxidizer turbine bypass duct. The purpose of the valve is to prevent an overspeed condition of the oxidizer turbopump.

(16) Propellant utilization valve. The propellant utilization valve is an electrically operated, two-phase, motor-driven, oxidizer transfer valve and is located at the oxidizer pump outlet volute. The propellant utilization valve insures the simultaneous exhaustion of the contents of the propellant tanks contents and varies engine mixture ratio.

(17) Oxidizer and fuel flowmeters. The oxidizer and fuel flowmeters are identical helical-vaned, rotor-type flowmeters, except that the oxidizer flowmeter uses a six-vane rotor and the fuel flowmeter uses a four-vane rotor. The flowmeters are calibrated and are located in the oxidizer and fuel high-pressure ducts to measure flow rates.

(18) Start tank discharge valve. The start tank discharge valve is a pneumatically controlled, spring loaded in the closed position, poppet valve. The purpose of the valve is to contain the gaseous hydrogen in the start tank until engine start. The valve is mounted on the start tank.

(19) Turbopump purge check valves. The turbopump purge check valves are poppet-type, spring loaded in the closed position, valves. The check valves are installed in the customer connect fuel pump turbine seal cavity, oxidizer pump turbine seal cavity, and fuel seal cavity purge lines. The purpose of the check valves is to prevent back pressure from flowing through the purge line into the vehicle pressure system during engine firing.

(20) Turbopump bleed check valve. The turbopump bleed check valve is a poppet-type, spring loaded in the closed position valve. It is installed in the customer connect bleed line of the fuel turbopump. The purpose of the valve is to ensure that a desired pressure is retained in the seal cavity.

(21) Start tank vent and relief valve. The start tank vent and relief valve is a spring loaded, ball seal-type relief valve and is mounted to a manifold on the hydrogen start tank. The purpose of the relief valve is to prevent over-pressurization of the start tank.



(22) Start tank discharge valve check valve.

The start tank discharge valve check valve is a spring loaded, gate-type check valve. It is mounted at the start tank discharge valve outlet port. The check valve functions to prevent combustion products from the gas generator from contacting the start tank discharge valve poppet.

(23) Start tank fill package. The start tank fill package consists of two poppet-type check valves. One valve allows hydrogen flow from a ground source to the start tank and the other allows pressurizing from a tapoff at the thrust chamber fuel injection manifold during engine operation.

(24) Helium fill check valve. The helium fill check valve is a poppet-type, spring loaded in the closed position, fill and check valve and is mounted on the start tank. The purpose of the helium fill check valve is to prevent loss of helium from the helium tank when the ground loading system is disconnected.

(25) High-pressure relief valve. The high-pressure relief valve is a spring-loaded, ball-type, relief valve. The relief valve is mounted to the pneumatic control package and bleeds off excessive pressure.

(26) Four-way solenoid control valve. The four-way solenoid control valve is an electrically operated, direct acting solenoid valve in which the opening and closing functions are actuated by the valve solenoid. The ports are arranged so that one is venting while the other is pressurizing. The purpose of the four-way control valve is to control pneumatically operated valves.

(27) Pneumatic control package. The pneumatic control package is a combination of two regulator assemblies, two relief valves, an actuator assembly, a series of solenoid valves, and a filter unit. The purpose of the pneumatic control package is to control helium gas flow to the engine components.

(28) Electrical control package. The electrical control package is a scaled, dome shaped, pressurized control assembly, and contains spark excitors and a sequence controller which consists of solid state module assemblies. The purpose of the electrical control package is to control the propulsion system.

(29) Accessory drive pad. An accessory drive pad is located on the turbine exhaust manifold at the oxidizer turbopump. The accessory is to be connected directly to the turbine shaft by a quill shaft. The engine is delivered with the accessory pad blanked-off and the quill shaft packaged separately.

## 2. Approach

The technical development plan, described in the initial paragraph of this Section C is implemented primarily through engine system testing, component development and testing, and facilities and special test equipment utilization.

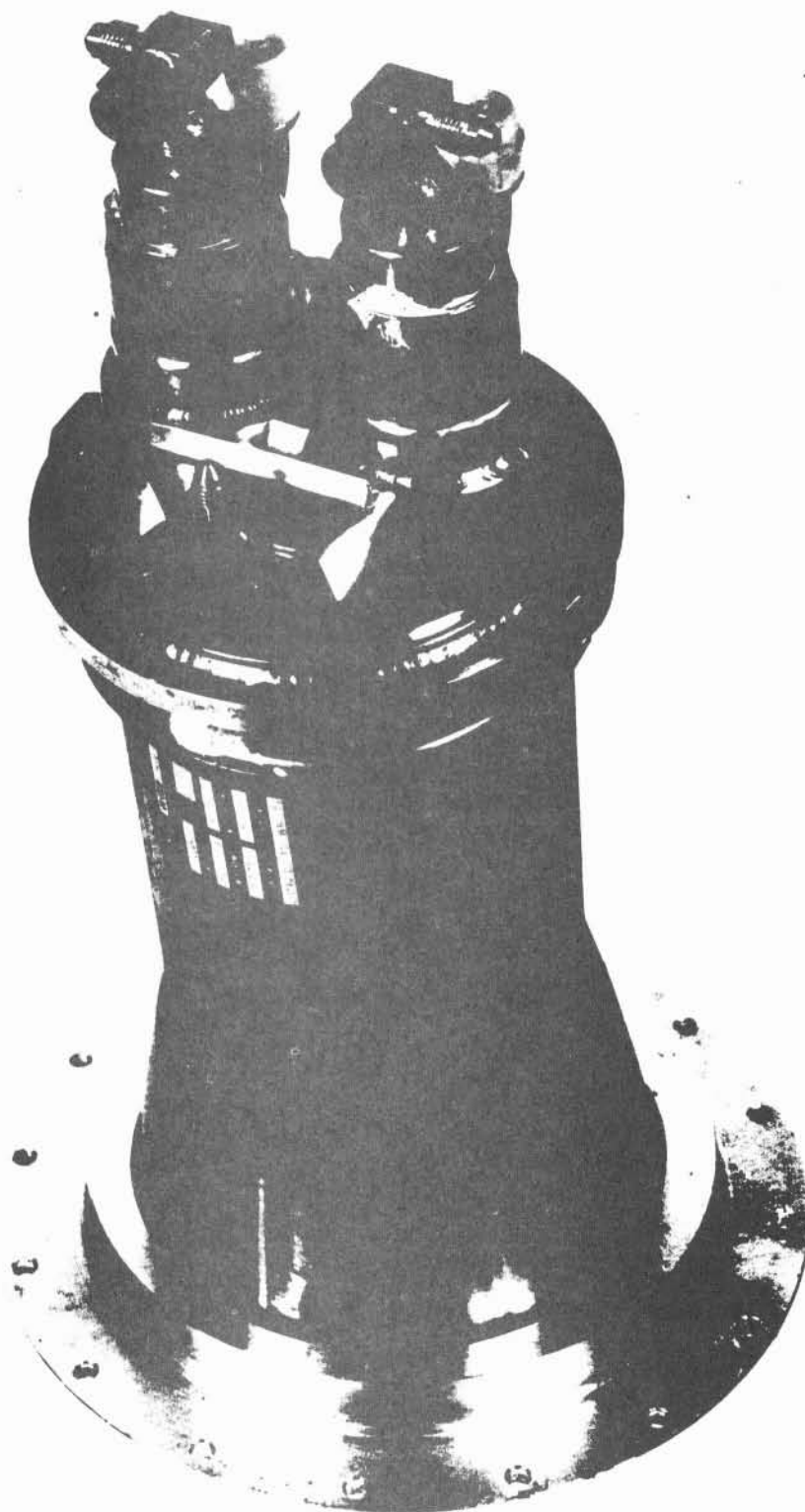
## D. SPACE ENGINES

### 1. S-IVB Ullage Engines

a. Description. The S-IVB ullage engine qualification plan is directed toward insuring the operational capabilities of the Gemini 100-pound thrust orbit and maneuver system engine when exposed to conditions that are peculiar to the S-IVB and to which the engine has not been exposed during previous testing. The MSFC qualification program will utilize four engines. The tests scheduled are shown in the following table.

ENGINE NO.	TEST SCHEDULED
1	S-IVB mission duty cycle
2	S-IVB mission duty cycle at 150°F. Presoak of engine with hot propellants
3	S-IVB mission duty cycle to catastrophic failure Determine performance at off-limits conditions Hot fire burst pressure testing at 400 psi
4	Vibration Shock S-IVB mission duty cycle to catastrophic failure





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Figure 3-7. Gemini Engine for SIVB Application

b. Gemini engine description. The SE-7 100-pound thrust, orbit attitude and maneuver system engine is a storable liquid, bipropellant, pressure-fed, ablation-cooled assembly. It is used in the orbit attitude and maneuver system for horizontal and vertical translational maneuver control of the Gemini spacecraft. Thrust level and bipropellant valve ratio are controlled by fixed orifices located at the propellant valve inlets. The propellants utilized are nitrogen tetroxide as the oxidizer and monomethylhydrazine as the fuel.

The thrust chamber body is made in two segments; the combustion zone segment and the nozzle segment. The combustion zone segment is fabricated from 6-degree oriented (referenced to engine centerline) high-silica, resin-impregnated ablative material. The nozzle segment is fabricated from 0-degree oriented (parallel to the engine centerline), resin-impregnated, high-silica fiber cloth. In addition, the thrust chamber body is wrapped with a layer of phenolic-bonded asbestos fiber to provide additional heat resistance and sealing capabilities. The bond line between the combustion chamber segment and the nozzle segment is located in a low-pressure, low-stress area aft of the throat insert. Structural support for the thrust chamber body assembly is provided by alternate layers of high-temperature high-strength glass cloth and filament-wound glass roving, bonded by phenolic resin. Additional layers of glass roving provide added strength in the injector attach and throat areas. The thrust chamber body is encased in a stainless steel shell to provide a positive seal between the thrust chamber and the spacecraft. The engine combustion chamber contains a one-piece JTA graphite liner. A throat insert of solid silica carbide is used to resist the erosive effects of the combustion gases. The thrust chamber injector is fabricated from stainless steel. It consists of 16 pieces of unlike doublets which impinge on a splash plate providing propellant mixing for high combustion efficiency.

Engine operation is controlled by two fast-acting electrically-operated solenoid propellant valves. These are attached to a mounting bracket which in turn is attached to the injector plate. The basic propellant valve design embodies a hermetically sealed solenoid. Valve sealing is accomplished through the use of a precision ground ball, attached to the armature, which rests on a Teflon seat in the closed position. A metal stop below the Teflon seat is incorporated to limit the armature stroke. Closing is accomplished through the use of a spring, and sealing force is obtained from the spring and the pressure of propellant acting on the ball.



c. S-IVB Ullage and Gemini engine comparison.

The following table compares the Gemini and S-IVB ullage engine applications:

PARAMETERS	GEMINI	S-IVB
Chamber Pressure	150 psia	100 psia
Supply Pressure	300 psia	195 psia
Chamber Tap	Sealed	Open
Thrust	95 lb.	72 lb.
Cumulative On-Time	557 sec.	454 sec.
Propellant Inlet Fitting	Tube Stubs	Right Angle
Vibration	Random only	Random & Sinusoidal
O/F Ratio	1.2	1.2

Figure 3-7 gives an overall view of the Gemini engine for S-IVB application.

2. C-1 Engine

a. Description. The C-1 Engine is an 80 to 100-pound fixed thrust, pressure fed, bipropellant engine capable of delivering steady state or pulse mode thrust. The engine consists of a basic engine and an ablative or radiation nozzle extension. By combining various nozzle extensions with the basic engine, the flight engines are able to meet the installation and performance requirements of various vehicles. Shown in figure 3-8 are the major design parameters for the C-1 Engine.

As shown in figure 3-8, the basic engine consists of a thrust chamber-injector assembly and a propellant control valve. The propellant control valve is either a linked bipropellant valve or a series-parallel quadredundant valve. The latter may be used as an alternate for the S-IVB application; both valves are fully interchangeable.

The thrust chamber-injector assembly employs a combination radiation and regeneratively cooled combustion chamber (Radiamic) and a full diameter vortex injector. The regenerative jackets and the outer jacket form the basic structure of the engine to which the other parts of the engine are assembled.

Interchangeable ablative and radiation nozzle extensions are provided to accommodate the various installations. Propellant orifices are provided to obtain thrust levels from 80 to 100 pounds.

The basic engine is designed for operation with nitrogen tetroxide ( $N_2O_4$ ) and either monomethylhydrazine (MMH) or a 50/50 mixture of unsymmetrical dimethylhydrazine.

b. Technical approach. The Phase II R&D Program is composed of several major blocks of work.

The initial step of the Phase II Program is the prototype development activity. Following attainment of the primary objectives of this work, the flight engine design will be released in two steps. The initial step will be the Block I flight design release. Release of this design will permit evaluation of the flight engine configuration concurrent with the final overlapping phases of the prototype engine development. The second step in the flight design development will be release of the Block II design at the completion of the prototype development. This two-step release permits optimum advantage to be taken of all available engine evaluation experience. The Block II flight engine development will emphasize the S/M-LEM configuration in order to permit a Flight Readiness Demonstration to be completed during the fifteenth program month, thereby making the C-1 engine available for early flight use, if required. Parallel with flight engine development, simulated engine-propellant supply system (C/M and S/M) tests will be conducted to determine compatibility of the flight engine with flight systems. Also included in flight engine development is margin limit testing of the flight engine. This task will be conducted to provide a firm baseline for the release of the qualification engine design. Formal qualification will start with component testing and will be concluded at the end of the twenty-first month. Margin limit testing of the qualification engine is scheduled for approximately three months and will be conducted in parallel with the formal qualification program.

Details on the various blocks of work leading to qualification of the C-1 engine are as follows:

(1) Prototype development. Prototype development has an initial goal of meeting a set of technical objectives that will allow the earliest possible release of a Block I flight engine design. The final phases of the prototype development program are intended to refine and characterize the engine design and will be performed following the Block I flight engine design release. These investigations will include: a low volume injector for increasing the pulsing specific impulse, a Rokided liner-injector interface for greater thermal margin by reducing the heat transfer to the injector from the liner, a conductive gasket between the jacket and the injector to increase the thermal margin during steady state operation, a 15° wrap short roll and long roll nozzle extension to prevent delamination and glassing, and reconstructed C/M nozzles to increase specific impulse and flight orifices integral with the engine.

Analytical tools will be used to establish critical operating regimes and to assure hardware designs capable of the operation throughout the range of natural and induced environments. Subsequent evaluation of the components will be made to obtain detail design information on individual parts, to provide data on their operational characteristics in confirmation of the analyses, and for use in the subsystem and integrated engine design and development. These evaluations will include an assessment of effects of combined stresses and will determine operational consistency, piece-to-piece and operation-to-operation.

(2) Flight engine development. The development of the C-1 Flight Engine is an integration of the components developed as a part of the work discussed in the prototype development section. Design refinements of the basic prototype engine will be made as required, based on the operational experience obtained. Effort will also be directed toward developing additional areas of performance and operational improvement required to meet the engine design goals by the Contract End Item (CEI) Specification.

This phase of the program will be initiated by release of the Block I flight engine design and will continue until Block II flight engine development is completed. The flight engine development program will: (a) provide the refinement in engine design required for commitment of qualification engine fabrication, (b) provide test demonstrations required as part of the reliability assessment, and (c) provide a Flight Readiness Demonstration for



the S/M-LEM Configuration which will measure design maturity in terms of readiness for command flight usage, and (d) provide additional development after the qualification design release to optimize the design, particularly in the area of increased design margins.

The flight engine development is subdivided into two closely allied efforts: (a) development of the basic engine assembled with bipropellant valves utilizing MMH and 50/50 as fuel and (b) development of the basic engine utilizing quadredundant propellant valves with MMH fuel.

This effort is planned in a manner which provides initial emphasis on meeting the performance and operational requirements of the engine. The fabrication of engines to support the effort is scheduled in a manner which will permit modification to be phased into new engines as refinements are developed.

The development begins with duty cycle evaluation tests to establish satisfactory operation under actual mission conditions. Evaluation will continue to assess operation under all of the environmental and operational conditions imposed by the various applications. Subsequently, the engines will be subjected to a series of tests which provide a rehearsal for the formal qualification demonstration. These tests include a design maturity demonstration which is one of the incentive plan schedule milestones. The Flight Readiness Demonstration of the S/M-LEM engine is scheduled as part of this test series. These tests serve to ensure that the engine will meet the qualification requirements and will permit qualification test procedures to be established under less formal test conditions. The final phase of engine development runs concurrently with qualification engine fabrication. This effort will develop methods of extending the design margins in any area where marginal specification compliance has been indicated.

Engine operation during this task will provide the major part of the flight engine reliability demonstration. In order to provide the required reliability data, standard duty cycles are to be used for the majority of the test evaluations.

(3) Flight engine margin limit testing. These tests are intended to demonstrate the margins inherent in the Block I engine and the matured Block II flight engine design. The

program employs: (a) statistically designed experiments to obtain the maximum amount of data on the operating characteristics under combined conditions, and (b) durability tests to determine cycle life and engine failure limits.

(4) Simulated vehicle-engine system testing.

The major work items in the system development of the C-1 engine are to analytically evaluate C-1 engine operation in conjunction with the various spacecraft systems, and to confirm these analyses with engine firings, using simulated Service Module and Command Module propellant feed systems. The system work starts with the analytical study of both engine and system, using mathematical models to determine their interface compatibility. The mathematical model will be developed in accordance with requirements defined in the Contract End Item (CEI) and the Scope of Work in the contract. The dynamic characteristics of the system versus engine and engine versus system interactions will be studied. This analysis will conclude with the definition of engine operating limits, the determination of engine performance at these limits, and the establishment of propellant supply temperature and pressure conditions at which the engine will operate with specification performance requirements.

The planned testing utilizes test run profiles derived from the applicable duty cycle. The type of testing includes:

(a) Dynamic compatibility tests which are specifically designed to investigate engine/system interactions.

(b) Mission simulation compatibility tests which will demonstrate engine/system operation in duty cycles representative of actual usage.

(c) Malfunction tests during which both engine and system component malfunctions are simulated.

(d) Operating limit tests which will demonstrate operation at the worst "off normal" conditions of propellant supply pressure, propellant temperature, supply voltage, and helium saturated propellants.



(5) Qualification. Qualification and Test Plan Specification will be used in the conduct of the qualification tests. This plan will describe in detail the requirements and conditions of each test and shall include schematic drawings and descriptions of all test apparatus, instrumentation, and requirements for data acquisition and handling.

The qualification demonstrations are to be made on complete engine assemblies, on individual valves, and on valve-injector subassemblies.

It is planned to perform qualification tests at the component level wherever CEI specification operation can be demonstrated without the complete engine assembly. Under this concept, propellant valve and injector-propellant valve subassembly qualification tests will be performed.

The engine qualification tests have been selected to emphasize engine operation and environmental exposure which are representative of actual mission usage. The tests are planned to demonstrate satisfactory operation to the CEI requirements under a full spectrum of environmental conditions and at combinations of operating conditions which encompass the full range of propellant and power supply conditions.

(6) Qualification engine margin limit test demonstration. The qualification engine design margin tests are planned to overlap the qualification tests and to permit final margin limit assessment of the qualification engine design. These tests will demonstrate the design margins provided by the deliverable engine design. This engine will include all refinements beyond the flight engine tested earlier in the program.

## PART IV

### RELIABILITY AND QUALITY ASSURANCE PROVISIONS

#### A. RELIABILITY PROGRAM

1. Requirements. The contractor Reliability Program Plans have been submitted, and approved as contractual documents fulfilling the contract requirements of NPC 250-1. They are:

ENGINE PROJECT	DOCUMENT NUMBER	LAST ISSUE DATE
F-1	R-5158-2	April 1964
J-2	R-5406-2	January 1966
H-1	R-6281	October 1966
C-1	RMD 6200-S4A	March 1966

A "Reliability Demonstration Procedure" is specified for each engine. Procedures are based on the Loyd and Lipow technique defined in Chapter 16 of the textbook: "Reliability: Management, Methods, and Mathematics." Estimates are reported monthly, based on static firing tests predeclared for reliability. Successes are tests that start, meet steady state performance conditions, and safely shutdown. Successes are weighed in relation to mission run durations. A sample adequate for a demonstration of reliability of .99 at a 50 percent confidence is required. An incentive fee is awarded for additional successes accrued after this demonstration.

A failure mode and effects analysis is required in accordance with the procedure in MSFC drawing 10 M 30111A. The following are available:

ENGINE PROJECT	DOCUMENT NUMBER	LAST ISSUE DATE
F-1	R-6541/R-6542	July 1966
J-2	R-6300-8	November 1966
H-1	R-6179	May 1966
C-1	RMD-6203-FMEA-4	August 1966

2. Plans for independent assessment. The basic reliability assessment is the estimate from the static tests. Currently, independent assessment is achieved by control and review of the contractor's demonstration procedure data. The resident NASA reliability representative evaluates the contractor's pre-test declarations and post-test classifications. Success decisions require NASA approval. In addition, static test data is trend charted by MSFC to show the influence of such factors as faulty facilities, operator errors, and hardware changes on reliability.

3. Responsibilities. Responsibility and execution of the reliability program is the responsibility of each engine project manager. Coordination of reliability matters within the Engine Program Office and between the office and other groups is the responsibility of the Engine Program Office Reliability and Quality staff. Project support, contractor monitoring, and independent reliability assessment is the responsibility of the MSFC Quality and Reliability Assurance Laboratory.

4. Principal elements of the Reliability Program

- a. Statistical design of tests and data analysis.
- b. Design reviews, value engineering reviews, human factor and maintainability studies.
- c. Failure mode determination through static firing tests, safety limits tests, component and engine qualification, and reliability verification tests. Failure mode elimination by hardware, process or procedure improvement.
- d. Maintaining a bank of test, malfunction, and configuration data.
- e. Malfunction reporting, recording, analysis, correction, and verification of failure mode elimination.

B. QUALITY ASSURANCE PROGRAM

1. Contract Requirements

- a. NPC 200-2 and NPC 200-3 set forth the basic quality assurance requirements for each engine program. Quality program plans are prepared by the contractors in accordance

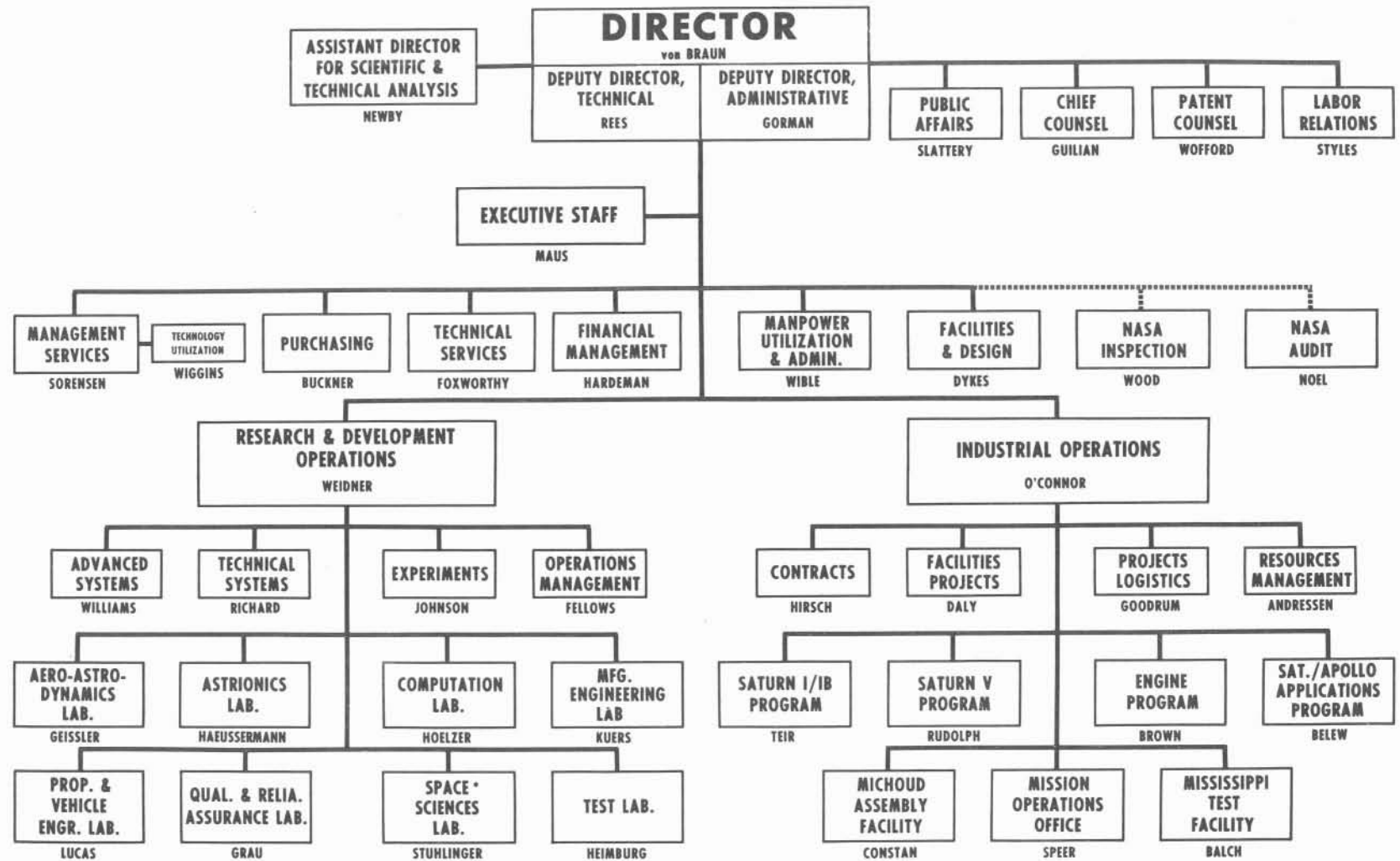
with NPC 200-2 and become contractual documents after approval by MSFC. The approved Quality Program Plans are:

ENGINE MODEL	DOCUMENT NUMBER	LAST ISSUE DATE
F-1	R-6158-1	May 1965
J-2	R-6158-1	May 1965
H-1	R-6158-1	May 1965
C-1	RMD 6200-S2A	March 1966

b. NPC 200-1A is the basic quality assurance requirement document applicable to Government Inspection Agencies: Air Force at Rocketdyne, Canoga Park, California; DCAS at Rocketdyne, Noesho, Missouri; and DCAS at Reaction Motors Division, Denville, New Jersey. Inspection plans have been submitted by each of the Government Inspection Agencies and letters of delegation accepted.

C. PROJECT MANAGEMENT DECISION. Project management makes all decisions on contract requirements, configuration changes, acceptance of hardware, and approval of costs. These decisions are constrained by policies, program authority, and allotted resources. Technical support for quality and reliability is provided by the Quality and Reliability Assurance Laboratory at MSFC. Within the bounds of the contract, laboratory personnel act to assure the adequacy of the contractor's quality program. They also confirm that the Government Inspection Agency and the contractor have inspected to the end item test plan and that the hardware is ready for acceptance.

# GEORGE C. MARSHALL SPACE FLIGHT CENTER



\*PENDING NASA HQS. APPROVAL

1/67 E-D A831Z

Figure 5-1. MSFC Organization

## **PART V MANAGEMENT PLAN**

### **A. INTRODUCTION**

This section provides a detailed description of the functions, management structure, and organizational interrelationship of the Engine Program Office. The NASA Management Manual was used as a basis for the organizational plan and the structure is consistent with established guidelines.

### **B. APOLLO PROGRAM MANAGEMENT**

The Apollo Program Office in Washington, under the direction of the Apollo Program Director, is responsible for overall Apollo Program Management, including the direction and integration of Apollo Program tasks being accomplished by MSF Field Centers (MSFC, MSC and KSC). Each Field Center appoints program managers who are responsible for directing Apollo Program activities assigned to the center. Directions from the Apollo Program Director on program matters go to Center Program Offices through the Center Directors.

The five program offices within the Apollo Program are the:

- o Apollo Spacecraft Program Office at Manned Spacecraft Center
- o Apollo Program Management Office at Kennedy Space Center
- o Saturn I/IB Program Office at Marshall Space Flight Center
- o Saturn V Program Office at Marshall Space Flight Center
- o Engine Program Office at Marshall Space Flight Center

### **C. ENGINE PROGRAM MANAGEMENT**

1. MSFC Organization. Basically, Marshall Space Flight Center has two line organizations: Research and Development Operations (R&DO) and Industrial Operations (IO) (see figure 5-1.)

# ENGINE PROGRAM OFFICE

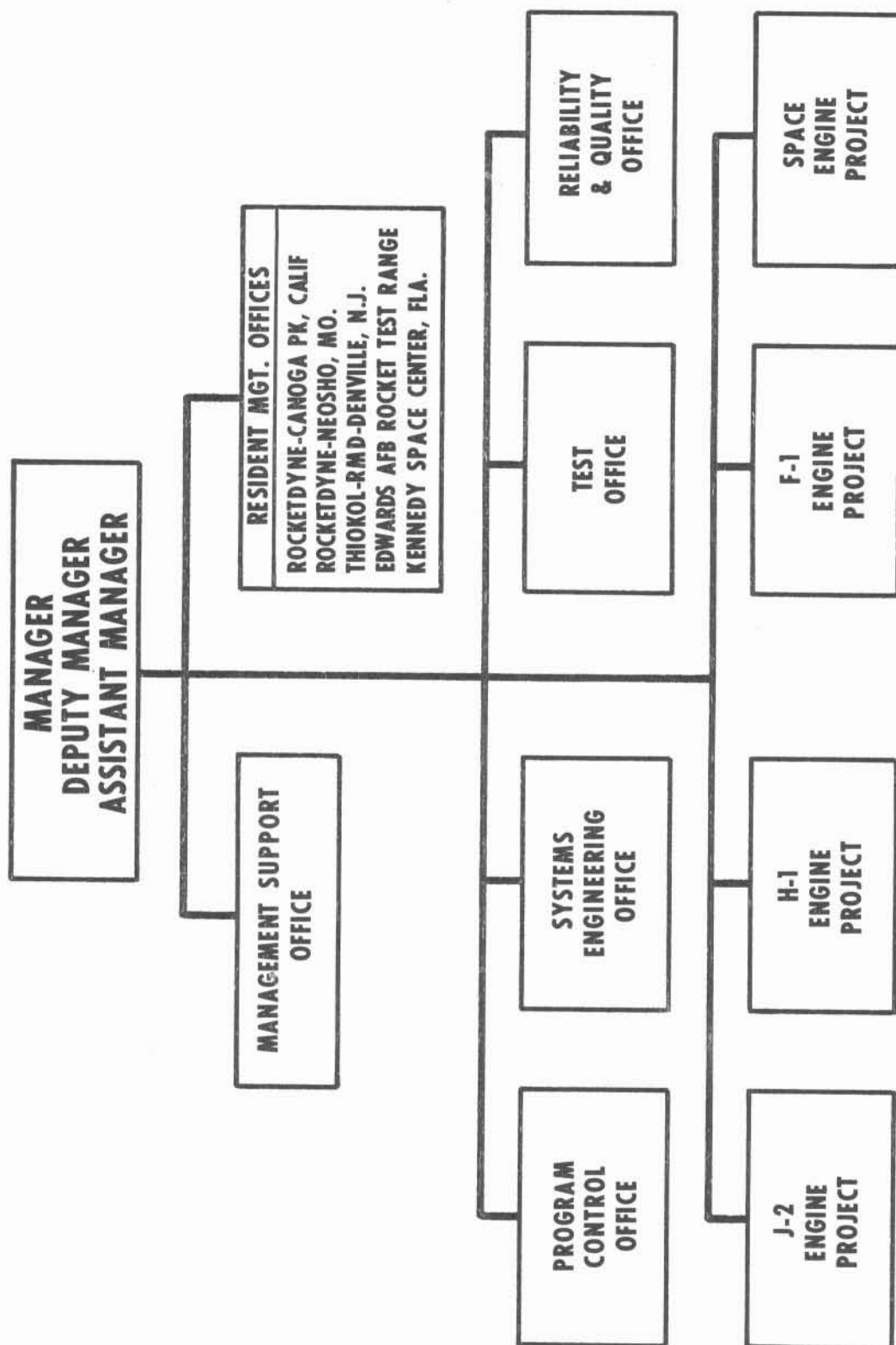


Figure 5-2. Engine Program Office Organization

a. Research and Development Operations. R&DO is responsible for maintaining competence in depth in all technical disciplines related to the science of rocketry. Research and Development Operations is responsible for the establishment and management of the scientific and engineering capabilities of the MSFC laboratories for the research and development of launch vehicle systems, engine and payload systems, supporting research and technology, and advanced studies.

b. Industrial Operations. Industrial Operations is assigned the overall responsibility for the conduct and management of the Saturn launch vehicle systems programs. This includes the Saturn IB and Saturn V vehicle projects, the Launch Vehicle Engines project, MSFC assigned payloads projects, related GSE and software, and all support, handling, and logistics requirements. In discharging these responsibilities, IO will:

(1) Take all action necessary to ensure that the entire series of Saturn launch vehicle systems is successfully developed, produced, tested, delivered and launched to carry out the specific missions on the officially scheduled dates and at the most reasonable cost to the government within allotted funds.

(2) Assure the technical adequacy of the overall launch vehicle system and the successful integration of vehicle stages, engines, GSE, associated equipment and MSFC assigned payloads.

2. Engine Program Office. The Engine Program Office, (figure 5-2), Industrial Operations, is assigned the task of planning, directing, coordinating, and managing all MSFC and contractor efforts related to engine programs.

a. Program Manager. The Engine Program Manager has the responsibility for planning and directing the execution of engine projects within established technical guidelines, schedules, and resources limitations. The project manager uses the composite MSFC/industry team through all program phases and assures the technical adequacy and the successful integration of the assigned engine projects into the launch vehicles.



b. Staff Offices. The Engine Program Office staff structure is modeled after that of the Apollo Program Office at Manned Space Flight, with similar areas of responsibility in the corresponding offices (Program Control, Reliability & Quality, Systems Engineering, and Test). The staff offices perform program-oriented functions related to planning, scheduling, budgeting, and assessment of program accomplishment. The staff offices assist and advise the project managers on matters related to their particular areas of assignment.

(1) Management Support Office. This office establishes and ensures implementation of internal administrative management policies. The office provides management services and support to all organizational elements of the Engine Program Office, including Resident Management Offices. Among these services are manpower and physical space, communications and management systems, functional alignment, and administrative operations.

(2) Program Control Office. This office is responsible for developing and establishing guidelines for program plans, and resource requirements reflected in budget and PERT schedules, technical operating plans, procurement and financial plans, and the MSF/NASA Headquarters Program Development Plan. The office develops guidelines and coordinates and implements refinements to the data management system. The Program Control Office consolidates managerial data for briefings, presentations, and reports.

(3) Systems Engineering Office. The Systems Engineering Office is responsible for the technical analysis of program specifications covering detailed functional and performance requirements of vehicle engine systems. It performs and directs the performance of technical analysis and coordination of working group and panel activities, mission requirements, assigned engine mechanics and propulsion, weight and performance, dynamics and control, flight evaluation and logistics.

(4) Test Office. This office is responsible for initiating optimum test programs; reviewing program tests and acceptance test plans submitted by contractors for approval; analyzing test results and problem area assessments; and developing and implementing the master test plan for engine systems.

(5) Reliability & Quality Office. The Reliability & Quality Office ensures a high degree of reliability for space flight engines and propulsion systems. The office coordinates all reliability activities between MSFC and contractor to determine status, deficiencies, proposed changes and accomplishments of approved programs.

c. Projects. The Engine Program Office encompasses four engine projects: H-1 Engine Project, J-2 Engine Project, F-1 Engine Project, and Space Engines Project. The function of each project is to define, direct, review and evaluate the composite MSFC/industry performance through all phases of planning, coordination and contractor direction in the design, development, integration, production, testing, acceptance, and delivery of assigned engines.

d. Resident Management Offices. These offices provide on-site program management and supervision of MSFC operations at Resident Management sites located in four geographical parts of the United States (Rocket Engine Test Site, California; Rocketdyne, Canoga Park, California and Neosho, Missouri; and Reaction Motors Division, Thiokol Chemical Corporation, Denville, New Jersey). They act as senior NASA representatives at these locations.

e. Engine Program Relationship

(1) Office of Manned Space Flight relationship. Communication between the Apollo Program Office of the Office of Manned Space Flight (MSF) and the Engine Program Office is primarily handled by the engine staff and project offices through informal contacts. Formal contacts are made periodically through written reports on various aspects of engine programs.

(2) In-house relationship. By daily contact with R&DO laboratories and vehicle stage managers, and through participation in activities of boards, working groups, committees, and panels, the Engine Program Manager, through his Project Managers, directs and coordinates all activities related to the design and development of engine systems and the integration of these systems into the using stage.

(3) Relationship with external organizations. In the management of the engine project, extensive use is made of organizations external to NASA. The Department of Defense provides support in the areas of secondary contract administration including audit, quality assurance and inspection. The Department of Defense is also instrumental in other fields such as propellant procurement, providing housekeeping services for NASA test area at Edwards Air Force Base, California, and performing tests at the Arnold Engineering Development Center, Tullahoma, Tennessee.

A close relationship exists with the Air Force so that maximum benefit on engine development can be available in other government agencies, industry, and educational institutions.

f. Schedule analysis and cost, configuration, and data management.

(1) Schedule and Review Procedure. Engine program schedules are maintained to reflect current project status consistent with the MSF approved schedules. Requirements for Manned Space Flight Program schedule documents are established by OMSF Instruction M-IM 9330.006, 007, and 008 (Program Scheduling Manual). This schedule and review procedure (SARP) illustrates major milestones and present status of the Launch Vehicle Engines Program.

(2) PERT, Line of Balance (LOB), and companion cost systems. Launch Vehicle Engine Projects use the PERT, LOB, and companion cost systems as management tools, whenever applicable to assist in meeting objectives on a timely basis. The systems consist of:

- o PERT/time
- o Line of balance
- o Companion cost system employing the contractor Financial Management Report (Form 533)

The NASA PERT and Companion Cost Handbook, LOB Manual and the NASA/MSFC - PERT Manual describe the system to be used.

(3) Configuration management. Prior to publication of the Apollo Configuration Management Manual, NPC 500-1, dated May 18, 1964, the configuration management elements of identification, control and accounting were established as an integral part of engine program management. Consequently, implementation of the NPC 500-1 configuration management refinements has imposed an evolutionary rather than a revolutionary task. For existing engine projects (H-1, J-2, and F-1) certain variations to the exact NPC 500-1 requirements are mandatory because of schedule and cost considerations; however, the overall objective of baseline management is not compromised. In general, the significant departures from NPC 500-1 are as follows:

- o Existing engine and ground support equipment end item specifications will not be rewritten in the NPC 500-1 (Exhibit II thru VI) format; however, Contract End Item (CEI) Specifications (Part II only) for engines will be accomplished.
- o The existing system of design reviews, design audits, quality assurance and acceptance inspection will not be revised to the requirements of NPC 500-1 (Exhibit XIV) except that First Article Configuration Inspections (FACI) for engines will be accomplished.
- o End item product baselines are established based on end item top assembly drawings and quality assurance documentation approved at time of acceptance of the first production configuration.
- o The existing numbering system for end item, engineering documentation, supporting documentation, technical manuals, etc., on existing projects will not be revised.

(4) Data Management. A data management system has been implemented to:

- o Identify essential data requirements
- o Eliminate redundant data requirements
- o Control new data requirements and changes to approved data elements
- o Establish minimum distribution requirements and control changes thereto
- o Provide data accountability.

## **PART VI MANAGEMENT REPORTING**

### **A. INTRODUCTION**

A system of management reporting has been instituted to keep NASA and MSFC management continually apprised of the status of Launch Vehicle Engine Projects. The primary aim of the reporting system is to keep the various management levels abreast of those program developments applicable to their respective areas of responsibility. In this way management is provided with the visibility required to assure prompt identification and resolution of problem areas. A number of formal and informal methods are used to implement the reporting system. These include memorandums, schedules, films, charts, teletype, telephone conferences, and reports that provide detailed information regarding selected program elements. The primary channels for program reporting are those between (1) MSFC and the contractor, and (2) MSF and MSFC. Although many internal reports are required by both MSFC and contractor levels, they are considered of secondary importance. Major areas of program reporting associated with LVE Projects are outlined below.

### **B. CONTRACTOR TO MSFC REPORTING**

Reporting requirements imposed on the contractor by the Engine Program Office assure the information required to effectively manage, direct, and monitor contractor performance. Reports which the engine contractors are obligated to provide include the following:

1. Program Plans. The program plans, with periodic revisions, provide the necessary information to assure MSFC management that all phases of the project will be conducted in an orderly and efficient manner. The plans include objectives and time phasing, discussion of anticipated technical approaches to achieve objectives, detailed test schedules, planned hardware fabrication, and major milestones. There are also Reliability Program Plans and Quality Program Plans.

2. Program Status Reporting. Throughout contract life, the contractor submits to MSFC both formal and informal records of current program status. The records include reports, charts, motion picture films and photographs, minutes of status meetings, technical interchange and coordination meetings.

3. Financial Management Reporting. The contractor is contractually required to submit monthly financial and cost reports on NASA Form 533. Costs are broken down into significant elements of the total contract for the reporting period. The quarterly reports include both cost experience for the monthly reporting period and cost projections for the remainder of the contract life. In addition, each quarterly report describes the magnitude and phasing of unfilled orders that are considered by the contractor to be firm obligations.

4. Reliability and Quality Data includes:

- a. Monthly "test summaries" of reliability trends, malfunctions, and test results for the F-1 and J-2 engines.
- b. Monthly Quality Status reports for all engine programs.
- c. Bi-weekly computer runs of test results and malfunctions.
- d. Monthly inspection agency reports.
- e. Flight Readiness Reports for each vehicle by stage.

C. MSFC TO MSF REPORTING

The reporting channel between MSFC and MSF has been established to provide Apollo Program management with the information needed to achieve effective overall program coordination. The reporting includes verbal communication, teletype, memorandums, films, charts, schedules, and formal reports. The following is a representative selection of the basic documents associated with this reporting channel.

1. Project Approval Document (PAD). That document which, when signed by the Associate Administrator, authorizes the responsible Program Director to initiate and carry out the project within the scope defined in the document.

2. Project Development Plan. The scope of the PDP is defined by the Project Approval Document. All aspects of the project and the way in which they will be managed are described in the Project Development Plan in detail. When signed by the Apollo Program Director, the Project Development Plan becomes the basic operating document for project implementation. The PDP is revised semi-annually as required.

3. Schedule and Review Procedure. The schedule and review procedure (SARP) report is prepared by MSFC and submitted monthly to MSF prior to each meeting of the Management Council. The report discusses the current project status in terms of milestones, funding, cost and manpower. Information is provided relative to level two and level three of program activity; level two includes detailed delivery schedules and supporting funding schedules for the overall engine program; level three provides development and delivery schedules for the individual engines.

4. Engine Program Office Weekly Report. This weekly teletype report provides a continuing source of up-to-date information concerning the engine programs. The report apprises MSF of major program accomplishments, critical problems and other items of general interest.

5. Filmed Reports. In addition to conventional reporting techniques, MSFC also employs the use of periodic motion picture film reports. While providing an effective means of reaching large audiences, the film reports also give an added dimension to the subject under review. Included in the films are: overall project status; progress related to specific program elements; i. e., assembly, tests, etc.; significant events that occurred during the reporting period; and other items that may be of particular interest.





## PART VII PROCUREMENT ARRANGEMENTS

### A. IDENTIFICATION OF MAJOR PROJECT ELEMENTS

1. F-1 Engine. The F-1 Engine Project consists of two major project elements; research and development through qualification and production and production support. The research and development effort is currently being conducted under contract NASw-16. The production of 76 of the F-1 engines is being accomplished under contract NAS8-5604. The remaining 30 engines to complete the Apollo Saturn V requirement and the production support is covered in a new contract (NAS8-18734).

2. H-1 Engine. The major elements of the H-1 Engine Project are research and development and production. Research and development is currently accomplished through contract NAS7-190, Part I, Production is accomplished through contract NAS7-190, Part II.

3. J-2 Engine. Major elements of the J-2 Engine Project are research and development/production support, and production. Research and development/production support and production are currently being conducted under contract NAS8-19.

#### 4. Space Engines

a. S-IVB Ullage Engine. The S-IVB Ullage Engine Project consists of two major project elements; qualification testing and production. The qualification test program is being accomplished as an MSFC in-house effort. Production is being accomplished through contract NAS9-170. This is a MSC contract with the Gemini spacecraft prime contractor, McDonnell Company.

b. C-1 Engine. The C-1 Engine Program consists of three major project elements; i.e., Phase I - Definition, Phase II - Development, and Phase III - Production. Phase I was conducted under contracts NAS8-14019, and NAS8-14022. Phase II is presently under contract NAS8-15486. Phase III is not authorized at the present.

Additional efforts pertaining to construction of facilities for the F-1, J-2, and H-1 engines are governed by contract NAS8-5609(F).

## B. RESPONSIBLE CONTRACTORS

### 1. F-1, H-1 and J-2 Engines

a. Research and development: Rocketdyne Division, North American Aviation

b. Production: Rocketdyne

c. Facilities: Rocketdyne

### 2. Space Engines

a. S-IVB Ullage Engine. As a subcontractor to McDonnell Company, Rocketdyne has production responsibility.

b. C-1 Engine. Phase I - Definition was conducted by TRW Systems Group and Reaction Motors Division (RMD) of Thiokol. Phase II - Development is being conducted by RMD.

## C. CENTER RESPONSIBILITIES

George C. Marshall Space Flight Center is responsible for the procurement of each project element.

## D. TECHNICAL MONITORING AND CONTRACT ADMINISTRATION RESPONSIBILITIES

Technical responsibility for monitoring the engine programs has been delegated to the George C. Marshall Space Flight Center Engine Project Managers. Contract administration responsibility has been delegated to the MSFC Contracting Officer and his duly authorized representatives.

## E. SCHEDULE OF MAJOR CONTRACTING MILESTONES

### 1. F-1 Engine

a. Research and development. The major contractual milestones under the research and development contract is the development of a 1,522,000 pound thrust rocket engine using RP-1 fuel and liquid oxygen as propellants. The reliability for the F-1 engine under limited field environment is 95 percent, which was demonstrated by FRT completed in December 1964. The objective of the development effort is to attain a reliability of 99 percent with a 50 percent confidence factor under extended field environment qualification specification requirements by December 31, 1966. The R&D contract with Rocketdyne was converted from CPFF to CPIF in August, 1965.

b. Production. The F-1 engine production effort in effect at this time contains a requirement for 106 deliverable F-1 engines in support of 15 Saturn V vehicles. Seventy-six engines, 24 engine transporters, security covers, gimbal-lock sets and associated equipment; 5 full-scale mockups, ground support equipment, support hardware and supporting services are currently under contract (contract NAS8-5604). The first deliverable F-1 engine was delivered in October 1963, and the current schedule provides for delivery of the 76th engine in November 1967. The contract was converted from CPFF to CPIF during May, 1966.

c. Procurement of follow-on engines and production support. The present relationship between the R&D (NASw-16) and production (NAS8-5604) contracts make it expedient to combine the follow-on procurement of engines and production support into a single contract. This combination will expedite the administration of the contracts. The procurement of an additional 30 engines for the Saturn V vehicles (SA-511 through SA-515) will be included with the production support needed to support the production and flight programs.

### 2. H-1 Engine

a. Research and development. The major milestone under the research and development contract is the development of a 205,000 pound thrust rocket engine using RP-1 fuel and liquid oxygen as propellants. The objective of the development effort is to attain a reliability of 99 percent with the highest possible confidence factor.

b. Production. The production contract in existence at this time, contains a requirement for 22 H-1 engines with a thrust of 205,000 pounds. Another 60 engines will be procured as a follow-on buy for the Apollo Applications Program.

### 3. J-2 Engine

The research and development and production contracts were consolidated under Contract NAS8-19 during the conversion of the R&D contract from CPFF to CPIF and the negotiation for the delivery of the balance of the engines required to support the Apollo schedule. This combined contract has been forwarded to NASA Headquarters for approval.

Exhibit "A," the R&D portion of the contract, as presently negotiated, extends the period of the contract through December 1968 to allow Rocketdyne to provide production support directed toward support of vehicle flight and static test programs and investigation of engine improvements which will enable major vehicle and operational simplification and additional mission capability. The major objective of this effort is in the qualification of the 205/230,000 pounds thrust engine with a reliability of 99 percent and a 50 percent confidence level by December 31, 1966.

The present Apollo schedule contains a requirement for 155 deliverable J-2 engines to support 12 Saturn IB and 15 Saturn V vehicles. The effort for all of the required engines has been negotiated; the effort for 103 engines has been transferred from the old production contract NAS8-19, Exhibit "B," under which the effort for the remaining 52 engines was negotiated.

### 4. Space Engines

a. S-IVB Ullage Engines. A total of 29 engines have been delivered. This completes the buy of engines under contract NAS9-170. A follow-on contract will be negotiated between MSFC and Rocketdyne to support Saturn V S-IVB 507 through 515 at a later date.

b. C-1 Engine. Work on the two Phase I - Definition contracts began on March 5, 1965. These contracts were completed on September 5, 1965. Phase II - Development effort was initiated on October 18, 1965. This contract is for a development effort only, to qualify the C-1 Engine with a 99 percent reliability at a 50 percent confidence level by July 19, 1967. This is a CPIF contract with incentives of cost, schedule and performance.

# ENGINE PROGRAM OFFICE

## CUMULATIVE PLANNED & ACTUAL DELIVERIES-ALL ENGINES

	63		CY 64					CY 65					CY 66					CY 67					CY 68																
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
H-I ENGINE																																							
SATURN 1B/S-1B STAGE																																							
RL10 ENGINE																																							
ATLAS/CENTAUR STAGE																																							
F-1 ENGINE	1	2																																					106
SATURN V/S-IC STAGE	1																																						
J-2 ENGINE																																							
SATURN 1B S-IVB STAGE																																							
J-2 ENGINE - SATURN V																																							112
S-II STAGE																																							
J-2 ENGINE - SATURN V	1																																						
S-IVB STAGE	1																																						
J-2 ENGINES	1																																						
TOTAL SATURN V	1																																						
J-2 ENGINE	1																																						155
GRAND TOTAL	1																																						
NOTES: UPPER QUANTITIES ARE PLANNED DELIVERIES - LOWER QUANTITIES ARE ACTUAL QUANTITIES.																																							

1340-1387-1431-1454-1456-1470-1471-1473-1474-1475-1483

1-E-P 1437K January 1, 1967

## **PART VIII SCHEDULES**

Updated scheduling data reflecting current program status relative to each engine project is available in the MSF Schedule and Review Procedure (SARP) report submitted monthly to MSF.

The data presented is effective as indicated and is based on the following contractor documents:

- o F-1 Engine Program Plan R-3214-11 (Rocketdyne)
- o H-1 Engine Program Plan R-5069P-3 (Rocketdyne)
- o J-2 Engine Program Plan R-350 14A (Rocketdyne)
- o C-1 Engine Program Plan (RMD, Thiokol)





## **PART IX RESOURCE REQUIREMENTS**

### **A. MANPOWER**

Resources Authorizations on civil service personnel ceilings are issued to MSFC by MSF on NASA Form 506 (White) without specific reference to programs, projects, or systems. Manpower authorizations are aligned in accordance with approved POPs with internal allocation by MSFC top management made semi-annually based on manpower reassessments. These reassessments result from endeavors to equalize manpower assignments with changing workloads, such as phase-out of the Saturn I Program, staffing of newly created offices, etc.

Within MSFC, the staff Program Planning and Resources Office controls ceilings for staff and service offices, Research and Development Operations and Industrial Operations.

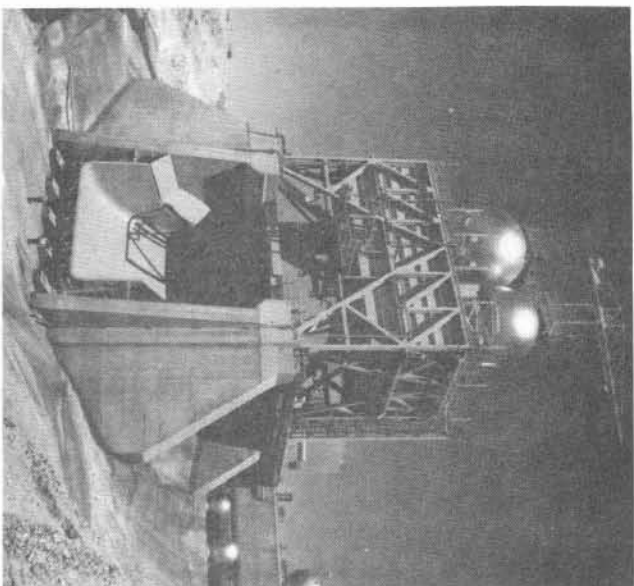
Within Industrial Operations, manpower ceilings are allocated by the Director, Industrial Operations, through the Resources Management Office to the Saturn IB, Saturn V, Engine Program Office, AAP, Facilities, Logistics, and other offices.

An MSFC Position Management Report submitted monthly to MSF contains the status of civil service positions and compilation by skills, grades, average salary and grade under regular, permanent, temporary and other classifications.

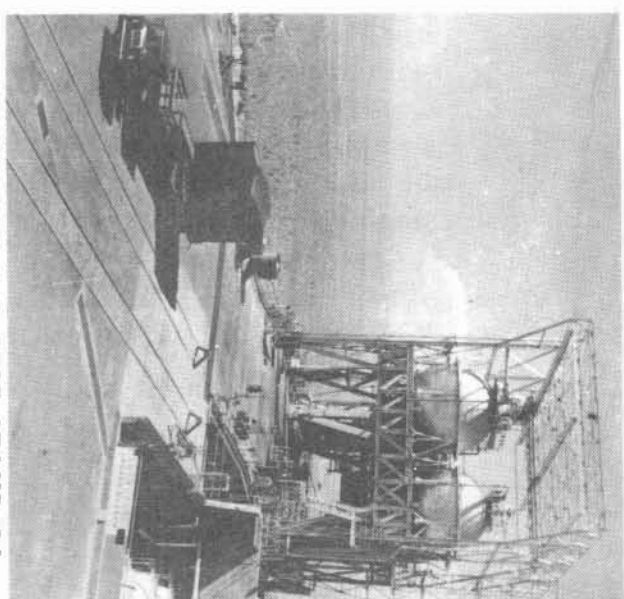
### **B. FUNDS**

Fund requirements for engine projects are presented in the Program Operating Plan. The POP is the official quarterly submission of the MSFC financial plan which provides NASA Headquarters with a basis for formulating the Agency budget estimates. This document presents a comprehensive detailed study of resources, and fund and manpower requirements essential to operational development and completion of mission assignments. Requirements are categorized by engine project and system account (major contractor and other) and are summarized by fiscal year through program completion.

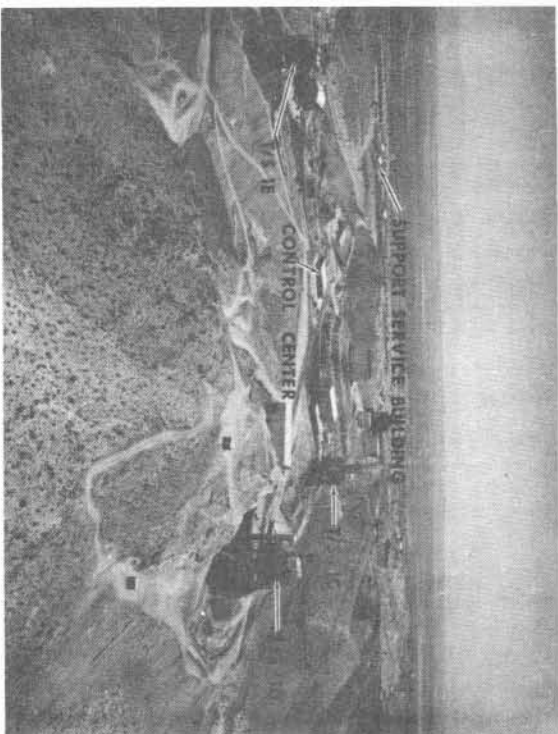
## F-1 ENGINE TEST FACILITIES



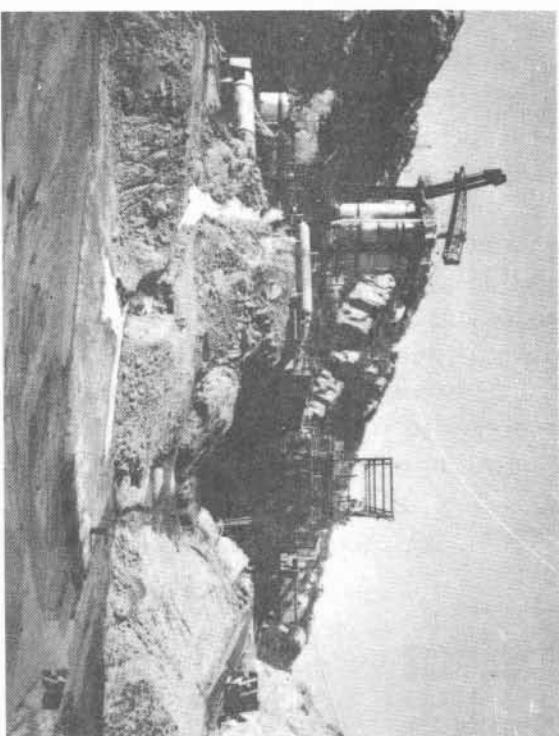
**EDWARDS PRODUCTION TEST STAND 1C**



**EDWARDS R & D TEST STAND 1A**



**EDWARDS AFB PRODUCTION TEST STANDS**



**SANTA SUSANA COMPONENT TEST STAND BRAVO 1**

Figure 9. F-1 Engine Typical Test Facilities

# F-1 ENGINE MANUFACTURING & TRANSPORTATION

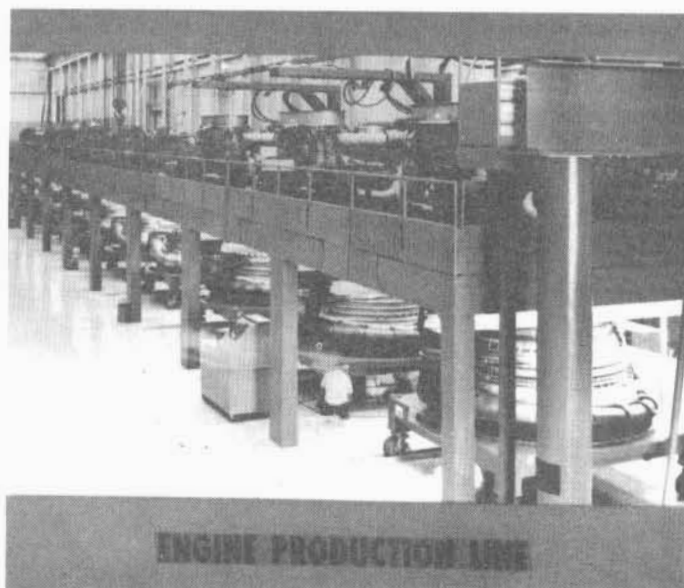
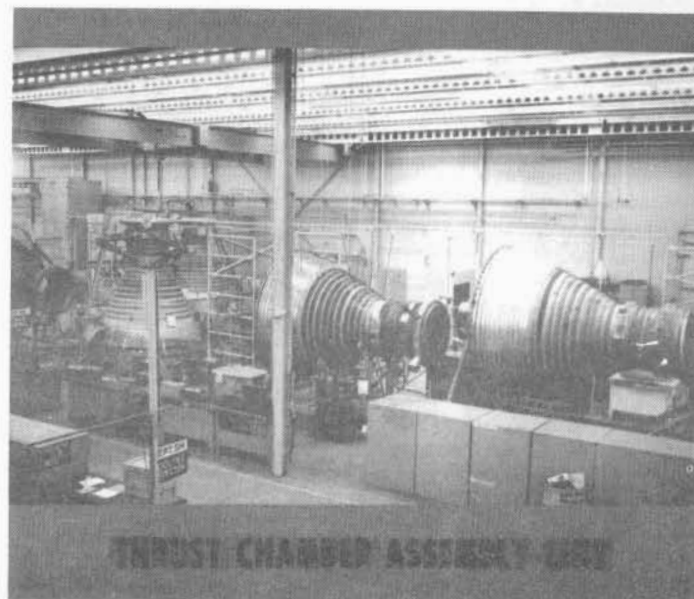
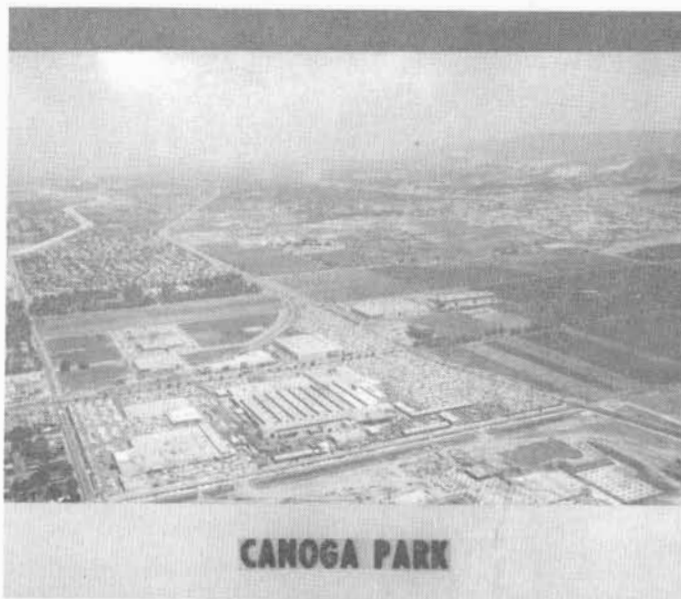


Figure 9-2. F-1 Engine Typical Manufacturing Facilities

## C. FACILITIES

1. F-1 Engine. Research, development, and manufacturing for the F-1 engine are being performed at the Rocketdyne facility. Rocketdyne headquarters, administrative offices and plant facilities, and Air Force Plant 56 are located at 6633 Canoga Avenue, Canoga Park, California. Project facilities relating to project management are referenced in Part V, Management Plan.

a. Santa Susana. The Propulsion Field Laboratory, Air Force Plant 57, in the Santa Susana Mountains at Chatsworth, California, is primarily a component test facility. Test stands at this location include:

(1) Bravo 1A, a chamber injector test stand capable of withstanding 1,000,000 pounds of thrust.

(2) Bravo 2, a three-position turbopump component stand capable of testing components under full-flow conditions.

b. Edwards Air Force Base. Rocket Engine Test Site is the rocket engine test facility at Edwards Air Force Base, California. Test stands used primarily for F-1 engine system testing, include:

(1) TS-2A, a two-position chamber/injector component test stand capable of withstanding a full thrust level firing for approximately 15 seconds.

(2) TS-1A, a single-position test stand capable of testing the engine system for its projected rated duration of 150 seconds at its full rated, nominal-thrust level.

(3) TS-1B, a two-position test stand capable of firing the F-1 engine at rated thrust and duration under limited gimbaling conditions in either of the two positions.

(4) TS-1C, -1D, and -1E provide the capability for acceptance testing production engines. These stands have a central control house and are capable of engine full duration and thrust firing. Thrust-vector control can also be demonstrated on these stands. Two of the stands will be used for acceptance testing and the other will be used for R&D environmental testing.

2. H-1 Engine. Engineering facilities for H-1 development are located in Rocketdyne's main plant at Canoga Park, California. Typical facilities are shown in figures 9-3 and 9-4

Facilities located at MSFC are considered adequate for component, single engine, and clustered-engine testing. These are as follows:

- a. Single-engine test stand (power plant test stand)
- b. Gas generator test stand
- c. Booster test stand (for engine cluster testing)
- d. Component test laboratory

Other facilities located at Rocketdyne's Propulsion Laboratory, in the Santa Susana Mountains of California, contain engine test stand Canyon 3b. This stand is considered adequate for development testing.

Manufacturing and acceptance testing facilities are located at Neosho, Missouri. Two dual-position test stands (one position on Stand No. 1 and one position on Stand No. 2) will be utilized for acceptance testing. Use of these facilities will depend on a continuation of the Air Force-NASA rental agreement. Any interruption in this arrangement would cause a costly delay in the overall Apollo Program.

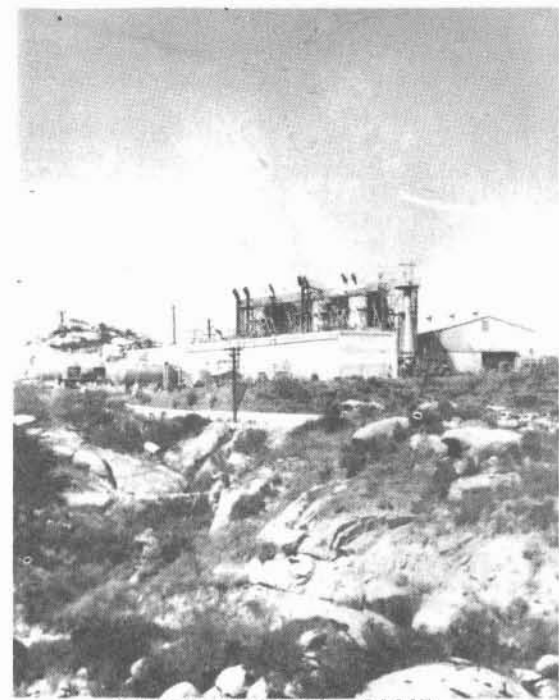
Facility utilization has been scheduled as follows:

- a. Development testing (40-hour weekly utilization equivalent to 100 percent effort).

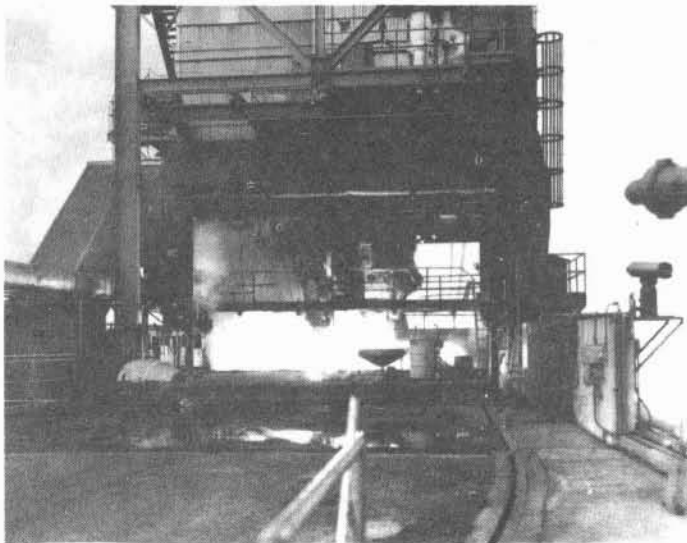


**NEOSHO, MO. DEVELOPMENT TESTING**

## **H-1 ENGINE TEST FACILITIES**



**SANTA SUSANA, CALIF.  
COMPONENT TEST LABORATORY NO. 2**



**NEOSHO, MO. ACCEPTANCE TESTING**



**SANTA SUSANA, CALIF. TEST STANDS**

Figure 9-3. H-1 Engin Typical Test Facilities



# H-1 ENGINE MANUFACTURING FACILITIES



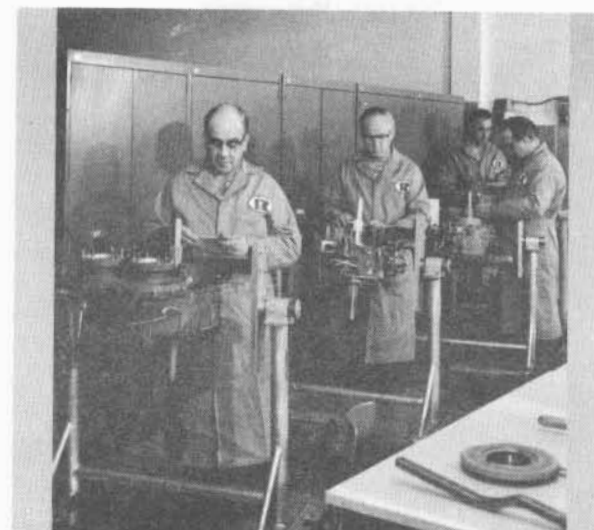
**MAIN PLANT**



**ENGINE ASSEMBLY AREA**



**FINAL ASSEMBLY AREA**



**COMPONENT ASSEMBLY**

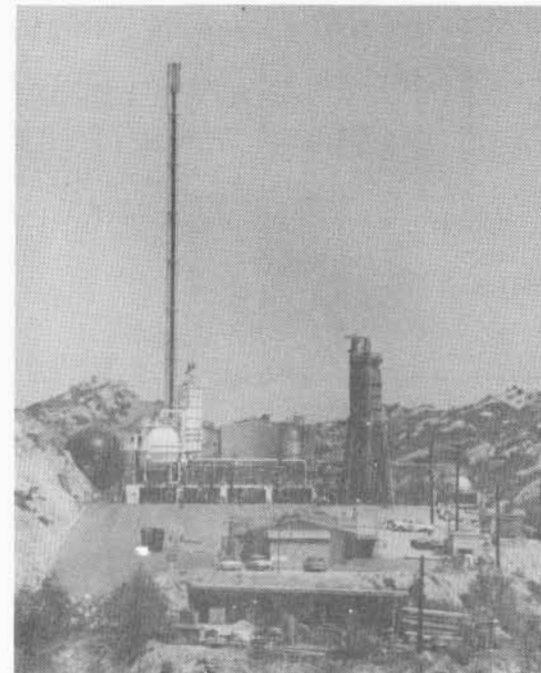
Figure 9-4. H-1 Engine Typical Manufacturing Facilities



# **J-2 ENGINE TEST FACILITIES SANTA SUSANA**



**DELTA 2 TEST STAND**



**COMPONENT TEST LAB 5**



**BOWL AREA TEST STANDS**



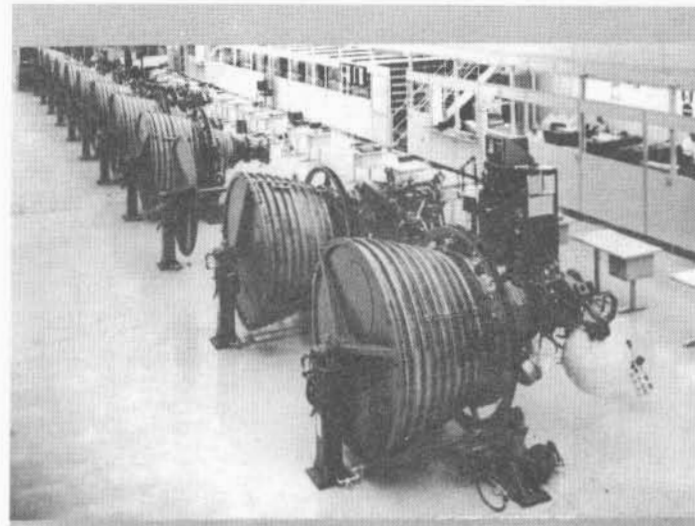
**COMPONENT TEST LAB 3**

Figure 9-6. J-2 Engine Typical Test Facilities

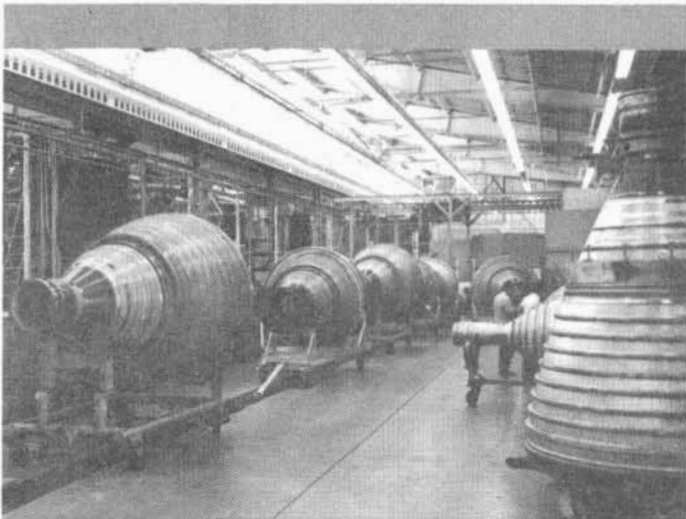
# J-2 ENGINE MANUFACTURING FACILITIES



**CANOGA PLANT**



**ENGINE PRODUCTION LINE**



**THRUST CHAMBER ASSEMBLY LINE**



**FUEL TURBOPUMP ASSEMBLY LINE**

Figure 9-7. J-2 Engine Typical Manufacturing Facilities

- o Engine test stand. 100 percent through FY 67.
- o Turbopump test stand. Inoperative - activation one month if required.

b. Production testing (40-hour weekly utilization equivalent to 100 percent effort).

- o Engine test stand. 100 percent through FY 67.
- o Turbopump test stand. Inoperative - activation one month if required.

3. J-2 Engine. Engineering and manufacturing facilities for J-2 development and production programs are located at the Rocketdyne Canoga Park, California and Neosho, Missouri plants. Test stands VTS-1, VTS-2, VTS-3A, and VTS-3B are located in the Bowl Area of the Rocketdyne Propulsion Field Laboratory. Delta-2A and Delta-2B, dual position test stands, are located in the Delta area of the Propulsion Field Laboratory. Bowl Area test stands, with the exception of VTS-2, are used exclusively for J-2 engine development. VTS-2 and the Delta area test stands are used for both development and production engine acceptance testing. Figures 9-5 and 9-6 illustrates typical J-2 engine facilities.

Test stand VTS-1, used for thrust chamber development, was activated in March 1961, and has a run duration capability of 20 seconds.

Test stand VTS-2 is used to support development testing and production engine acceptance testing at sea-level conditions. The test stand has a run duration capability of 450 seconds and was originally activated in January 1963.

Test stand VTS-3 is a dual position facility consisting of test stands VTS-3A and VTS-3B. Test stand VTS-3A is used to test the engine in horizontal position for start, run, and shutdown evaluation under simulated altitude conditions. Test stand VTS-3B is used for vertical testing at sea-level conditions. VTS-3A test stand was originally activated in January 1963, and VTS-3B was originally activated in January 1962. Both stands have a run duration capability of 250 seconds.

Test stand Delta-2 is a dual position facility consisting of positions 2A and 2B. Both positions have a run duration capability of 500 seconds. Delta-2B was completed in November 1963, while Delta-2A was completed in December 1963. The facility is for sea-level testing in support of development and production acceptance testing.

Engine component testing is performed in the following Santa Susana facilities: CTL-1, CTL-2, CTL-3, and CTL-4. Each of the test areas has several test cells used for component development.

Additional engine systems testing is planned at USAF Arnold Engineering Development Center. Modification of the test cell J-4 which included installing the S-IVB battleship stage, has been completed and testing began in August 1966. This testing will verify J-2 engine environmental capability for the Saturn launch vehicle, and will include engine restart modes.

#### D. LOGISTICS SUPPORT PLAN

1. General. The primary goal of the engine logistics support program is to insure that support of the Saturn/Apollo operations is planned, accomplished, and managed as an integrated whole to obtain the maximum ratio of mission readiness to cost effectiveness. It has been developed to insure that the optimum support services, personnel services, and materials are provided when needed, where needed, and in the quantity needed.

2. Scope. Logistics is an integral element of each engine project. Its scope includes the support of all phases of assembly, checkout, test, refurbishment, transportation and operations of the engine subsequent to the acceptance of the production engines.

3. Responsibilities. Launch Vehicle Engines Project Office logistics coordinator provides a focal point for all engines to establish a reasonable degree of uniformity and integration between the engine projects and coordinates with other program offices and the Project Logistics Office. This is to insure a functional logistics support program for vehicle support.

#### 4. Procedure

a. Each engine project office defines the required elements for engine support at all sites where engines must be maintained. These defined areas then become a part of the contractor support for the engine project. Each engine logistics support program reflects the following:

(1) Supports all sites where engines are utilized. This is provided as government-furnished support to the stage contractor at all sites except that of the engine contractor.

(2) Provides a minimum-cost program and minimum-residual inventory at program completion.

(3) Reflects the general philosophy of remove and replace on site with repair limited to those items which are shown by the maintenance analysis to be scheduled or cost saving. Failed items requiring repair, retest, refurbishment or modification will normally be returned to the contractor's plant or to a NASA approved off-site facility for failure analysis and necessary work.

(4) Maintain engines by using experienced and skilled technicians with engineering personnel monitoring, and in many cases directing, detailed maintenance tasks.

(5) All spares provided or furnished to the supported sites will be flight-qualified and ready for use.

(6) Establishes and controls the stock levels and provides adequate configuration definition control.

(7) Provides a systematic analysis of end items from initial concept through final operation. This analysis will be with respect to the availability of material and human resources to insure the timely support of the vehicle schedule.

b. Each engine requires a sufficient logistics support, definition, and supporting documentation to provide good management visibility. This includes as a minimum the following:

(1) Logistics program plan. The logistics program plan includes the philosophy of logistics support, the management and operational elements to be used and their functions, a milestone plan, required documentation and the material and human resources required.

(2) Maintenance plan. The maintenance plan reflects the maintenance concept, maintenance analysis requirements, repair, refurbishment and modification requirement by site, warehousing requirements, training requirements and special skills required.

(3) Configuration accounting. A means of configuration accounting is utilized which is in consonance with the requirements of NPC 500-1. (See Part V, Management Plan.)

(4) Inventory control. A method of inventory control is used which provides total visibility of materials required for the logistics support program and the status of these materials at anytime. Provisioning of spares is accomplished in accordance with the results of the maintenance analysis. A continual review of the configuration and status of the provisioned spares is performed and replenishment or replacement of parts is provided. The general philosophy within the objectives outlined above is to maintain a minimum number of spares on site with the majority of the high cost items being stocked at the engine contractor facility. Spare parts are provided through the use of support hardware release notices (SHRN) which give approval to the contractor to obtain hardware in support of specific sites and vehicles.

c. Each engine project insures that the planning data provides adequate detail for the selection and implementation of material and human resources in the following areas:

- o Tools and test equipment
- o Ground support equipment
- o Warehousing
- o Handling equipment
- o Removal of materials

- o Training
- o Maintenance manuals
- o Status reports
- o Transportation (including Packaging and Preservation)

d. Each engine project coordinates with the appropriate stage office for the provisioning of stage contractor support at the stage contractor facility, the Mississippi Test Facility, Marshall Space Flight Center, and Kennedy Space Flight Center.

e. Since propellants and pressurants are GFP to the contractor, each engine project insures that the forecast of requirements for propellants and pressurants is furnished to the government in a manner compatible with the logistics supply.