THE M-1 ROCKET ENGINE

1. Introduction and Summary

The M-1 Rocket Engine, shown in Figure 1, is being developed for the NASA-Lewis Research Center by the Aerojet-General Corporation under Contract NAS 3-2555.

The M-1 is a 1.5 million pound thrust, liquid hydrogen-liquid oxygen, high performance system. A design philosophy is maintained to permit eventual engine growth to about 1.8 million pounds thrust. The engine consists of a single regeneratively cooled thrust chamber, separate turbopump assemblies series driven by gas generator reactants, and a turbine exhaust cooled nozzle extension. Thrust vector control is provided by gimbaling the entire assembly.

Significant engine performance and descriptive features are summarized in Table 1.

Table 1 - Engine Performance and Descriptive Features

Nominal thrust at altitude (200,000 ft)	1,500,000 lbs.
Nominal specific impulse	428 sec.
Nominal thrust chamber pressure	1000 psia
Nominal O/F weight ratio	5.0
Nozzle area ratio	40:1
Rated duration	500 sec.
Gimbal angle	± 7-1/2 (square pattern)
Length-gimbal block to nozzle exit	321 in.
Diameter at nozzle exit	208 in.
Weight, dry	20,000 lbs.

Development efforts were begun early in 1962, and significant progress has been made to date. System design and analysis is essentially complete and full scale hardware fabrication is progressing. Testing of gas generators, bearings, seals, ignitors, and system sub-components have begun. Full-scale thrust chamber firings are scheduled for June 1964. Sub-scale fuel turbomachinery testing has started and sub-scale oxidizer turbomachinery testing is scheduled for June. Full scale turbopump testing will begin this fall. Full scale engine testing will commence early in 1966.

Considerable progress has been made in construction of facilities to support the M-1 development program. Laboratories and fabrication facilities are complete. Three major component test facilities for turbomachinery, thrust chamber, and start transient testing are either complete or in advanced stages of completion. Three engine system test stands are planned and these are in the design and early construction phase.

As a result of recent funding limitations, engine PRFT is presently scheduled for 1971. Qualification is anticipated to be within two to three years of that date.

II. Program Philosophy

The objective of the M-1 Program is to provide a high performance propulsion system of an appropriate size for Post Saturn launch vehicles, on a time scale consistent with requirements of having a qualified man-rated system available in the 1970's. The philosophy of the program is to use design approaches which provide a step forward in technology over present systems, but only to proven limits. Maximum flexibility and adaptability is to be designed into the system so that varied requirements can be met. The intent is to provide the most efficient and useful system for the development dollars spent.

III. Development Plan

The phases of effort and activities required for developing the M-1 engine through PFRT are stated in Figures 2 and 3. Figure 2 describes the engine development schedule milepost summary. Figure 3 describes scheduled construction of facilities required to perform the development program.

The approach used in establishing the program summarized in Figure 2 was based on efficiently obtaining the program objectives. Experience gained from previous and current development efforts was used. The program is designed to verify all functional and peripheral requirements of the system and its components. Estimates based upon previous experience were used to establish the number of tests needed to verify the design features.

The program provides that, within the capabilities of the test facilities, each of the major components will be adequately developed and tested before being incorporated into the overall engine system. Design verification and peripheral full range testing will be accomplished with each component prior to the first engine test. For anticipated problem areas, subcomponent tests and alternative designs are scheduled for parallel evaluation.

IV. Development - Status

The overall program as outlined in the development plan, Figure 2, is continuing. System design and analysis is essentially complete and full-scale hardware fabrication is progressing.

Gas generator testing was initiated in May of 1963. Eighteen tests with six injector configurations have been accomplished to date. While some problems have been encountered, basic design expectations have been verified and an injector configuration has been established.

The first uncooled thrust chamber assembly has been installed in the C-9 facility and testing is eminent. Fabrication of cooled assemblies is progressing, two are complete.

Testing of J-2 type ignitors experienced difficulties. The design has been changed to incorporate features of the RL-10 ignitor.

Numerous component tests have been conducted on seals, bearings, valves, controls, and lines.

Scale fuel pump testing has begun with eight runs to date.

Full scale turbopump testing will begin this fall. Full scale engine testing will commence early in 1966.

V. Development Facilities - Status

The M-1 Engine Development Program is supported by three categories of facilities - engine system test stands, engine component test stands, and a collection of laboratories and fabrication shops. Total funding, for construction of Facilities and Special Test Equipment will be nearly eighty million dollars. The modification and new construction for shops and laboratories (among which are a hydraulics lab, cryogenics lab, and various electrical labs) are completed. Three component test areas are indicated in the Figure 3 schedule. These are the C-9 stand for thrust chamber and injector testing; the H-8 stand for cooled thrust chamber; start transient, and gas generator testing; and the two E area turbomachinery stands. Three engine system test stands will support the engine development program. These are: the K-1 vertical stand for short duration and start transient testing under simulated altitude and space environment conditions, the K-2 stand which includes two horizontal positions, one having extended altitude capabilities; and the K-3 vertical test stand with full 500 second duration capabilities. The component test stands are nearly complete. The K-1, K-2, and K-3 engine system test stands are in the design and early construction phase with long-lead procurement being initiated. Facility progress is shown by several recent photographs. These are included as Figures 4 through 8.

VI. M-1 Engine Description

The M-1 rocket engine, shown in Figure 1, is a 1.5 million pound thrust, liquid hydrogen-liquid oxygen, high performance system. It consists of a single regeneratively cooled thrust chamber, separate turbopump assemblies series driven by gas generator reactants, and a turbine exhaust cooled nozzle extension. Thrust vector control is provided by gimbaling the entire assembly.

The M-1 system is schematically described in Figure 9. Engine startup is initiated by a 28-volt opening signal to the helium start valve, allowing high pressure helium to begin spinning the turbines. The thrust chamber and gas generator spark ignitors are energized concurrently. Initial pump rotation deadheads propellants against the thrust chamber and gas generator valves. These valves are spring loaded-flow pressure actuated. The fuel and oxidizer sides are mechanically linked to assure simultaneous opening times. Rising pump discharge pressure opens these valves and combustion begins. Combustion in the gas generator supplies the rising turbine needs and full engine thrust is rapidly achieved. Helium flow is terminated by gas generator pressure which closes the helium bottle check valve.

Propellant utilization is provided by the fuel turbine by-pass line and valve. This by-pass system also serves to control the start transient fuel turbine conditions. A fuel pump recirculating valve is also shown. The function of this valve is to recirculate flow to the hydrogen tank during startup to alleviate pump stall during the start transient. The valve is open prior to start-up thus aiding in pump chilldown, closes during the start transient, and is closed during steady-state operation.

Engine shutdown is initiated by venting the gas generator propellant valve actuators. Spring forces then close the valves and stop propellant flow to the gas generator. The turbines are deprived of flow and pump output decays permitting spring forces to close the thrust chamber valves.

The fuel turbopump is an eight main, plus inducer and transition stage axial pump directly driven by a two-stage velocity compounded turbine. A cut-away view of the hydrogen turbopump is shown in Figure 10.

The oxidizer turbopump consists of a single stage backward swept centrifugal pump directly driven by a two-stage axial flow turbine. Figure 11 shows the features of the LOX turbopump.

The gas generator burns main chamber propellants. The gas generator combustion chamber is uncooled and uses a coaxial pattern, porous rigimesh face injector.

The main thrust chamber is of jacketed tube bundle construction, regeneratively cooled to a 14:1 area ratio. Figure 12 shows the tube layup of an M-1 thrust chamber during fabrication. The 42-inch diameter main chamber injector has a coaxial pattern with a porous rigimesh transpiration cooled face. Figure 13 indicates the construction and design of the M-1 injector.

A turbine exhaust dump cooled skirt extends the engine nozzle area ratio to 40:1. This nozzle extension is of tube bundle fabrication and is attached to the thrust chamber at the 14:1 point.

Complete and detailed performance and design features of the M-1 rocket engine are found in the M-1 Model Specification No. 40091C, dated 1 August 1963, and the M-1 Design Information Report, Report No. 9430-DIR-1.

The data contained in the above documents is summarized to facilitate use for preliminary studies. This M-1 Engine data summary is presented as Table 2. The M-1 Engine assembly drawing is also included as Figure 14. The M-1 start-up and shut-down transients (calculated) are shown in Figure 15.

VII. Applications

The M-1 system is presently envisioned for future large upper stage applications. The present program is designed to develop the engine to fit these requirements. Concepts being studied as part of the Post Saturn Vehicle Studies (NAS 8-5135, NAS 8-5136, and NAS 8-11123) being managed by MSFC, have helped in determining M-1 specifications. Vehicle design and propulsion studies, and operational analysis have continued in-house at LeRC to further define M-1 requirements.

Aside from the primary intended application of Post Saturn upper stage propulsion, the M-1 has been visualized to suit many other existing and possible applications. Among these other uses of the M-1 are included Saturn V improvement, Saturn V uprating and modification, intermediate payload (100K) booster, all chemical Mars spacecraft propulsion, and others.

An additional important envisioned application of the M-1, or its derivatives, is that of large hydrogen booster stage propulsion. Analytical studies have shown that the M-1 can be adapted to first stage as well as upper stage applications. Studies and experimental efforts are underway to define this system. Vehicle performance and costing analysis have indicated an all M-1 two-stage vehicle to be nearly optimal. Figure 16 shows one all M-1 vehicle concept. This concept is currently being evaluated in the Post Saturn Vehicle Studies (Contract NAS 8-11123).

A booster version or derivative of the M-1 engine is not currently a part of the M-1 development program. However, preliminary estimates indicate that with a small additional outlay of funds and manpower, a first stage version can be qualified on nearly the same time scale as the present M-1. Little modification other than recontouring the thrust chamber nozzle is required to obtain a high performance first stage M-1 engine.

Two first stage versions have been investigated to some detail. One for conventional cluster arrangements, the other for advanced nozzle cluster schemes. Performance and physical data on these two M-1 first stage versions are included as attachments A and B of this document.

Edward W. Gomersall
M-1 Engine Project

Table 2

Nominal Engine Thrust	1,500,000 lb. @ 200,000 ft. altitude
Nominal Chamber Pressure Calculated Nozzle Total Pressure	1000 psia 983 psia
Nominal Engine Specific Impulse	428 sec. @ 200,000 ft. altitude
Characteristic Exhaust Velocity (Thrust Chamber)	7480 ft/sec.
Propellants	Liquid Oxygen (MIL-P-25508) and Liquid Hydrogen (MIL-P-27201)
Nominal Engine Mixture Ratio	5.0 (± 10% for Propellant Utilization)
Nozzle Area Expansion Ratio	40:1
Nozzle Throat Area	803 sq. in.
Net Positive Suction Pressure	(Values are minimum required at maximum O/F excursions due to Propellant Utilization Control)
LOX	16.1 psia @ -297°F
Fuel	10.9 psia @ -423.5°F
Pump Inlet Diameters	19.5 in.
Engine Weights (not including suction lines, prevalves, and gimbal actuators)	
Dry	20,000 lb. (Design target weight)
Wet	22,000 lb. (Design target weight)
Burnout	21,086 lb. (Design target weight)
Rated Duration	500 sec.
Service Life	5 years storage, with a 20 cycle service life between overhauls
Thrust Vector Control	Gimbaled - (± 7-1/2° in actuator planes including 1° for snubbing, and ± 10.5 degrees in the corners. Maximum angular velocities of 15°/sec. in the actuator planes and 21°/sec. in the corners).

Propellant Feed	Turbopumps driven by LOX/LH_2 gas generator (These are two single, separate turbopumps each having single-inlet, single-outlet pumps directly driven by gas turbines. Gas flows in series through turbine sets, passing first through the LH_2 turbopump turbine set.)
Pneumatic Systems	Helium
Power Supply	Electrical - 28 volts D. C., 115 volt 400 cps.
Starting	Ignition of the main chamber and the gas generator is by auxiliary spark ignition. Starting is initiated by opening a valve between the helium sphere and the fuel turbine.
Pressurization features	Propellant tanks are pressurized by passing propellants through heat exchangers located in turbine exhaust ducts.
Reliability	Goal 95% at PFRT, 99% at Qualification.
Sponsoring Agency	NASA/Lewis Research Center, NAS 3-2555.
Status	Testing of major components began in May 1963. Preliminary design completed in May 1963. With present funding plan scheduled for calendar year 1971 PFRT. Qualification and Flight dates not scheduled.
Assembly Drawing	Figure 14
Vacuum Thrust Build-up and Decay	Figure 15

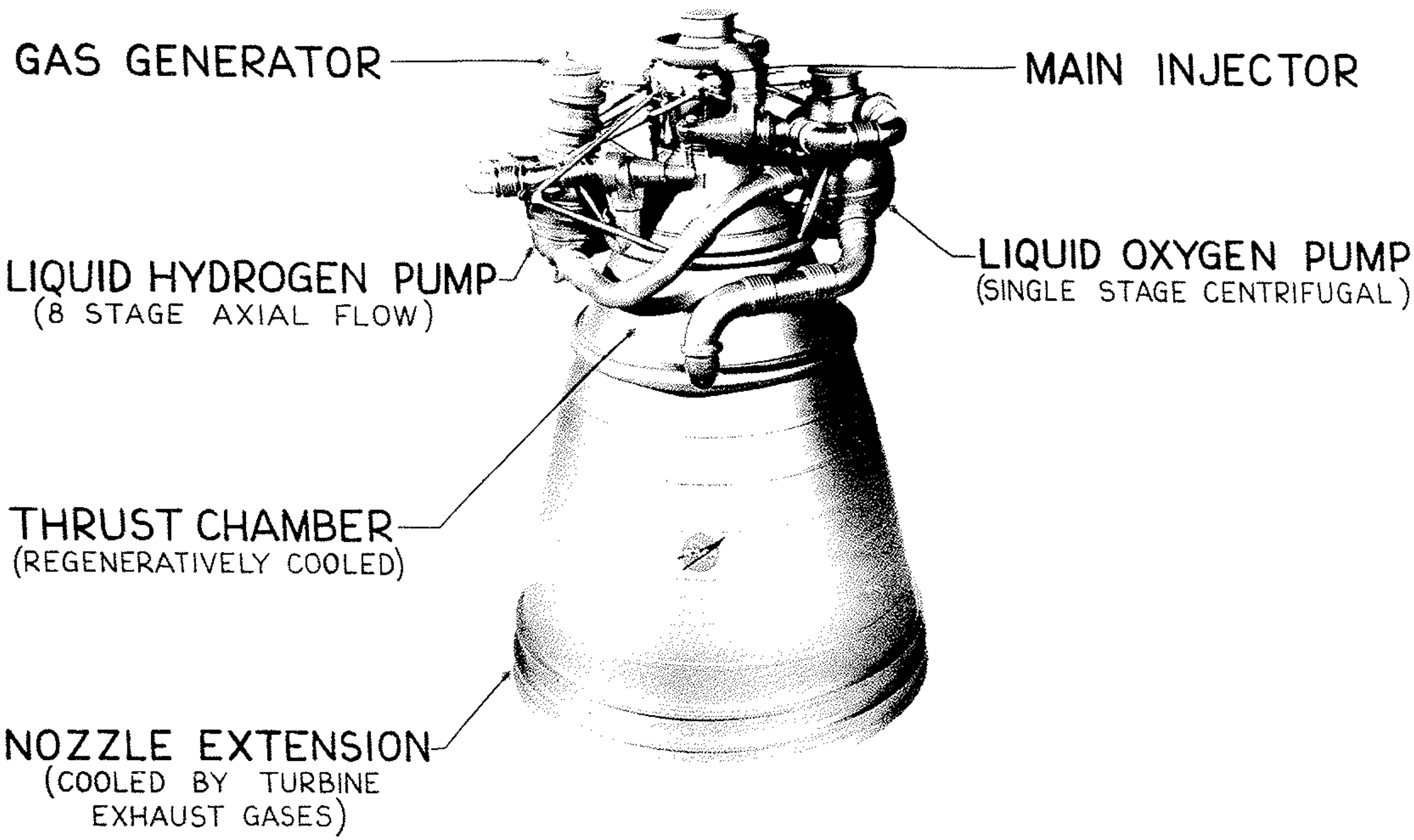


Figure 1. - M-1 Rocket Engine Features.

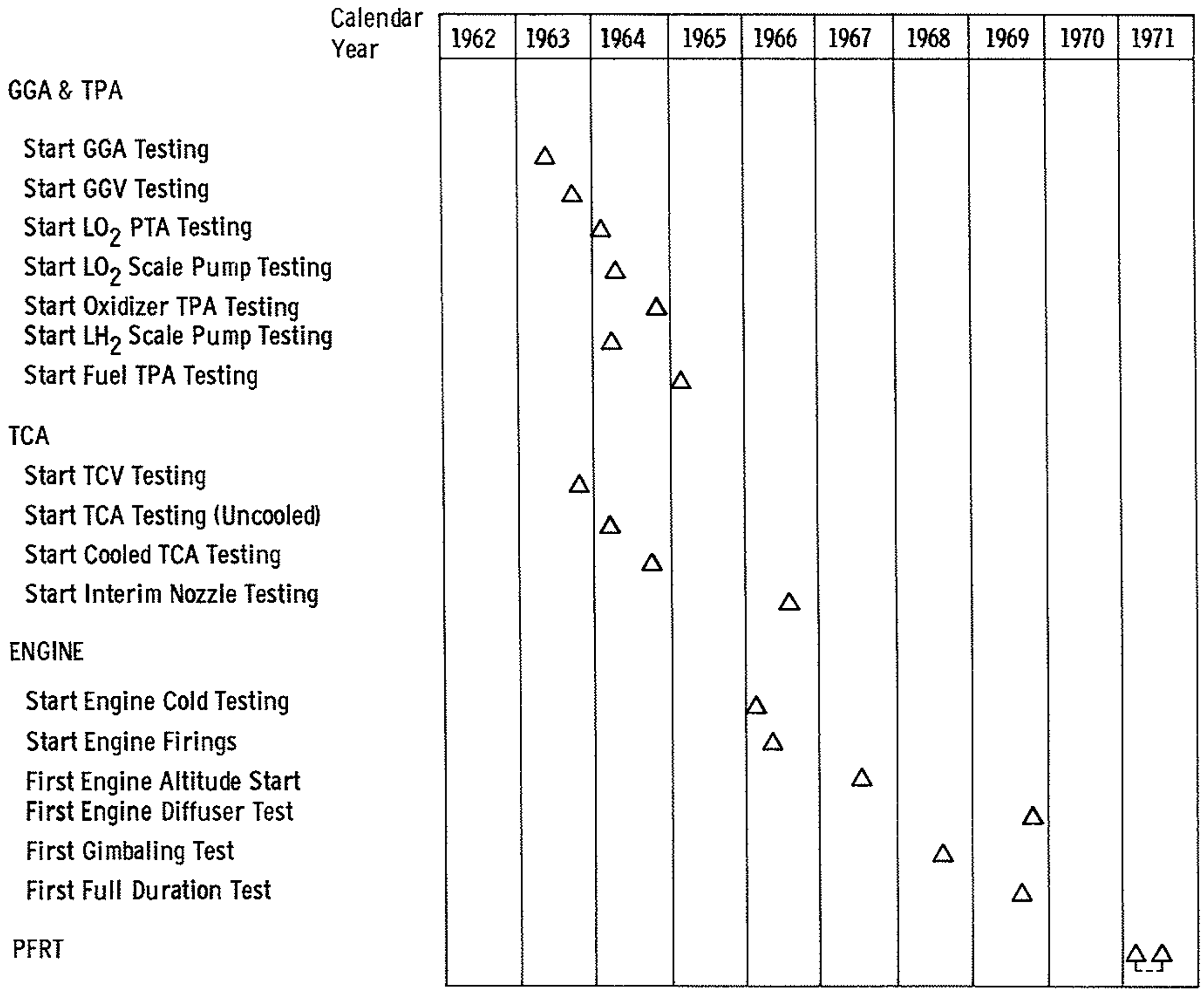


Figure 2. - M-1 Rocket Engine Program Milepost Summary.

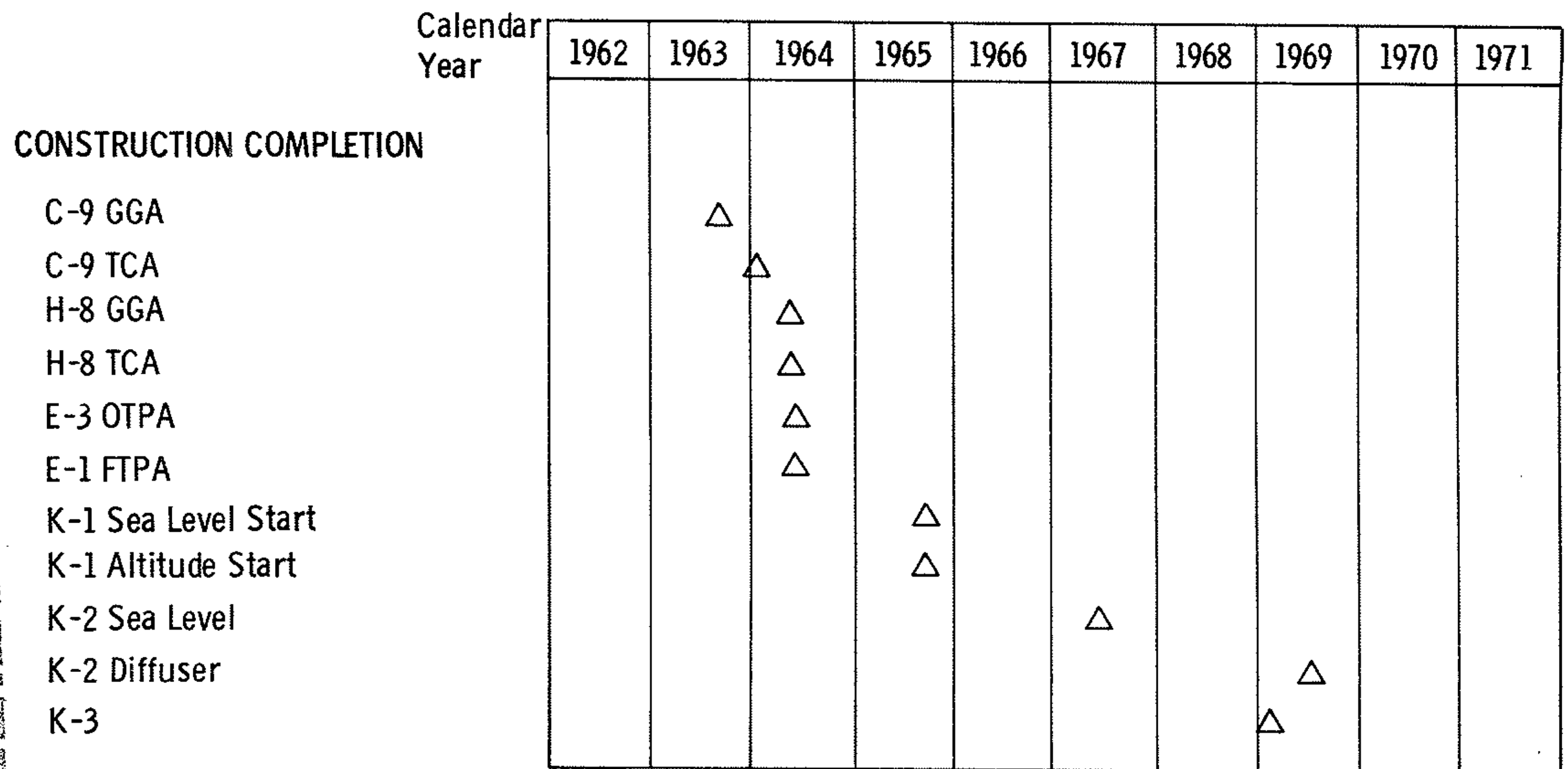
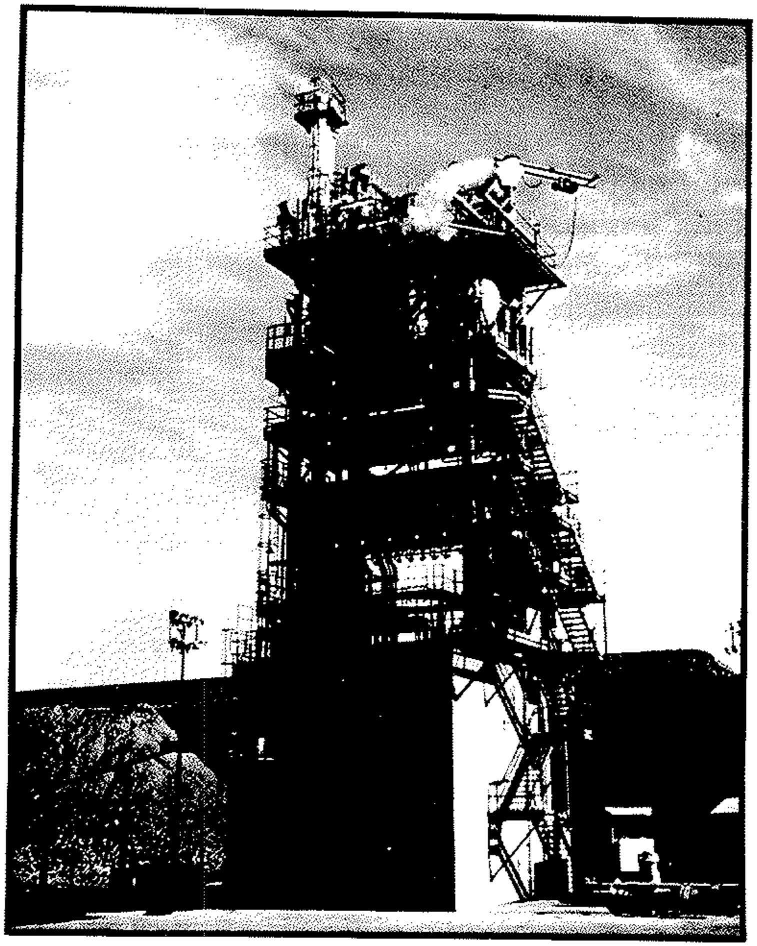


Figure 3. - M-1 Rocket Engine Facility Construction Milepost Summary.



PURPOSES

- TCA START TRANSIENT EVALUATION AND STABILITY INVESTIGATION
- GGA PERFORMANCE AND DEVELOPMENT TESTING

DURATIONS

- 3 SEC (TCA) AND 50 SEC (GGA)

DESIGN INITIATED

- JANUARY 1962

CONSTRUCTION INITIATED

- APRIL 1962

PERCENT COMPLETED

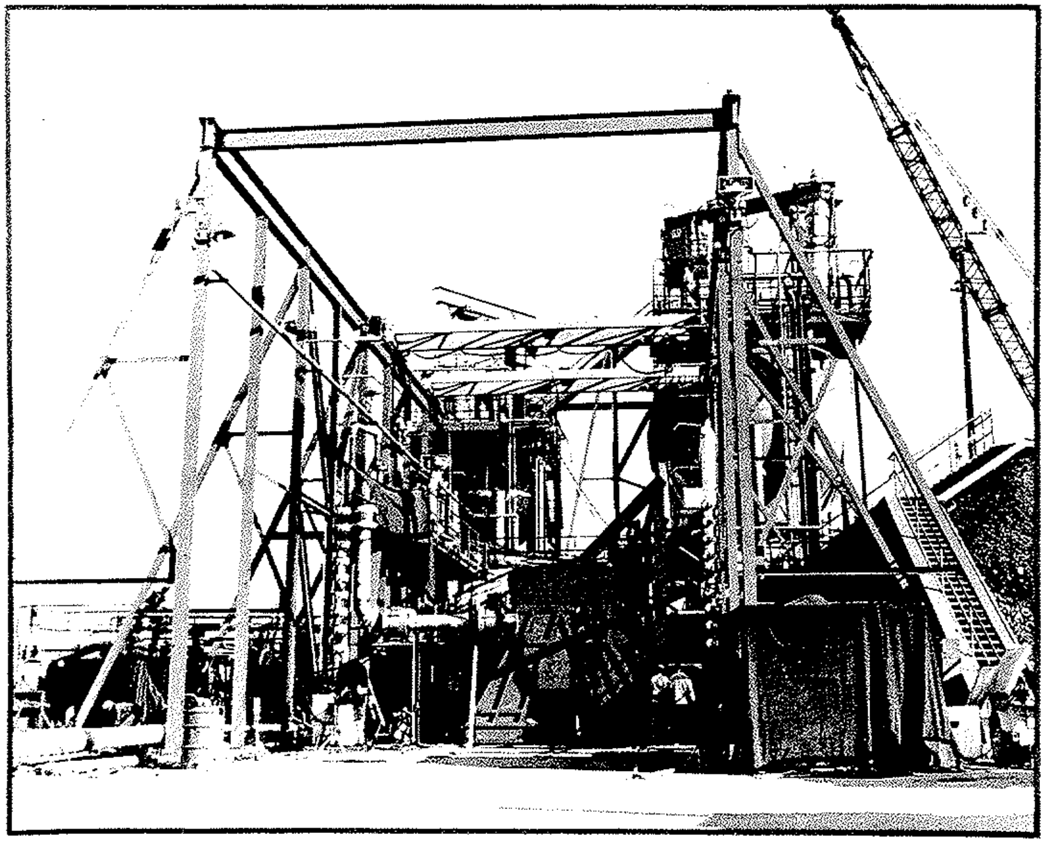
- 100

FIRST FIRING

- OCTOBER 1963 (GGA), MAY 1964 (TCA)

Figure 4. - M-1 Rocket Engine Test Stand C-9.

PURPOSE
THRUST CHAMBER AND GAS GENERATOR DEVELOPMENT TESTING



DURATION
TCA-20 SEC GGA-210 SEC

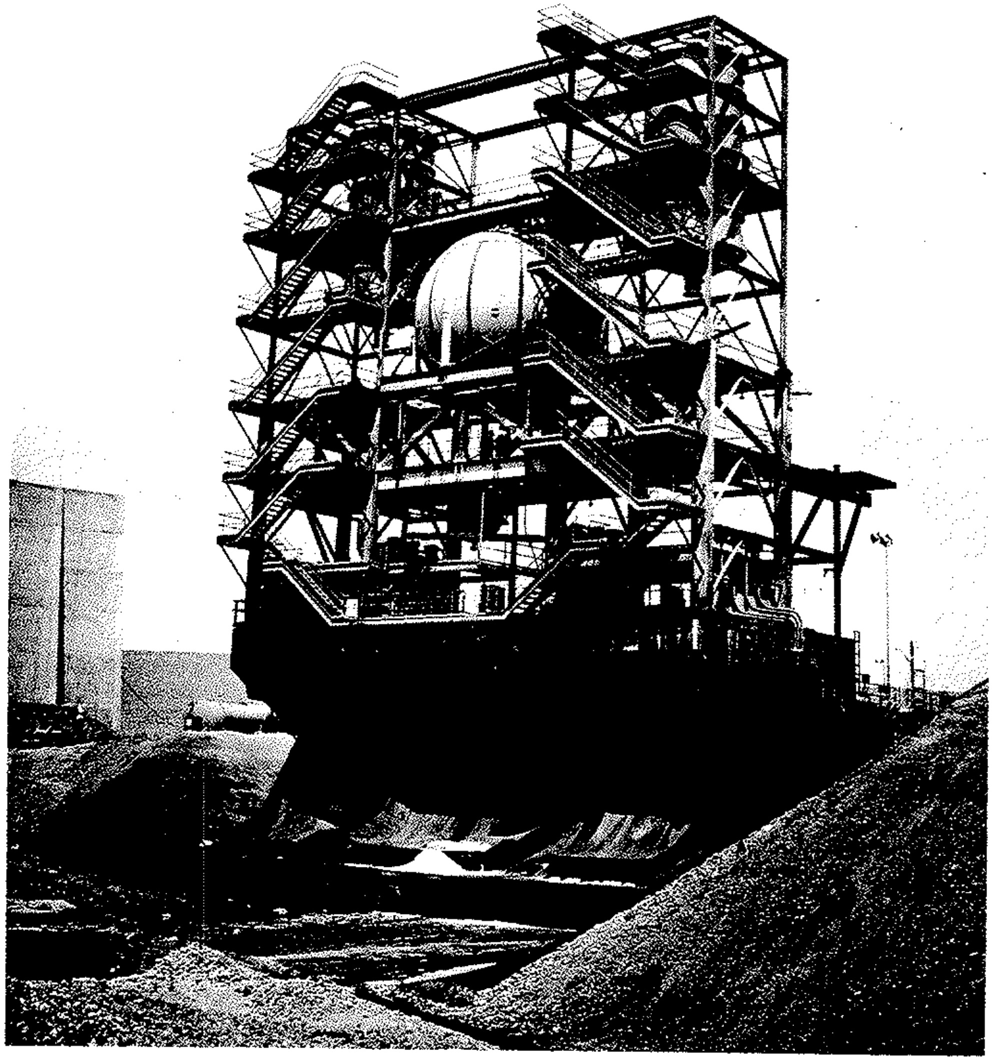
DESIGN INITIATED
JANUARY 1962

CONSTRUCTION INITIATED
MAY 1962

PERCENT COMPLETED
95

FIRST FIRING
TCA NOV. 1964
GGA JUNE 1965

Figure 5. - M-1 Rocket Engine Test Stand H-8.



PURPOSE
TURBOPUMP DEVELOPMENT TESTING

DURATION
335 SEC

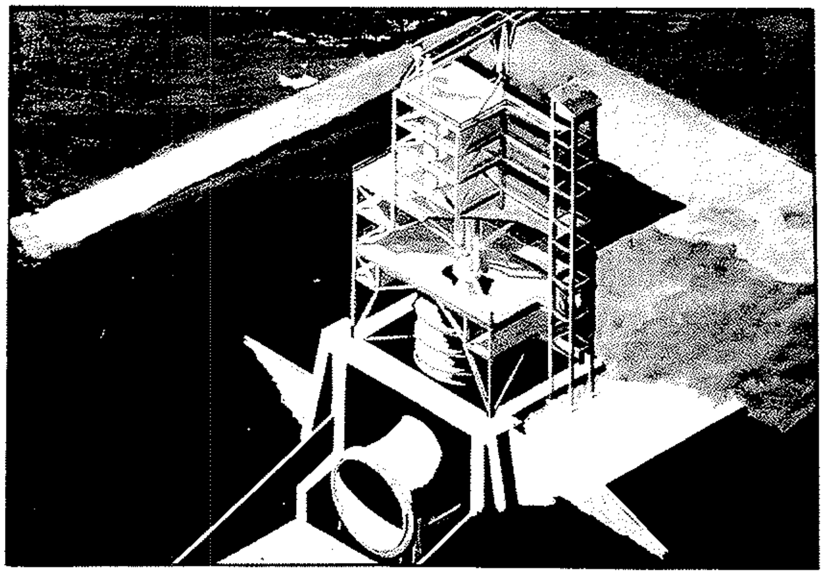
DESIGN INITIATED
JANUARY 1962

CONSTRUCTION INITIATED
MAY 1962

PERCENT COMPLETED
80

FIRST FIRING
SEPT 1964

Figure 6. - M-1 Rocket Engine Test Stand E-1, E-3.



PURPOSE
ENGINE ALTITUDE START AND ENVIRONMENTAL TESTING

DURATION
30 SEC

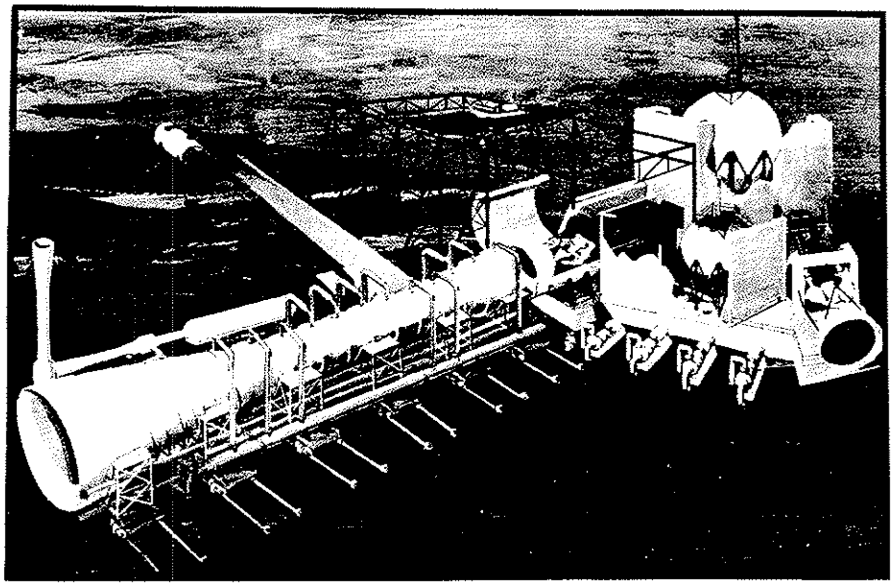
DESIGN INITIATED
JULY 1963

CONSTRUCTION INITIATED
JAN. 1964

PERCENT COMPLETED
10%

FIRST FIRING
SEA LEVEL - MAY 1966
ALTITUDE STARTS - JULY 1967

Figure 7. - M-1 Rocket Engine Test Stand K-1.



PURPOSE
ALTITUDE PERFORMANCE AND OPERATION EVALUATION

DURATION
320 SEC

DESIGN INITIATED
MAY 1965

CONSTRUCTION INITIATED
NOV 1965

PERCENT COMPLETE
0%

FIRST FIRING
SEA LEVEL - DEC. 1967
ALTITUDE - OCT. 1969

Figure 8. - M-1 Rocket Engine Test Stand K-2.

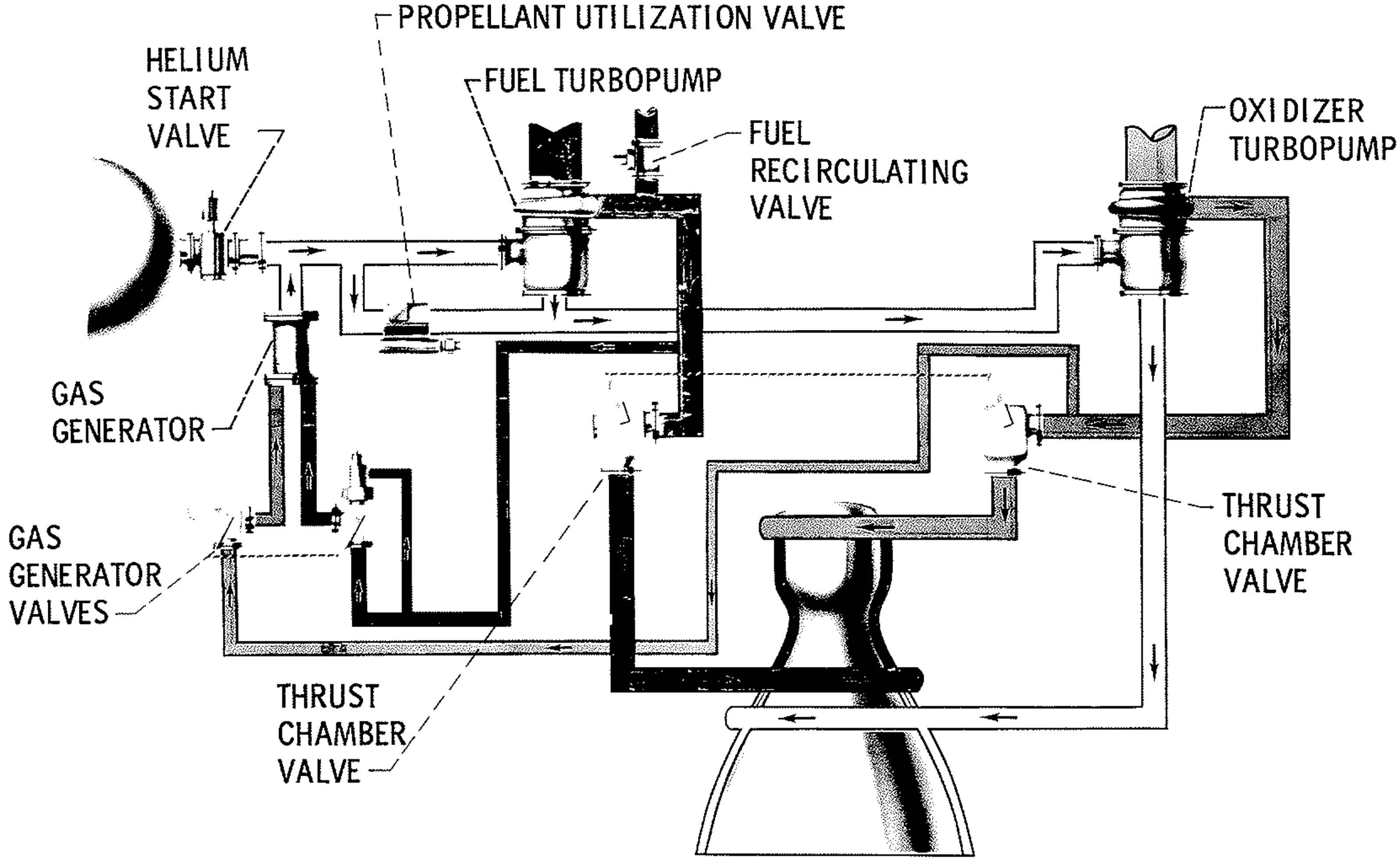


Figure 9. - M-1 Rocket Engine - Engine Fluid-Flow System.

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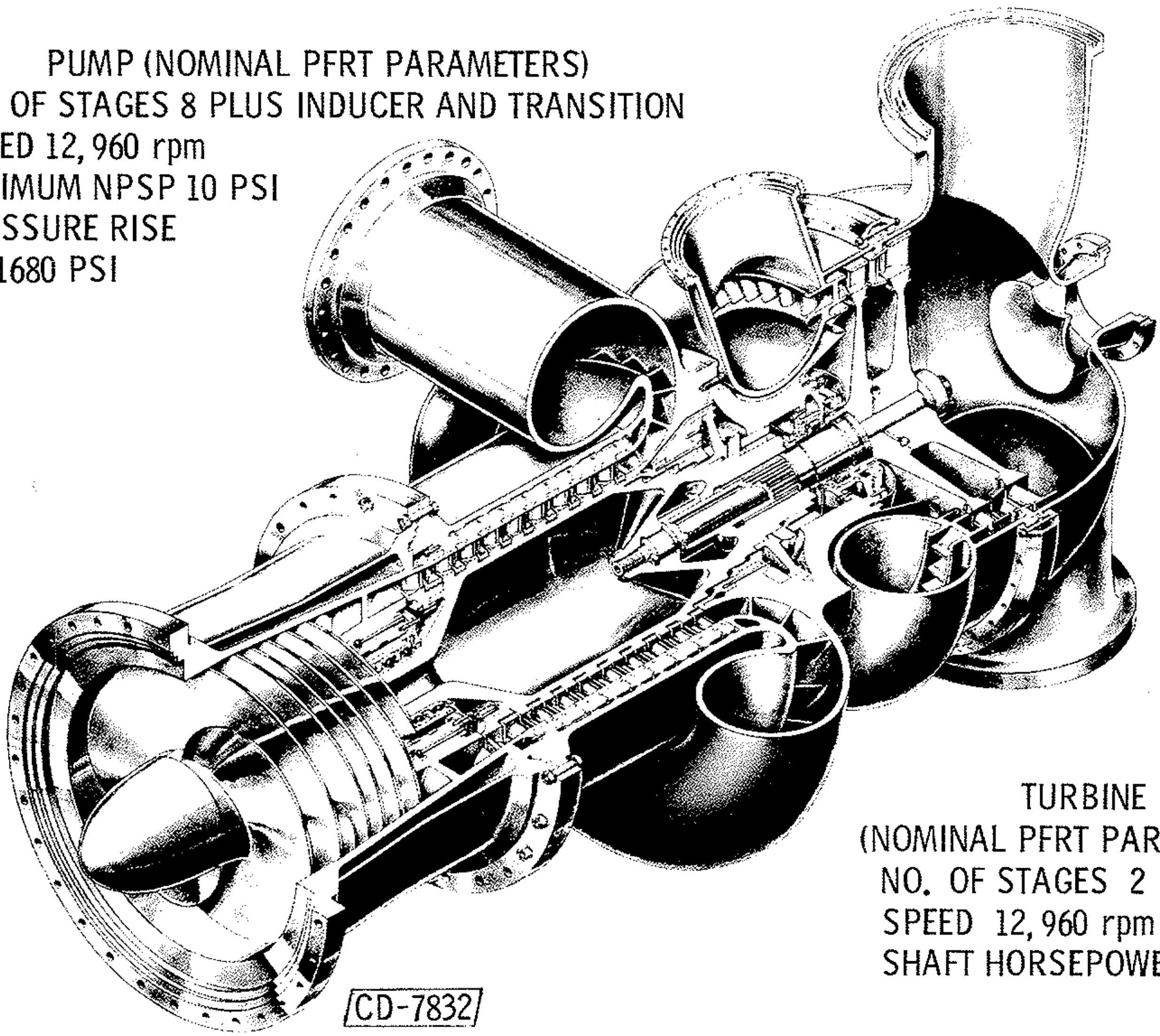

Figure 10. - M-1 Rocket Engine - Liquid Hydrogen Turbopump.

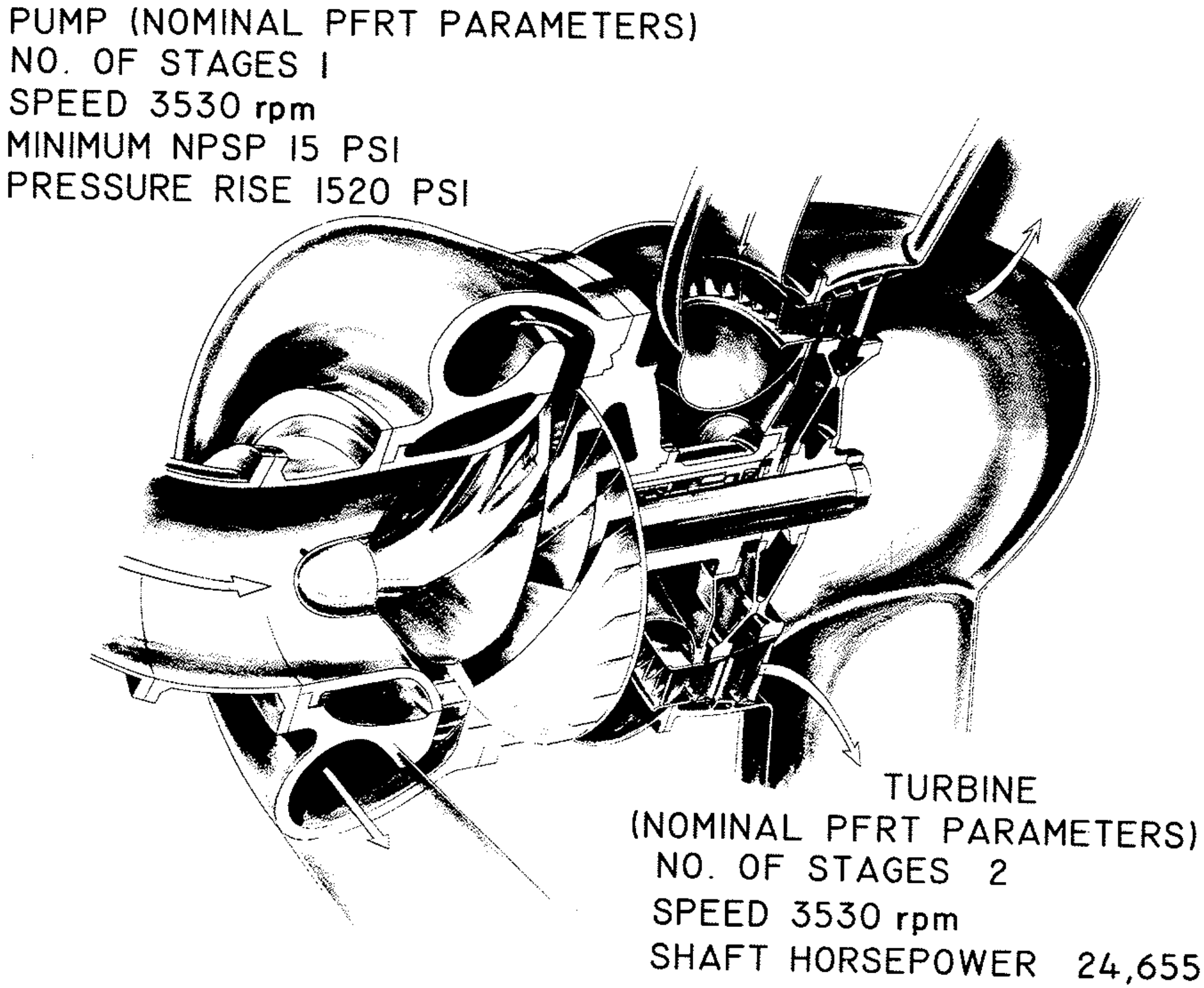

Figure 11. - M-1 Rocket Engine - Liquid Oxygen Turbopump.

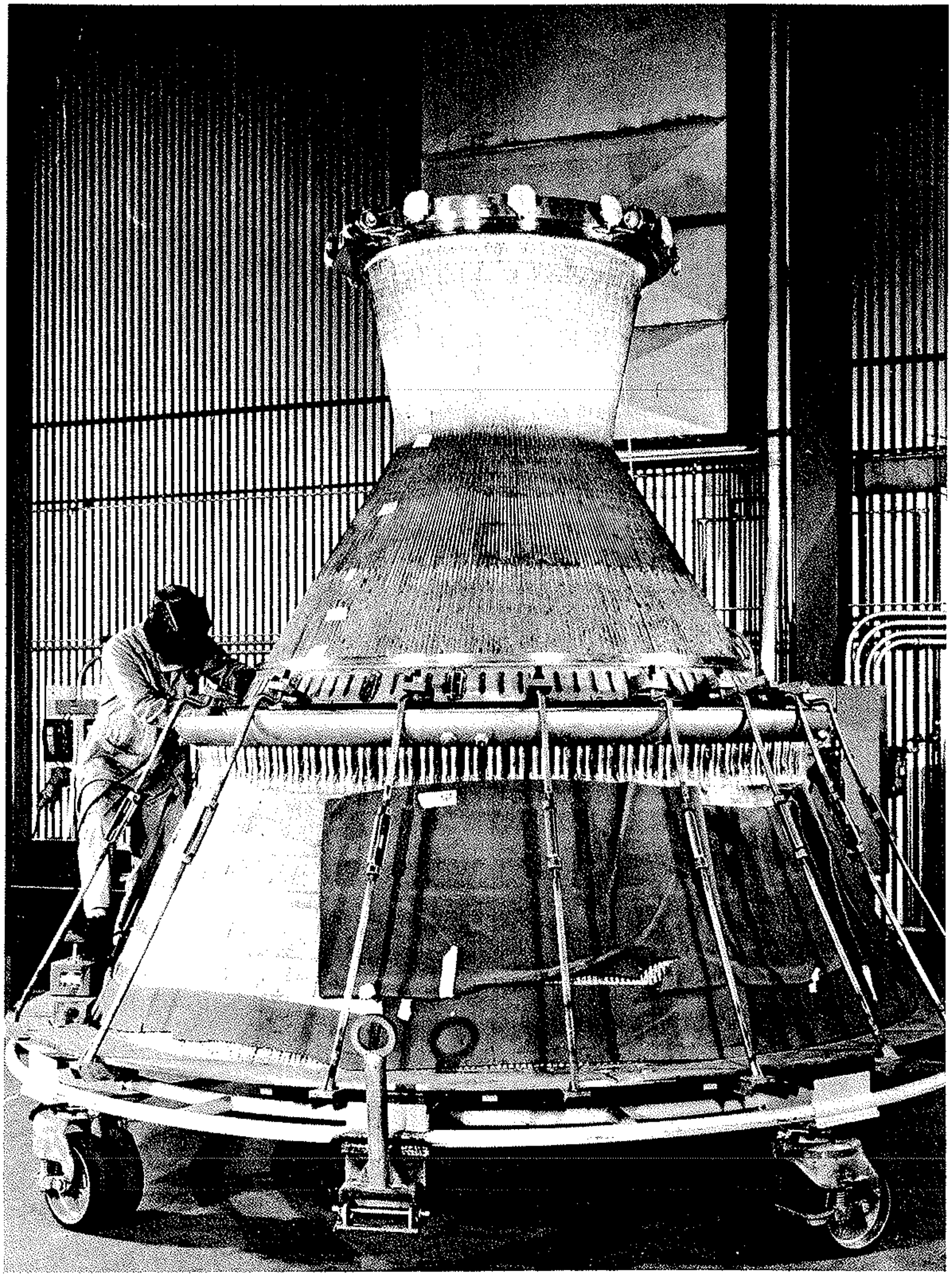

Figure 12. - M-1 Rocket Engine. Welding Fuel Torus on First Article Cooled Combustion Chamber.

E-2335

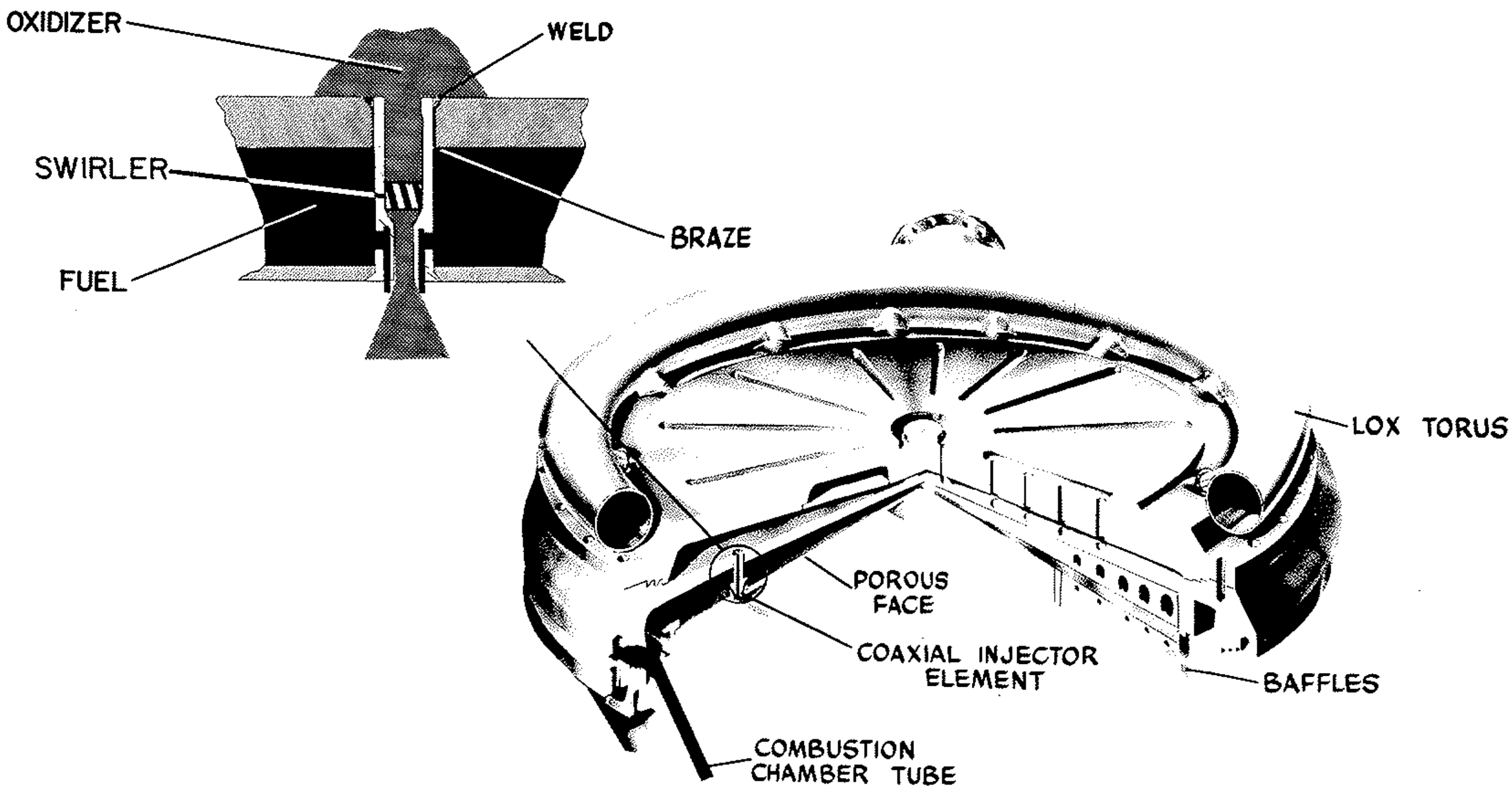

Figure 13. - M-1 Rocket Engine - Thrust-Chamber Coaxial Injector.

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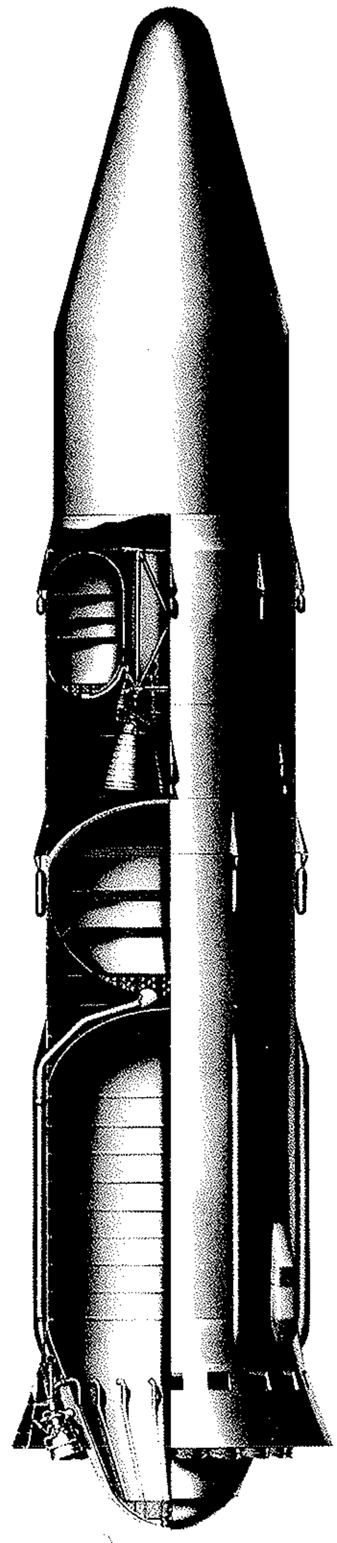
CONFIDENTIAL



453 FT

18 M-1/2 M-1
1,000,000 POUND
PAYLOAD CLASS

Figure 16. - M-1 Rocket Engine Post Saturn Vehicle.

UNCLASSFIED

CONFIDENTIAL

APPENDIX A

The data contained herein is part of a data package submitted to MSFC for use in the Phase III Post Saturn (NOVA) Studies. This data was for use in the conventional, or Class 1 all M-1 vehicle. The Class 1 M-1 configuration has conventionally clustered M-1's in the first stage. TVC is by gimbaling.

The sea level version data represents the performance, weight, size, etc., expected for a standard M-1 engine with a recontoured nozzle for first stage application. An area ratio of 20 is about optimum for the first stage. First stage performance vs. altitude and an engine envelope layout is included.

The altitude version data is simply current M-1 performance, weight, etc., data.

M-1 ENGINE DATA

For Use in Class 1 NOVA (Phase III) Study

	M-1 Sea Level Version	M-1 Altitude Version
Vacuum Thrust	1.450×10^6 lbs.	1.5×10^6 lbs.
Sea Level Thrust	1.213×10^6	
Specific Impulse		
Vacuum	413.6 sec.	428 sec.
Sea Level	346.2	
Area Ratio	20:1	40:1
Chamber Pressure	1000 psia	1000 psia
Radius Throat	15.99/in.	15.99/in.
Engine O/F (Nominal Operating)	5	5
Engine Dry Weight	19,150 lbs.	20,000 lbs.
NPSP		
Hydrogen	10.9 psi (O/F = 4.5)	10.9 psi (O/F=4.5)
Oxygen	16.1 psi (O/F = 5.5)	16.1 psi (O/F=5.5)
Moment of Inertia about Gimbal Center (Engine wet)		
x-x	18012 slug-ft^2	19177 slug-ft^2
y-y	40460 slug-ft^2	53760 slug-ft^2
z-z	32365 slug-ft^2	45665 slug-ft^2
Center of Gravity (Wet) (Throat is x = 100)		
x-x	x = 115.0 in.	x = 123.1
y-y	y = -1.5 in.	y = -1.5
z-z	z = -1.8 in.	z = -1.8
Flow Rate (Does not include 2% tank pressurization flow)	3504.7	3504.7

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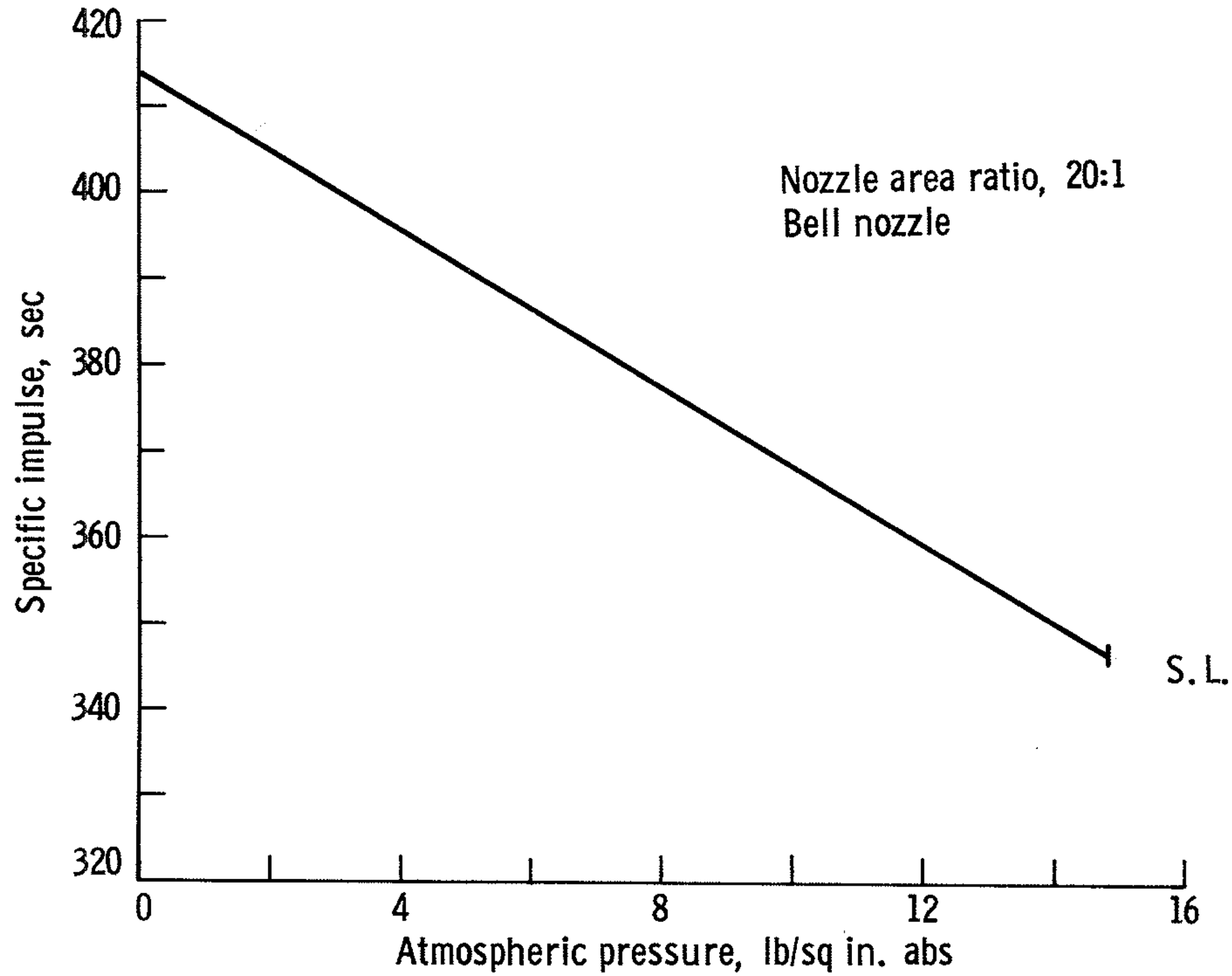

Figure A-1. - M-1 Rocket Engine (Sea Level) Performance.

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• SAME ENGINE PACKAGE AS BASIC M-1

MODIFICATION :

• RECONTOURED THRUST CHAMBER NOZZLE

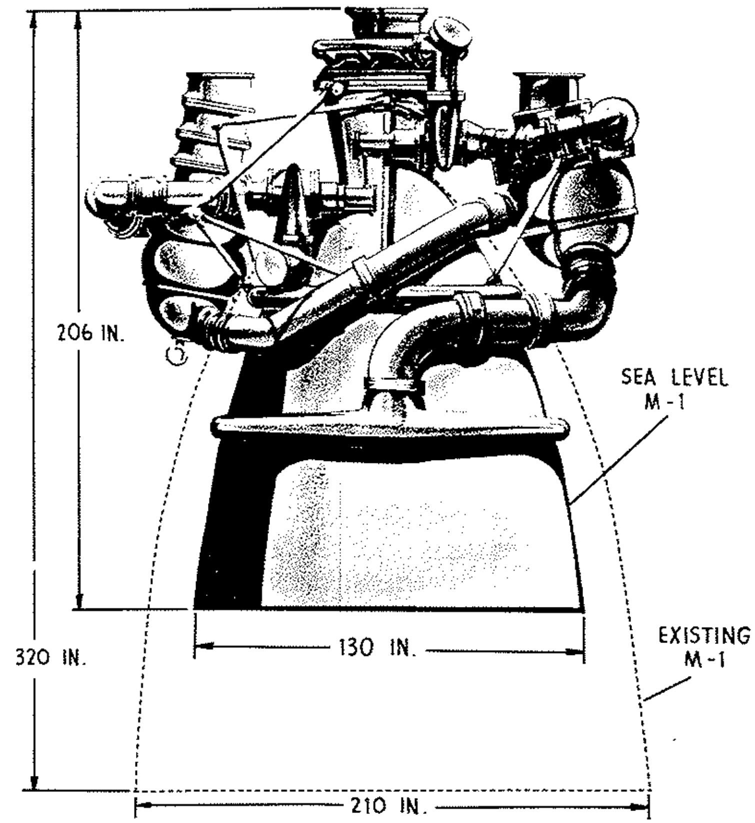

Figure A-2. - M-1 Rocket Engine (Sea Level) Features.

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TP 1751

CCC7-T

APPENDIX B

The data contained herein is part of a data package submitted to MSFC for use in the Phase III Post Saturn (NOVA) Studies. This data was for use in a Class II vehicle. The Class II vehicles are characterized by new technology, advanced nozzles, and partial recovery.

The booster stage data represent the performance, weight, size, etc., expected for a modified M-1 engine for use in a plug cluster approach. The modifications are: removal of the propellant utilization capability, mounting modifications, and nozzle recontour including increasing throat area.

The second stage data are simply current M-1 performance, weight, etc., estimates.

The full data submittal to MSFC included parametric data to enable variations in mixture ratio and internal area ratio to be made. Alternate mounting arrangements were also included. For simplicity these are not included herein.

The LeRC analysis indicated that the 12.5/1 module was about best and that a hinged module with a turbine exhaust cooled plug was at present the most interesting.

M-1 ENGINE DATA

For Use In Class II Nova (Phase III) Study

M-1/M-1 Sea Level (Plug)

ENGINE	Booster Stage M-1 Sea Level (Plug) Module Data	Second Stage M-1 A_e/A+ = 40:1
Vacuum Thrust (Pounds)	$1,515 \times 10^6$	$1,500 \times 10^6$
Sea Level Thrust (Pounds)	$1,352 \times 10^6$	
Engine Dry Weight (Pound)	18,980	20,000
Flow Rate (lbs/sec) (Does not include 2% tank pressurization flow)	3796.7	3504.7
Delivered Vacuum Isp (sec)	399	428
Delivered Sea Level Isp (sec)	356	
O/F Ratio	5.5	5.0
Propellant Utilization Range	None	± 10%
LH_2 Pump NPSP (psi)	10.0	10.9(@O/F=4.5)
LO_2 Pump NPSP (psi)	16.4	16.1(@O/F=5.5)
Center of Gravity (Wet) (Throat is x = 100)	x = 110	x = 123.1
Moment of Inertia About Gimbal Center (Engine Wet) slug-ft^2		
x-x	16,827	19,177
y-y	34,160	53,760
z-z	26,065	45,665

THRUST CHAMBER	Booster Stage M-1 Sea Level (Plug) Module Data	Second Stage M-1 $A_e/A_t = 40{:}1$
Chamber Pressure (psia)	1000	1000
Throat Area (in^2)	858	803
O/F Ratio	6.0	5.5
Flow Rate (lbs/sec)	3684.7	3394.7
Vacuum Isp (Sec)	402	
Sea Level Isp (Sec)	361	

GAS GENERATOR AND TURBINE EXHAUST		
Gas Generator Flow Rate (lbs/sec)	112	110
Gas Generator O/F Ratio	0.9	0.8
Turbine Exit Gas Pressure (psia)	120	120
Turbine Exit Gas Temperature (°R)	1230	1050

Note:

1. Performance for the M-1 Sea Level (Plug) represents a point design module engine with nozzle area ratio 12.5/1. Data from the two-dimensional thermochemical computer program indicates this area ratio gives an exit pressure of approximately 14.7 psia at the nozzle wall. Data provided is for the individual module (internal expansion) only in all cases.

2. Information provided on the M-1 Engine for second stage applications refers to the design nominal operating engine O/F ratio of 5.0 unless otherwise noted. The data provided is for a nozzle area ratio of 40:1.

3. Main Combustion Chamber combustion efficiency (C*) used was 97.1% of theoretical equilibrium. Nozzle (C_f) efficiency used was 98% of one-dimensional equilibrium. These values yield 95.16% of one-dimensional equilibrium specific impulse or about 95.9% of the two-dimensional value.

4. Parametric data for the M-1 Sea Level (Plug) at various O/F ratios is derived by holding engine fuel flow constant at the present M-1 nominal (584 lbs/sec) and increasing LOX flow to reach other O/F ratios. The considerable range of performance capability in the present M-1 LOX pump design makes the increased flow rates possible without hardware changes. Engine dry weight is affected as the nozzle throat area is increased to keep chamber pressure at 1000 psia with increased flow rates.

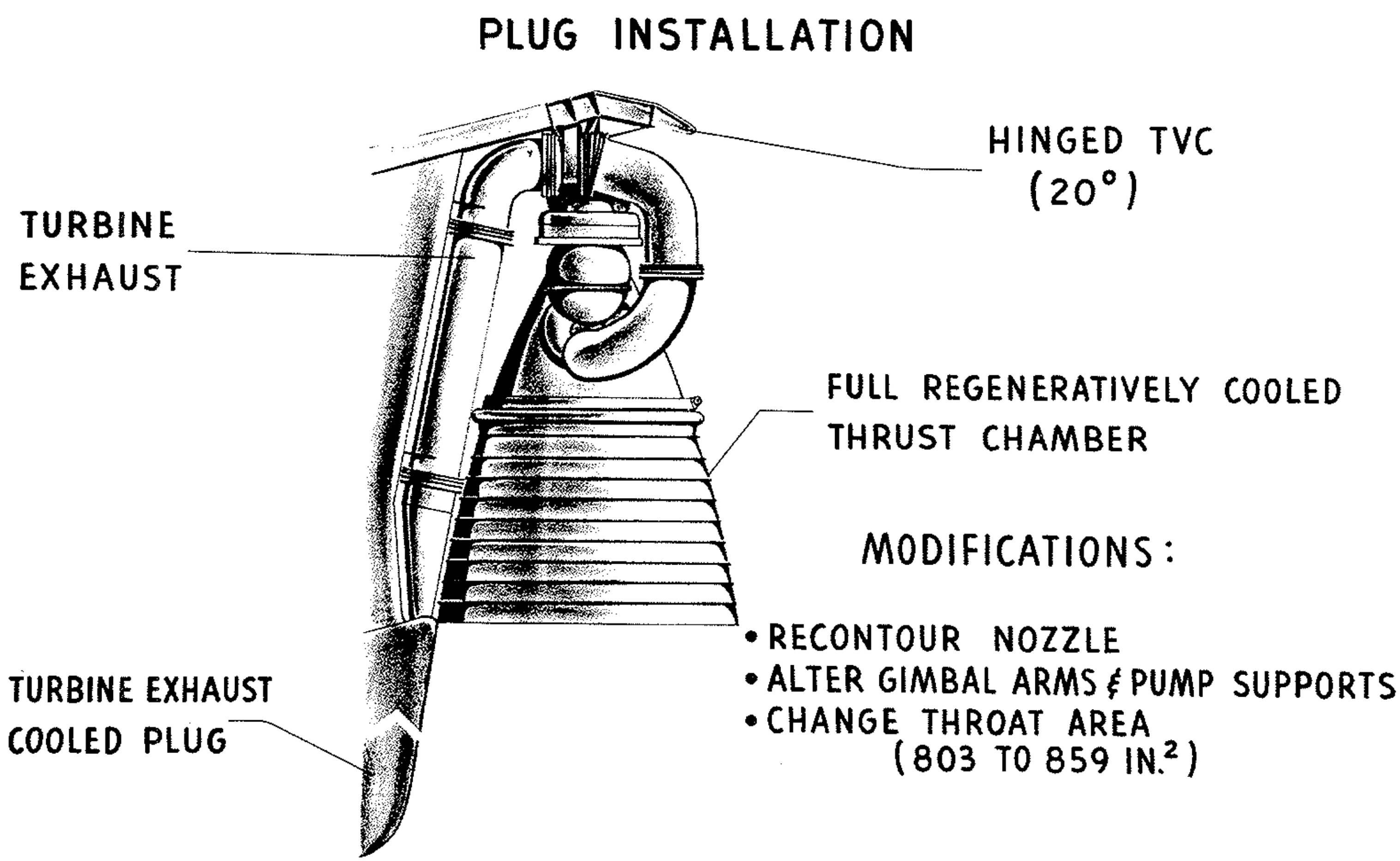

Figure B-1. - M-1 Rocket Engine (Plug) Features.

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