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DESIGN STUDY AND EVALUATION
OF A HYPERGOLIC ENGINE
FOR A SPACE POWER SYSTEM

Final Report for Phase III:
SPACE POWER UNIT BREADBOARD SYSTEM
for the Period 12 February to 15 July 1966

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Final Report for Phase III:
SPACE POWER UNIT BREADBOARD SYSTEM
for the Period 12 February to 15 July 1966

Contract: NAS 9-857
Phase III

Project: 287


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# I. SUMMARY

This report describes the Phase III program which was conducted to fabricate and test a hypergolic, reciprocating engine-driven, breadboard electrical generation system. This work was performed for the Manned Spacecraft Center of the National Aeronautics and Space Administration under Contract NAS 9-857 during the period 12 February to 15 July 1966.

The selection and application of the "off-the-shelf" components (including various pumps, motors, and controls) that were used in conjunction with the hypergolic reciprocator to make up the breadboard system are discussed. The reciprocator was improved slightly since the completion of the Phase II feasibility development program. A completely mobile propellant cart was fabricated and included as a part of the breadboard system to allow simulation of the propellant supply from the space vehicle and also to provide system operation independently of any blockhouse or laboratory support.

A performance test of the complete breadboard system yielded a specific propellant consumption of 10.5 lbs/KW-hr while producing 2.0 KW of power at 29 volts d-c.

During the period of system development, the prime mover was tested to determine its operability with exhaust at ambient pressure. The engine was modified to reduce the expansion ratio from approximately 50:1 to 10:1. Satisfactory operation at ambient exhaust pressure was obtained and, in addition, a new low specific propellant consumption of 5.3 lbs/HP-hr was achieved while operating with the modified expansion ratio (exhaust at 3 psia).

New combinations of piston ring and cylinder wall materials were evaluated.

A study was made to investigate the Lunar Module (LM) installation possibilities of the hypergolic reciprocator space power system. This study included a visit to the Grumman Aircraft Engineering Corporation, the contractor engaged in the construction of the LM vehicle.

## II. INTRODUCTION

The Phase I portion of Contract NAS 9-857 was initiated in October 1962 under the sponsorship of NASA MSC to determine the feasibility of a hypergolic propellant-fueled reciprocator for space power generation. This program resulted in the successful operation of an engine constructed in accordance with the prevailing state of the art of conventional engines with features added to promote efficiency and propellant compatibility. A notable feature of the engine was the short period injection system developed to allow engine operation closely along the efficient constant volume process.

The feasibility program was extended into the Phase II program on 1 July 1964 to determine the potential endurance and reliability of the engine. This program resulted in the demonstration of a continuous run of 90.4 hours at a two-level power output of 2.4 and 3.2 horsepower. Problem areas encountered during the development for extended periods of operation were those of the piston and rings, injector valves, bearings, and lubricants. Improvement in operating efficiency was not the intent. However, adjustments made in injection and engine operation resulted in a reduction in specific propellant consumption. At the end of Phase II, the engine was operating with a specific propellant consumption of 6.3 lbs/HP-hr.

The details of Phases I and II programs are reported in Marquardt Corporation final reports (See References 1 and 2).

The Phase III program reported herein integrated the hypergolic reciprocator and accompanying subsystems into a breadboard electrical generating system. This system demonstrated the feasibility of the hypergolic engine and generator system with features of self-starting, full automatic control, and complete independence of services except for propellant storage.

# III. ENGINE DEVELOPMENT

## A. Description of SPU-3 Test Engine

### 1. General Characteristics

The Marquardt SPU-3 test engine was utilized during the test period, 12 February to 15 July 1966. This engine is a single cylinder liquid cooled, reciprocating machine capable of driving a 2 KW electric generator. The engine operates on metered injection of nitrogen tetroxide ($N_2O_4$) oxidizer and a 50-50 blend of $N_2H_4$ and UDMH (Aerozine 50) fuel. The operating cycle is a modified two-stroke cycle. The design features of the engine are described below.

### 2. Configuration

The basic SPU-3 test engine configuration was evolved during the Phase II test program. Several detail changes were incorporated during the Phase III program. However, these changes were mainly modifications to allow the engine to be used as part of the breadboard system.

The external configuration of the basic SPU-3 engine is shown in Figure 1. The basic specifications for this engine are as follows:

1. Piston displacement: 2.06 cu in. (Effective); 2.43 cu ins. (Actual)
2. Bore: 1.380 in.
3. Stroke: 1.625 in.
4. Nominal maximum engine speed: 6000 rpm
5. Exhaust: Piston controlled port
6. Bearings: Antifriction ball and roller bearings for the main and rod journals, respectively
7. Lubrication: Low pressure, dry sump oil system
8. Cooling: Liquid cooled cylinder assembly
9. Injection system: Short dwell system using dual concentric, flat mono seat valves and individually adjustable cams
10. Expansion ratio: 10:1 to 40:1
11. Engine weight: 35 lbs (less flywheel)
12. Engine envelope: 8 by 15 by 15 in. with basic injection pump and less generator

The materials and processes used in the major components of the SPU-3 engine are as follows:

1. Crankcase: 2024-T351 aluminum alloy
2. Crankshaft: 431 stainless steel
3. Main bearings: MRC 204S-ST 440-C stainless steel
4. Rod big-end bearings: McGill GR-16 full complement roller bearing
5. Rod: 2024 T351 aluminum alloy
6. Cylinder: 17-7 PH stainless steel
7. Cylinder liner: 17-7 PH stainless steel heat treated with dense chrome plated bore
8. Piston: Composite Rene' 41 crown, D-132 aluminum alloy skirt
9. Piston rings: 440-C stainless steel
10. Cylinder head: 6061-T6 aluminum alloy
11. Injector valves: 440-C stainless steel, chrome plated O D
12. Camshaft: 440-C stainless steel
13. Cam lobes: Speed Star H.S. tool steel heat treated to $R_c$-65
14. Rocker arms: 6150 steel, flash chrome plated
15. Rocker arm shafts: 8620 steel, flash chrome plated
16. Timing gears: 416 stainless steel

The major components of the SPU-3 engine are shown in Figure 2. The assembly drawing of the engine is presented in Figure 3. A fully detailed description of the engine is given in Reference 2.

## B. Components

### 1. General Considerations

During the test period, several components of the engine were fabricated from materials differing from those used in the standard components. These were installed in the engine when they became available and tested as part of the system test program. Three major components were evaluated. They were:

1. X21446 plate
2. X22768A piston ring
3. X22767 inner sleeve

2. Plate Evaluation

The X21446 plate fits between the top of the cylinder and the cylinder head and forms the top of the combustion chamber. This component is normally fabricated from T6061-T6 aluminum. However, two plates were made from 321 CRES for evaluation purposes. In addition to the material change, the combustion chamber was counterbored deeper to reduce the engine expansion ratio from 36:1 to 12:1. The plate was evaluated on 8 June 1966 (Test 5169-2). During this test, the engine was subjected to operating conditions of high horsepower (5.34), high BMEP (251 psi), and high coolant temperature (200°F). The exhaust was vented directly to ambient pressure while the engine was operating in excess of 3 horsepower. This test required 1.68 continuous hours to complete and it was concluded with a normal shutdown. Subsequent engine inspection disclosed warping of the plate but no erosion of the combustion chamber face.

The combustion chamber erosion occasionally encountered with aluminum plates was the major reason for investigating the CRES material for this application. Subsequent testing with low expansion ratio aluminum plates having the same configuration as the CRES design also showed no tendency to erode. It was therefore concluded that either material can be successfully used in this area of the engine because erosion appears to be a function of combustion roughness resulting from high expansion ratios rather than a material problem.

3. Piston and Cylinder Evaluation

Several sets of X22768A piston rings were modified for evaluation with an X22767 inner sleeve fabricated from high grade cast iron. The piston ring modification consisted of grinding down the outside diameter of the standard 440-C stainless steel rings and dense chrome plating the surface to return it to proper size. Chrome rings operating on cast iron cylinder walls are almost universally utilized for conventional reciprocating engines. Therefore, the major question to be answered was whether or not cast iron could be successfully used as a cylinder material with hypergolic propellants. Test 5169-12 was conducted on 6 July 1966 with this piston ring and cylinder combination installed. The engine was operated for 0.68 hours at power levels up to 2 horsepower. Subsequent inspection of the engine disclosed a badly worn and eroded cylinder bore. The bore increased in diameter approximately 0.040 in. at the top of the cylinder. The condition of the cast iron cylinder liner after this test is shown in Figure 4.

Although the cast iron cylinder liner wore rapidly, the chrome plated piston rings showed no measurable wear, galling, or tendency to flake the chrome plating. The piston and rings are shown in the "as removed" condition in Figure 5.

Because of the excellent condtion of the piston and rings, it was decided to operate this assembly with the standard 17-7 PH chrome plated bore SPU-3 cylinder liner. Since chrome on chrome is basically an incompatible bearing combination, it was concluded that, if these units would operate together at all, the lubricating system and the lubricant for the engine was adequate and that the galling tendency of the standard 440-C unplated piston rings was a material compatibility problem. Tests 5169-13 through 5169-21 were conducted with the chrome on chrome piston ring and cylinder combination without engine seizure or indications of incipient seizure. A total of 1.81 hours of engine operation was accumulated during this period. The piston rings and the cylinder bore were inspected following Tests 5169-13 and 5160-21. These inspections disclosed progressive increase of the galling of both the piston rings and the cylinder bore. However, the severity of the galling was not sufficient to cause degradation of the performance of the engine.

Two additional material combinations for the piston rings and cylinder bore under consideration for evaluation in the next program are as follows:

1. Monel rings and the standard chrome bore
2. Monel rings and Vanderhorst process "Porus-krome" plated bore

These candidate materials combinations offer good bearing qualities and propellant compatibility and, in the case of Item 2, improved retention of lubricants.

## C. Performance

### 1. General Considerations

Three parameters affecting engine performance were evaluated during the contract period. These parameters were as follows:

1. Reduced expansion ratio
2. High coolant temperature
3. High exhaust back pressure

In addition, two assembly techniques were evaluated as follows:

1. Increase in piston ring side clearance
2. Investigation of the lubricant used in installing the piston

The results of these investigations and their effect upon engine performance are discussed in the following sections.

2. Reduced Expansion Ratio Effects

To enable reliable system operation and compatible injection pressures with the exhaust open directly to ambient pressure, it was necessary to reduce the expansion ratio (by increasing the clearance volume) to 12:1. A direct benefit was the reduction in specific fuel consumption at all power levels. Indications are that a significant improvement in propellant combustion occurred to offset the reduction in cycle efficiency caused by the reduced expansion ratio. The absence of metal erosion and heat concentration on the piston crown and combustion chamber indicates more uniform mixture ratio distribution and a reduction in heat transfer film coefficients. The increased combustion chamber volume results in reduced peak pressures and pressure rise rates providing an increase in reliability and endurance of the piston assembly.

The performance of the engine with this low expansion ratio is shown in Figure 6 as a function of brake mean effective pressure (BMEP). These data were obtained at an exhaust pressure of 3 psi so that direct comparison could be made with previously documented performance characteristics.

3. High Coolant Temperature Effects

In order to assure proper operation of the engine in the breadboard system, it was necessary to evaluate performance at higher than normal coolant temperatures. It was assumed that the engine would operate in the breadboard system at temperatures between 10°F and 50°F higher than those normally allowed during facility type testing. Therefore, the engine was operated in the 3 horsepower range and allowed to reach a coolant outlet temperature of 200°F and stabilize at that value. Comparison of the data with those from previous tests where maximum coolant outlet temperatures were nominally maintained at 150°F showed no significant differences in any recorded parameter. Performance differences that may have existed were within the normal instrumentation accuracy bands and therefore were not discernible.

4. High Exhaust Back Pressure Effects

The effect of operating at ambient exhaust conditions was evaluated only sufficiently enough during this period to determine the required increase in propellant injection pressures. A nominal increase of 300 psi for both fuel and oxidizer injection pressures at any given point in the power spectrum was found to be required. A secondary and expected result from operating at ambient exhaust pressures was an increase of approximately 200°F in exhaust temperature. No difficulty was anticipated or experienced in achieving and maintaining normal engine power levels.

5. Assembly Techniques

Two changes were made in assembly techniques during the Phase III test program. Both dealt with the piston. Specifically they were:

1. Increase in piston ring side clearance
2. Elimination of petroleum base lubricants for initial piston installation

Throughout the Phase I and II test programs, sticking of the piston rings in their grooves had been a problem. Generally, the basic reason for ring sticking was carbon buildup in the grooves. Because carbon buildup had been noted after tests of less than one hour, it was theorized that much of the carbon was created from oil trapped in the grooves as a result of heavy oiling of these components during assembly. Additionally, the thermal expansion of the piston decreased the ring side clearance sufficiently to prevent proper "working" of the rings in their respective grooves. Therefore the rings were decreased 0.002 inch in thickness and fitted in the pistons as tabulated below:

| Ring No. | Side Clearance (Old) (in.) | Side Clearance (New) (in.) |
|---|---|---|
| 1 | 0.0035 | 0.005 |
| 2 | 0.003 | 0.0045 |
| 3 | 0.0025 | 0.004 |
| 4 | 0.0025 | 0.004 |

Upon assembly, the components were lubricated with PR143AC lubricant instead of the standard BRAYCO-30 oil. These changes, combined with the more even thermal distribution obtained with the lower expansion ratio, eliminated seizure of the piston rings in their grooves during the test period.

# IV. PROPELLANT PUMP DEVELOPMENT

The storable liquid propellants must be fed to the engine at high pressures (1000 to 3000 psia) for rapid injection. The propellants are boosted from normal supply pressure (approximately 200 psi) to operating pressures by a pump which is driven by the engine crankshaft.

## A. Initial Pump System

The initial propellant pumps (shown shecmatically in Figure 7) utilize the proven inner and outer valves of the injector valve mechanism. The design concept was selected on the basis of minimum required development work because of the advanced status of these components, low cost of manufacture (several semi-finished components were available), and the low actuating force level to change the pumping capacity. Both pumps are identical and they operate as separate units to preclude the possibility of mixing of the propellants.

The pressure control system uses a pair of inclined planes which can be easily fabricated. This permits a single lever actuation to vary the power level of the engine while maintaining constant O/F ratios throughout the power range.

The unit was assembled and tested with low viscosity turbine lubricating oil and distilled water. Bench tests were made with the pump attached to an engine (driven by an electric motor) complete with the exception of the cylinder, piston, and connecting rod. The cylinder head was fastened to the timing gear cover. The injector valves were in normal operation and the tests were performed with the test fluid pressurized to simulate engine run conditions. The test fluid was captured at the combustion chamber and measured for flow rate. Various timing relationships between the start of pump to start of injection was used, but most calibration tests were performed at 180° out of phase. Pump speeds ranged from 100 to 2,900 rpm. Injection pressures were varied between 50 and 3,000 psi.

One problem was leaking of the discharge check valve. This was corrected by using a larger check ball and remachining the valve seat to obtain the required sealing.

Another problem was a seizing and resulting galling of the roller cam followers. This caused fracture of the slip-on cam at a stress concentration point in the key slot. The tendency of the cam to fail was eliminated by changing to a rounded key slot configuration. The cam follower failures were eliminated by incorporating a ball bearing type follower.

Two additional problems were encountered, namely, (1) cutoff sensitivity with speed, and (2) resonance of the outer valve system at high pump speeds.

The first problem was satisfactorily resolved by elimination of the heavy follower between the inner valve and the inner valve return spring. The second problem was solved by replacement of the high acceleration cam with an eccentric cam.

After the tests with oil and water had demonstrated the capability of the pump to provide adequate volume supply at the required speed and pressures, the propellant pump was tested dynamically with $N_2O_4$ and Aerozine 50 for calibration and evaluation. This bench test demonstrated that the pump was not ready for installation on the engine because of excessive propellant leakage from both oxidizer and fuel elements and also because of control problems. The pump was set up for further evaluation and development on the water flow test bench.

Figures 8 and 9 show the effect of suction pressure and preloading of the center plunger spring on propellant flow versus control stop setting.

B. Modified Initial Pump System

The pump was modified to eliminate the center plunger. The resulting fixed displacement pump was to be driven at various speeds through an engine driven, hydraulic, variable speed drive to supply propellants as required. A governor would sense the change of engine speed and accordingly signal the hydraulic variable speed drive to change the pump output and maintain the desired engine speed. An overboard drain was also incorporated in the revised pump. Modification of this pump was complete but testing was not accomplished inasmuch as the alternate pump system described below was satisfactory.

C. Alternate Pump System

An alternate propellant pump was fabricated in the event that the initial pump could not be developed in this test period.

This pump consists of a Bosch dual plunger unit sending controlled hydraulic pulses to two balanced diaphragm isolator units (one for each propellant). The working fluid used was a non-hazardous mixture of 7 parts water and 1 part soluble oil. This system provides precisely controlled pumping of propellants at high pressures with complete isolation of propellants and working fluids. The isolating diaphragm is not subject to net pressures greater than the diaphragm deflection pressure of 7 psi. The diaphragm deflection is held to 0.003 inch and the resulting stress does not exceed 10,000 psi, insuring very long fatigue life. The Bosch governor was used without modification. The pump was driven by the engine at 1/3 crankshaft speed. A schematic of this alternate propellant pump system is shown in Figure 10.

# V. BREADBOARD SYSTEM DEVELOPMENT

## A. Description of Breadboard System

The breadboard system is composed of the following major components:

1. SPU-3 hypergolic reciprocating engine
2. Isolation propellant boost system (Marquardt designed and fabricated) using a two-element Bosch Diesel injection pump as a signaling device
3. Speed Governor-American Bosch
4. Lubrication pump and scavenge system (Engine driven from the engine-generator connector shaft)
5. Coolant circulation pump (Engine driven from rear of generator)
6. Coolant thermostatic control
7. Coolant radiator
8. Engine starter system consisting of oil tank, hydraulic motor, piston-type hydraulic accumulator, overruning clutch system, and hand pump for charging the accumulator.
9. Alternator and regulator

In addition to the basic breadboard system, propellant supply tankage was also fabricated. Figures 11 and 12 are photographs of the breadboard system. Figure 13 shows the system complete with the propellant supply subsystem. A schematic of the breadboard system is presented in Figure 14.

Excluding the engine and generator, the breadboard system is composed of five major supporting subsystems. They are

1. Starter subsystem
2. Lubrication subsystem
3. Cooling subsystem
4. Propellant pressurization subsystem, including governor
5. Propellant supply subsystem

The functions and development of these subsystems are described in the following sections.

B. Subsystem Development

1. General Considerations

In general, the components used in the breadboard subsystems were off-the-shelf items and they were either commercial or AN standard types. The exceptions were the SPU-3 engine, some propellant pump components, and the VARO alternator and power conditioning unit. Emphasis was placed on available hardware, with resulting compromise of weight and size because of time and funding limitations. Accordingly, the operating efficiency and size of the various components are not representative of an optimized system.

2. Starter Subsystem

The starter subsystem is composed of the following basic parts:

1. Vickers MF-24-3906-30-BCD-4 hydraulic motor
2. Honda overruning clutch assembly with modified sprocket and bearings
3. Greer 30P-1/2 3000 psi accumulator, 116 cu in. capacity
4. Blackhawk high pressure hand pump
5. Starting valve
6. Oil tank

These components were selected and sized to provide a smooth operating starting subsystem capable of turning the engine over at 1200 rpm for approximately 6 to 10 seconds. The subsystem requires no external power except manual pumping to charge the accumulator. The starting subsystem was used extensively during the Phase III test program for both starting and component motoring duties without malfunction. Wear was noted in the sleeve bearing of the clutch. This minor problem was eliminated by replacing the sleeve bearing with two ball bearings. The system used engine oil as the working fluid to minimize supporting fluid storage.

3. Lubrication Subsystem

The lubrication subsystem is a dual system that provides pressurized lubricants to the engine and a scavenge pump to remove lubricant from the engine. The components of the subsystem are as follows:

1. Pesco 1P-320 oil pump
2. Chandler-Evans 4103-23 fuel pump (Scavenge pump)
3. Republic 649XRB-2-8 pressure relief valve, 70 psig
4. Moore Pneumatic pressure regulator, 3 psig
5. Norgren 11900-2 pressure regulator ($GN_2$)

The oil pressure and scavenge pumps are straddle mounted on a common shaft and they are driven by a chain at one-half engine speed. The Pesco oil pump is a standard aircraft component and it is rated at 1 gpm at 1500 psi. This unit was reset to deliver oil at a pressure of 70 psi to the main oil manifold.

The dual pump assembly was tested as a component prior to installation to determine its power requirement and to set the pressure relief valves.

In order to quickly determine the power requirements of the oil pumps and other accessories, a Gast 8AM air motor was calibrated at various air pressures using the water dynamometer formerly used to absorb engine power. This calibration is shown in Figure 15. The air motor was then used to drive the accessories and thus determine their power requirements. The oil pressure and scavenge pumps were determined to require a total 0.6 horsepower for the two pumps when operating at the proper conditions to support engine operation. An oil pressure pump specifically designed for the Space Power Unit would require an estimated maximum of 0.1 horsepower. A scavenge pump would not be required in a final design as long as a gravity field of approximately 0.15 g were present during operation.

The lubrication subsystem operated satisfactorily during the breadboard testing. However, several short runs were required to determine the exact pressure relief valve setting for safe operation following installation of the pumps in the complete system. As indicated in the starter subsystem section, the oil stored in the oil tank is shared by the engine lubrication and starter systems to minimize supporting fluid storage requirements. This tank holds 1.5 gallons of oil.

4. Cooling Subsystem

The cooling subsystem is composed of the following major components:

1. McCord 41555-A condenser, 2 each, used as radiators
2. Amot Model C, 130°F thermostat
3. Tuthill 100 WV coolant pump

These components were individually tested to insure proper operation when assembled into the breadboard system. The Tuthill pump was subjected to a 28 hour, intermittent, duration test at 4800 rpm prior to evaluating its flow versus rpm characteristics. The pump is constructed of corrosion resistant materials and there was a question as to the durability of the carbon vanes when operated at speeds exceeding twice their normal rating. The pump is normally rated for operation at 1750 rpm and it was desired to run the unit at speeds as high as 5000 rpm. Therefore the pump was subjected to a high speed performance

test. Pump operation during this period was completely satisfactory therefore its pumping characteristics were evaluated as a function of rpm. The results of this test are shown in Figure 16. The flow rate range selected for engine operation was 100 to 115 gph with the engine operating at 4000 rpm. Therefore, the pump was installed on the breadboard, fitted with a variable speed pulley, and belt-driven from the aft end of the generator. The variable speed pulley allowed adjustments in driving speed to accommodate system plumbing characteristics and still achieve the desired flow rate.

The radiator and thermostat units were evaluated together using the facility coolant pump, tank, and heating system. With ambient conditions of 80°F, a single McCord condenser unit would provide a 35° to 40°F temperature drop when the inlet temperature was 125° to 130°F and the flow rate was 1.6 gpm. The thermostat proved accurate within ± 1°F.

To assure proper cooling under high engine power outputs, two McCord condensers were coupled in tandem and equipped with header tanks. The complete cooling system as installed on the breadboard has a capacity of four liters and it is set to operate at 57 psig. Final cooling subsystem performance in the breadboard system proved adequate. The coolant inlet temperatures were held within the 130° to 150°F range at system power levels up to 2 KW.

5. Propellant Pressurization Subsystem

The propellant pressurization subsystem selected for use in the breadboard system was the alternate isolation type unit previously discussed in Section IV-C. This system consists of the following components:

1. Bosch Type APE dual element diesel injection pump
2. Bosch Type GV mechanical governor
3. Bosch Type AKB 25R37 injection valve, 2 each
4. Marquardt diaphragm type isolated propellant pump, 2 each
5. Inert fluid tank with $GN_2$ pressurization system
6. Mechanical drive: Chain sprocket type, stepped down to operate the pump at one-third engine speed
7. Millipore XX45 04700 filters, 1.5 μ, 2 each

The concept of this system is to pressurize the propellant manifolds leading to the engine. Actual injection is controlled by the dual concentric, mono seat injector valves located in the engine cylinder head. Engine power output is varied by changing the propellant manifold pressures. This variation is achieved by changing the displacement of the Bosch pump via the governor control. The inert fluid pressurized by the Bosch pump in the form of

controlled hydraulic pulses actuates the diaphragm units. The diaphragm units physically pump the propellants.

The components of the pump subsystem were tested on the bench sufficiently to demonstrate their capability to perform the propellant pressurization function. The governor was then adjusted to control the propellant supply at pressures up to 1500 psi at a speed of 1350 rpm. Since the pump subsystem operates at 1/3 engine speed, this would be equivalent to a nominal speed of 4050 rpm.

The complete propellant subsystem was tested on the breadboard system with satisfactory results. The governor showed a sensitivity in the 1.3 to 1.5 KW output range by causing a 0.6 cps cycling condition. However, the speed is affected only by approximately 100 rpm. The present governor/Bosch pump setting is capable of supporting an output of 1.8 KW at a minimum speed of 3750 rpm. Adjustments can be made to these units to alter the above conditions. However, limitations of time and funds did not permit further development and testing.

6. Propellant Supply Subsystem

The propellant supply subsystem is a self-contained unit capable of supplying propellants to the basic breadboard system. The unit is in the form of a small cart that is easily transported. The cart contains two identical tankage systems (one for oxidizer and one for fuel) and the necessary nitrogen pressurization equipment to supply propellants to the breadboard system at 160 psig for a period in excess of 1 hour. A drawing of the unit and a schematic of its plumbing are shown in Figure 17.

The unit was designed and built in accordance with accepted ground facility safety standards and regulations. Therefore the propellant cart is not of flightweight configuration or construction. The unit was fabricated mainly as a convenience to allow operation of the breadboard in remote locations or at test facilities not equipped to supply the required propellants at the necessary conditions.

# VI. TEST PROGRAM

## A. General Test Plan

### 1. Introduction

The Phase III effort with the SPU-3 engine was oriented toward systems requirements, configuration, and operation. Testing was accomplished to demonstrate the functional operation of the system. Where appropriate, subsystem and component tests were required.

### 2. Test Items

The test items composing the system were as follows:

1. SPU-3 hypergolic reciprocating engine
2. Injection pump (Marquardt and Bosch)
3. Varo generator and power conditioning system
4. Vickers hydraulic starter motor
5. Greer hydraulic accumulator
6. Starter clutch and drive assembly
7. Governor system
8. Coolant pump and temperature control system
9. Self-contained lubrication system

These items were assembled on a special test stand in a sequential manner until the system was completed. Tests were performed between each sequence prior to the final system evaluation. In addition to the system components listed above, a Frederic Instrument Company Ro-Torq unit was a part of the test system. Unfortunately, this unit failed to operate properly and severely limited the detailed performance evaluation of the engine.

### 3. Test Objectives

The basic objective of the Phase III program was to continue the development and evaluation of the hypergolic propellant, reciprocating space power unit and its more important supporting subsystem leading toward a flight-type system. The breadboard system was assembled and developed sufficiently to obtain satisfactory operation. Testing was designed to demonstrate component and system functions. The specific test objectives were as follows:

1. Demonstrate the capability of the engine to drive a generator system

2. Determine the control requirements of the engine and generator system

3. Evaluate the generator and power conditioning subsystem

4. Evaluate the electrical power absorption device

5. Evaluate the hydraulic starter subsystem

6. Evaluate the engine propellant pump

7. Evaluate the effectiveness of the governor subsystem

8. Evaluate the performance of the coolant pump and temperature regulating subsystem

9. Evaluate the self-contained lubrication system

4. Test Method

a. Test Program Philosophy

Tests were performed with the SPU-3 engine and breadboard supporting subsystems to demonstrate the functional adequacy of the components and the interrelated effects of the subsystems.

The test program was divided into four basic sections as follows:

| Section | Description of Test |
|---|---|
| 1. | Prime mover checkout |
| 2. | Test of prime mover with generator, hydraulic starter, and coolant pump |
| 3. | Test of prime mover as in Item 2 plus engine driven lubrication system and radiator system |
| 4. | Test of prime mover as in Item 3 plus propellant system |

5. Test Facility

a. General Description

The test facility resulting from the Phase II effort was utilized for the Section I testing. Because there was an anticipated periodic requirement throughout the test program for Section 1 testing as well as for

component testing, a one work shift changeover capability was maintained between the Phase II engine installation and the breadboard mount system. A full description of the facility used during the Phase II program is presented in Reference 2.

b. Test Facility Requirements

The basic test facility requirements were augmentations to the Phase II test stand. However, as the breadboard system evolved, many of the facility functional requirements diminished or were discontinued as these systems were made part of the breadboard. The test facility requirements are listed below:

1. Propellant system - Initially standard Phase II
2. Cooling system - Phase II plus augmentation for generator cooling
3. Lubrication system - Phase II
4. Exhaust system - Phase II
5. Hydraulic system - 3,000 psi charging system with remote and manual control to permit accumulator charging and continuous starter operation
6. Electrical power absorption system - 28 to 30 volts d-c to a 3 KW water rheostat with remote positioning of its control rods

A schematic diagram of the setup for the initial breadboard testing is presented in Figure 18. This schematic shows the various breadboard, facility, and blockhouse interfaces and the supporting equipment used for testing in the facility.

The electrical power absorption system was the major addition to the test facility for this test phase. The system was simple and very effective. The basic concept was that of a water rheostat in which 4 aluminum rods were remotely positioned in a brine solution as a function of required power absorption. This unit is shown in Figure 19.

c. Instrumentation

The instrumentation requirements to document the system performances are listed in Table I. The instrumentation list is divided into visual and recorded sections. The recorded data utilized sampling technique as directed by the Development Engineer.

The locations of the various transducers and other items are indicated in the system schematic (Figure 18).

TABLE I

SUMMARY OF INSTRUMENTATION USED FOR TESTING THE BREADBOARD SPU-3 SPACE POWER SYSTEM

| Parameter | Symbol | Range | Display Method | |
|---|---|---|---|---|
| | | | Recorded | Visual |
| 1. Torque | T | 10 to 125 in.-lb | x | x |
| 2. Engine speed | rpm | 0 to 6000 rpm | x | x |
| 3. Generator output | W | 0 to 3 KW | -- | x |
| 4. Generator voltage, raw | $V_R$ | 0 to 15V a-c | -- | x |
| 5. Generator voltage, conditioned | $V_c$ | 0 to 30V d-c | x | x |
| 6. Generator amperage, conditioned | $A_c$ | 0 to 150 amps | x | x |
| 7. Facility $GN_2$ pressure | $P_{N_2}$ | 0 to 1000 psi | -- | x |
| 8. Oxidizer manifold pressure | P | 0 to 250 psi | -- | x |
| 9. Fuel injection pressure | $P_{f_i}$ | 0 to 4000 psi | x | x |
| 10. Oxidizer injection pressure | $P_{o_i}$ | 0 to 4000 psi | x | x |
| 11. Exhaust manifold pressure | $P_{ex}$ | 0 to 1 atmos | -- | x |
| 12. Oil manifold pressure | $P_{oil_M}$ | 0 to 100 psi | -- | x |
| 13. Oil inlet pressure | $P_{oil_{in}}$ | 0 to 5 psi | -- | x |
| 14. Hydraulic oil pressure | $P_{O_H}$ | 0 to 3000 psi | -- | x |
| 15. Oil tank level | $L_{o_t}$ | E to F | -- | x |
| 16. Coolant pressure | $P_{cool}$ | 0 to 100 psi | -- | x |
| 17. Fuel flow rate | $\dot{W}_f$ | 0 to 20 gph | x | -- |
| 18. Oxidizer flow rate | $\dot{W}_o$ | 0 to 20 gph | x | -- |
| 19. Coolant flow rate | $W_{cool}$ | 0.5 to 5.0 gpm | -- | x |
| 20. Exhaust temperature (dual) | $T_{ex}$ | 0 to 2000°F | -- | x |
| 21. Oil inlet temperature | $T_{oil_{in}}$ | 0 to 250°F | -- | x |
| 22. Oil outlet temperature | $T_{oil_{out}}$ | 0 to 250°F | -- | x |
| 23. Coolant inlet temperature | $T_{c_{in}}$ | 0 to 250°F | x | x |
| 24. Coolant outlet temperature | $T_{c_{out}}$ | 0 to 250°F | x | x |
| 25. Oxidizer line temperature | $T_{o_T}$ | 0 to 200°F | -- | x |
| 26. Fuel line temperature | $T_{f_T}$ | 0 to 200°F | -- | x |
| 27. Generator coolant temperature, in | $T_{g_{in}}$ | 0 to 250°F | -- | x |
| 28. Generator coolant temperature, out | $T_{g_{out}}$ | 0 to 250°F | -- | x |
| 29. Generator coolant flow rate | $\dot{W}_g$ | 0 to 10 gph | -- | x |
| 30. Fuel manifold pressure | $P_{f_M}$ | 0 to 250 psi | -- | x |

B. System Test Results

During the Phase III test program, a total of 8.03 hours of operation of the engine was accumulated at the Marquardt Research Field Laboratory (RFL) at Saugus, California. In addition to this, a total of 42 hours of testing was accumulated at the NASA Manned Spacecraft Center at Houston, Texas. The results of the MSC, Houston testing will be covered by an internal NASA report. The total engine operating time accumulated during the three test phases (Phases I, II, and III) was 427.43 hours. The results of the Phase III testing are summarized in Table II.

The initial test of a partial breadboard system was made on 20 June 1966. The components installed for these tests were as follows:

1. SPU-3 "B" engine
2. Varo generator and power conditioning system
3. Coolant pump
4. Hydraulic starter subsystem
5. Rotorq torque sensing unit

A series of short system runs was made and adjustments were performed to achieve the desired performance characteristics of the various system and facility components. The Rotorq torque sensor did not operate properly during these tests. This instrumentation failure restricted accurate engine performance evaluation because it necessitated using vendor quoted generator efficiencies to calculate engine parameter values. However, this failure did not affect performance calculations in terms of kilowatt-hours output versus specific propellant consumption.

A full span power traverse test was made on 29 June 1966 to evaluate the performance of the system up to 2 KW and to establish the hysteresis characteristics and injection pressure requirements. The results of this test are presented in Figures 20 and 21 which show specific propellant consumption and injection pressures, respectively, versus KW output. A specific propellant consumption of 10.1 was demonstrated at a 2 KW output. The maximum power required from the SPU-3 engine during this test was calculated to be 3.48 HP at a BMEP of 167 psi. The injection pressure requirements were used for propellant pump calibration targets. However, these data were increased 200 psi at the maximum power point to accommodate estimated power losses resulting from driving the propellant and lubrication pump subsystems.

For the next series of tests, the coolant and lubrication subsystems were included. These tests disclosed the desirability of changing the thermostat setting from 150°F to 130°F because the time to achieve engine thermal

TABLE II

SUMMARY OF PHASE III TESTS OF THE SPU-3 SPACE POWER SYSTEM

| Run No. | Date (1966) | Duration (hr) | Nominal Run Conditions | | | Engine Configuration | Remarks |
|---|---|---|---|---|---|---|---|
| | | | Power | rpm | BMEP (psi) | | |
| 5169-1 | 29 March | 1.05 | 3.25 HP | 3250 | 198 | Basic SPU-3 w/Mod. No. 1 piston; 440-C rings; 0-5 F-5 valves; 20.8:1 C.R.; timed 1°BTC, 8° dwell | Green run and checkout of engine for NASA Houston testing. SPU-3 "A" engine |
| NASA, Houston | 11 to 29 April | 42 (Approx. total) | Various | Various | Various | Basic SPU-3 | NASA Houston testing of both "A" and "B" Engines |
| 5169-2 | 8 June | 1.68 | 5.34 HP | 4210 | 251 | Basic SPU-3 w/CRES head spacer plate & low expansion ratio, i.e., 12; 1; timed 1° BTC; 8° dwell | Full operating envelope. Test HP to 5+, ambient exhaust, high temp. coolant. SPU-3 "B" engine. Demonstrated SPC as low as 5.3 lb/HP-hr |
| 5169-3 | 20 June | 0.06 | -- | -- | -- | Basic SPU-3 w/alum. spacer plate. Low expansion ratio, i.e., 10:1; timed 1° BTC; 8° dwell | Initial breadboard system run w/hydraulic starter, coolant pump, & generator. SPU-3 "B" engine. Shut down to adjust coolant flow rate. |
| 5169-4 | 20 June | 0.52 | 2.04 KW | 4000 | -- | Same as 5169-3 | SPU-3 "B" engine. 1st Test w/generator operating. Load control critical. Otherwise excellent test. |

TABLE II (Continued)

| Run No. | Date (1966) | Duration (hr) | Nominal Run Conditions | | | Engine Configuration | Remarks |
|---|---|---|---|---|---|---|---|
| | | | Power | rpm | BMEP (psi) | | |
| 5169-5 | 21 June | 0.09 | -- | -- | -- | Same as 5169-3 | Low coolant flow, reset pump drive ratio |
| 5169-6 | 21 June | 0.09 | -- | -- | -- | Same as 5169-3 | Fuel injector valve chrome failed and valve stuck open |
| 5169-7 | 25 June | 0.44 | 0.6 KW | 4150 | 46 | Same as 5169-3 except new fuel valve No. F-7; timed 1° BTC; 8° dwell | SPU-3 "B" engine. System checkout run |
| 5169-8 | 27 June | 0.25 | 0.8 KW | 4040 | 62 | Same as 5169-7 | NASA Demonstration Run |
| 5169-9 | 27 June | 0.47 | 1.69 KW | 4070 | 132 | Same as 5169-7 | Initial test w/self-contained radiator system. Thermostat setting too high |
| 5169-10 | 27 June | 0.46 | 2.08 KW | 4120 | 160 | Same as 5169-7 | Injection pressure vs. KW output traverse evaluation |
| 5169-11 | 29 June | 0.43 | 2.16 KW | 4110 | 167 | Same as 5169-7 | Injection pressure vs. KW output traverse and hysteresis evaluation |
| 5169-12 | 6 July | 0.68 | 0.96 KW | 3900 | 79 | Same as 5169-7 except fitted w/cast iron cylinder liner & chromed 440-C rings; "B" engine | Cast iron/chrome piston ring evaluation. Run terminated - oxidizer valve malfunctioned |

TABLE II (Continued)

| Run No. | Date (1966) | Duration (hr) | Nominal Run Conditions Power | rpm | BMEP (psi) | Engine Configuration | Remarks |
|---|---|---|---|---|---|---|---|
| 5169-13 | 8 July | 0.92 | 1.65 KW | 3950 | 133 | Basic SPU-3 B engine w/440-C chromed rings & new oxidizer valve No. 0-7 | Chromed cylinder liner/chrome ring evaluation. Run terminated-oxidizer valve chrome plating failed. |
| 5169-14 | 13 July | 0.01 | -- | -- | -- | Same as 5169-13 w/Mod. 0-7 oxidizer valve | Full system test less propellant pump. Oil scavange pump leaked |
| 5169-15 | 13 July | 0.08 | -- | -- | -- | Same as 5169-14 | Shut down, oil manifold pressure too high. Readjusted |
| 5169-16 | 13 July | 0.01 | -- | -- | -- | Same as 5169-14 | Accumulator start, low oil manifold pressure. Reset |
| 5169-17 | 13 July | 0.03 | -- | -- | -- | Same as 5169-14 | Accumulator start, low oil manifold pressure. Reset |
| 5169-18 | 13 July | 0.32 | 1.07 KW | 3900 | 88 | Same as 5169-14 | Accumulator start, system checkout-ok |
| 5169-19 | 13 July | 0.19 | 1.07 KW | 3950 | 87 | Same as 5169-14 | Accumulator start, system checkout with ambient exhaust-pressure - ok |

TABLE II (Continued)

| Run No. | Date (1966) | Duration (hr) | Nominal Run Conditions | | | Engine Configuration | Remarks |
|---|---|---|---|---|---|---|---|
| | | | Power | rpm | BMEP (psi) | | |
| 5169-20 | 15 July | 0.12 | -- | -- | -- | Same as 5169-14 | Full system (w/propellant pump) check-out |
| 5169-21 | 15 July | 0.13 | 1.47 KW | 3950 | -- | Same as 5169-14 | Full system demonstration run for NASA acceptance |

stabilization was shorter than the anticipated time. Although the initial thermal rise rate does not change with the different thermostat setting, the procedure of bringing the radiator into the cooling loop sooner lengthens the time required to achieve complete thermal stability of the entire system. This procedure was deemed desirable to preclude thermal shocking of any critical component and to avoid severe thermal gradients in close fitting assemblies, such as the injector valves.

Several short test runs were required to obtain correct lubrication system pressure settings. Once all the desired settings had been achieved in all subsystems, the various hand valves used to obtain proper regulation were removed and replaced with equivalent flow orifices. The final pre-propellant subsystem installation test verified proper operation of all other subsystems. This final test was conducted at ambient exhaust pressure conditions and the starter subsystem accumulator was utilized as the sole starting power source. Starting was immediate and the performance of the entire system was satisfactory.

The alternate propellant pump system was installed in the breadboard system on 14 July 1966, thus completing the entire system. Figures 22 and 23 are photographs of the installation of the complete SPU-3 breadboard system in the test facility. This system was tested on 15 July 1966, and these tests were witnessed by a representative of the NASA Western Operations Office. Two system demonstration runs were successfully accomplished. Power levels as high as 1.79 KW were achieved. The governor maintained speed at 3950 $\pm$ 200 rpm. However, a slow 0.6 cps hunting condition was noted at power levels between 1.25 and 1.45 KW. Reduction of the data showed the specific propellant consumption at 1.79 KW to be 10.5 lbs/KW-hr.

# VII. BREADBOARD SYSTEM OPERATION PROCEDURES

## A. Prerun Preparation

### 1. Propellant Supply System

The propellant supply system supplied with the Space Power Unit Breadboard system is a self-contained unit that provides both $N_2O_4$ oxidizer and Aerozene 50 fuel tankage and the necessary $GN_2$ pressurization equipment. The unit as shipped is propellant cleaned and ready for filling. A drawing showing the location of all valves, etc. and a system schematic is shown in Figure 18.

The prerun preparation requirements are separated into the two basic procedures of filling the cart tanks and then using the filled cart to operate the breadboard system. Detailed procedures for accomplishing both procedures are presented.

a. Pretransfer Procedure

1. Bring in the fuel transfer cart and hook up the ground cables between transfer cart and propellant system.

2. Secure and isolate the area with safety ropes.

3. Set up a 3-man crew with adequate safety equipment.

4. Check the water supply and charge the water hose.

5. Set up and check the $GN_2$ purge gas supply lines.

b. Fuel Transfer Procedure

1. Verify that all valves are closed.

2. Set up the fuel transfer cart, vertical stacks, and transfer hose.

3. Start low $GN_2$ purge through the transfer hose from the cart and connect the transfer hose to the fuel fill connection on the Marquardt propellant cart.

4. Secure the $GN_2$ purge and open Valve V-7 (gage valve) and open Valve V-11 (vent valve).*

5. Open the customer furnished transfer rig fuel fill (transfer) valve.

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* Refer to Figure 17 for valve numbers.

6. Open Valve V-1 (tank shutoff) and fill the fuel tank. Visually leave 3 inch ullage on the sight glass.

7. Close the customer furnished transfer rig fuel fill (transfer) valve.

8. Close Valve V-1 (tank shutoff).

9. Secure the customer fuel transfer rig.

10. Set R-3 $GN_2$ regulator to 15 psi.

11. Open the customer fuel transfer rig atmosphere vent and fill valves.

12. Open Valve V-3 ($GN_2$ purge) and purge out the transfer hose.

13. Close Valve V-3 ($GN_2$ purge).

14. Close the customer fuel transfer rig vent and fill valves.

15. Disconnect the transfer hose from the Marquardt propellant cart.

16. Replace all caps and plugs.

17. Close Valve V-11 (vent valve).

18. Set R-3 regulator to 50 psi.

19. Open Valve V-9 ($GN_2$ supply).

20. Set R-1 to 25 psi standby pressure. Observe loading pressure gage (31) and tank pressure gage (33).

21. Close Valve V-9 ($GN_2$ shutoff).

22. Reset R-1 and R-3 to zero.

c. <u>Oxidizer Transfer Procedure</u>

1. Verify that all valves are closed.

2. Set the up fuel transfer cart, vent stacks, and transfer hose

3. Start the low $GN_2$ purge through the transfer hose from the cart and connect the transfer hose to the oxidizer fill connection on the Marquardt propellant cart.

4. Secure the $GN_2$ purge and open Valve V-8 (gage valve) and open Valve V-12 (vent valve).

5. Open the customer furnished transfer rig oxidizer fill (transfer) valve.

6. Open Valve V-2 (tank shutoff) and fill the oxidizer tank. Visually leave 3 inch ullage on the sight glass.

7. Close the customer furnished transfer rig oxidizer fill (transfer) valve.

8. Close Valve V-2 (tank shutoff).

9. Secure the customer oxidizer transfer rig.

10. Set R-4 $GN_2$ regulator to 15 psi.

11. Open the customer oxidizer transfer rig atmosphere vent and fill valves.

12. Open Valve V-4 ($GN_2$ purge) and purge out the transfer hose.

13. Close Valve V-4 ($GN_2$ purge).

14. Close the customer oxidizer transfer rig vent and fill valves.

15. Disconnect the transfer hose from the Marquardt propellant cart.

16. Replace all caps and plugs.

17. Close Valve V-2 (vent valve).

18. Set R-4 regulator to 50 psi.

19. Open Valve V-10 ($GN_2$ supply).

20. Set R-2 to 25 psi standby pressure. Observe loading pressure gage 32 and tank pressure gage 34.

21. Close Valve V-10 ($GN_2$ shutoff).

22. Reset R-2 and R-4 to zero.

d. Run Procedure (Fuel)

1. Verify that Valves V-3 and V-1 are closed.

2. Connect the 10 foot fuel line from the propellant cart to the test item.

3. Set the engine at BDC or verify.

4. Open the $GN_2$ supply and set R-3 at 175 psi.

5. Open Valve V-7.

6. Open Valve V-3 and purge $GN_2$ through the engine fuel dump valve.

7. Close the engine dump valve.*.

8. Close Valve V-3.

9. Open Valve V-9 and set R-1 to 50 psi.

10. Open Valve V-1.

11. Open the engine fuel dump valve and charge the fuel line until no bubbles are visible in the liquid.

12. Close the engine fuel dump valve.

13. Set R-1 to 160 psig.

e. Run Procedure (Oxidizer)

1. Verify that Valves V-4 and V-2 are closed.

2. Connect the 10 foot oxidizer line from the propellant cart to the test item.

3. Set the engine at BDC (Bottom Dead Center) or verify.

4. Open the $GN_2$ supply and set R-4 at 175 psi.

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* Do not proceed further until the Breadboard System Prerun Procedures are completed.

5. Open Valve V-8.

6. Open Valve V-4 and purge $GN_2$ through the engine oxidizer dump valve.

7. Close the engine dump valve.*

8. Close Valve V-4.

9. Open Valve V-10 and set R-1 to 50 psi.

10. Open Valve V-2.

11. Open the engine fuel dump valve and charge the oxidizer line until no bubbles are visible in the liquid.

12. Close the engine oxidizer dump valve.

13. Set R-2 to 160 psig.

2. Breadboard System

Prior to initiating the prerun procedures, four line extensions were fabricated and installed on the Breadboard System. These lines were not included for simplicity in packaging and shipping the unit. The four lines were fabricated from 1/4 inch CRES and then were propellant cleaned prior to use. The four lines were:

1. Oxidizer overboard drain line extension

2. Fuel overboard drain line extension

3. Oxidizer dump line extension

4. Fuel dump line extension

The two overboard drain line extensions are attached on either side of the base near the forward mount flanges. The lines need only be long enough to clear the wooden base plate approximately 6 inches. These lines must be open to the atmosphere during engine operation. The dump line extensions attach to the forward bulkhead at the fittings provided. It is suggested that these extensions be a minimum of 6 feet in length and that the ends deployed as far apart as possible. These lines must also be open to the atmosphere during engine operation.

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*Do not proceed further until the Breadboard System Prerun Procedures are completed.

a. Prerun Procedures

1. Fill the oil tank to 1 1/4 gallons with Brayco No. 443 lubricating oil (MIL-L-21260, Grade 2).

2. Fill the cooling system with distilled water or a 50-50 mixture of distilled water and Prestone (system capacity = 4 liters).

3. Check the level of the isolation pump fluid tank; if low, fill with a 7/1 mixture of distilled water and DuPont soluble oil, respectively.

4. Check the Bosch pump lubricating oil level. A dip stick is provided at the top of the pump for this purpose. If low, add Brayco No. 443 oil. If high and/or contaminated, drain, and refill to proper level.

5. Check the Bosch governor oil level. A drain cock is provided on the side of the unit for this purpose. Add Brayco No. 443 oil through the breather cap on the top of the unit until a flow is noted from the open drain cock.

6. Pressurize the propellant pump fluid tank to 25 to 35 psig. Connect the line provided between the tank fitting and the propellant cart $GN_2$ fitting. Set the pressure with Valve R-8. Check the $GN_2$ setting of the low oil pressure regulator. The gage should read 4.5 psi $\pm$ 0.5 psi. Reset if required.

7. Fill and bleed the inert fluid side of each diaphragm pump at the Bosch pressure relief valves (downstream from the diaphragm pumps) and allow sufficient flow to insure complete filling of each system. Note: It may be necessary to rotate the engine slightly to properly position the Bosch pump plungers to allow unrestricted flow through the lines. No trapped air can be tolerated in this system. Reset the engine to BDC.

8. Open the bulkhead-mounted hand valve between the starter accumulator and the starter 1/4 turn and secure it with safety wire in this position.

9. Check the accumulator $GN_2$ charge. A pressure of 2000 to 2200 psig is required.

10. Extend the starter control cable to the position desired and pump up the accumulator with the hand pump provided until 3000 psi is registered on the gage. The "start" hand valve must be in the off-position.

11. Remove the cap from the crankcase breather filter line.

12. Attach the electrical load lines to the top of the power conditioning system at the aft end of the breadboard. Red is plus.

13. Resume the propellant supply procedures at Item 7 of the fuel and oxidizer run procedures.

B. Operating Procedures

The operating procedures for the breadboard system are quite simple and direct.

1. Starting Procedure

1. Remove the plugs from the exhaust pipes.

2. Cock the governor control arm and retain it with the spring loaded plunger; extend the attached cable to the desired position.

3. Clear the downwind area of personnel.

4. Pull the starter cable.

If the prerun procedures have been properly carried out, especially the propellant line filling and isolation pump inert fluid bleeding segments, the engine will start immediately and stabilize automatically at 4000 rpm.

2. Running Procedure

The system is completely automatic during operation and will adjust itself to any imposed electrical load up to 1.8 KW. Power levels above 1.8 KW can be achieved. However, the present governor settings can not maintain the nominal 4000 $\pm$ 200 rpm conditions. It is suggested that

prolonged operation in the power range from 1.3 KW to 1.5 KW be avoided because the governor control is slightly unstable in this power band. The method of applying the load to the system is customer provided. Any incrementally adjustable 29 volt d-c system is satisfactory.

3. Stopping Procedure

1. Reduce the electrical load to zero.

2. Pull the governor control cable and observe that the control arm is released. (The engine should slow down to approximately 2500 rpm.)

3. Close the propellant cart main shutoff Valves V-1 and V-2.

4. Open $GN_2$ purge Valves V-3 and V-4. (The engine will continue running until the residual propellants are expended.)

5. After engine operation ends, open the propellant dump valves individually in short bursts and insure that all propellants are vented from the supply lines. Close the dump valves.

6. Rotate the engine to BDC (bottom dead center) per flywheel marking.

7. Reinstall the exhaust pipe plugs.

8. Reduce the $GN_2$ purge pressure to 10 psig.

9. Close the hydraulic starter line cable operated valve.

10. Turn off the $GN_2$ supply to the inert fluid tank.

C. Storage Requirements

1. Short Term Breadboard System Storage

If it is anticipated that the breadboard system will again be operated within a 48 to 60-hour period, the following requirements should be observed in addition to normal good housekeeping cleaning of the unit.

1. Maintain a 10 psig $GN_2$ head pressure on the propellant system.

2. Close the bulkhead mounted hand valve in the starter line between the accumulator and the starter motor.

3. Remove the crankcase breather line and the fitting cap opposite this line on the crankcase. Fill the crankcase with Brayco No. 443 oil until it runs out the breather line fitting. Note: The line between the starter accumulator and hand pump can be disconnected and a tube connected between the hand pump and the crankcase fitting to accomplish this requirement, if desired. The oil added to the crankcase must be drained prior to restarting. A tube fitting on the oil scavenge manifold opposite the oil pumps is provided for this purpose.

4. Replace the crankcase breather line and cap end.

5. Cap all propellant overboard vents.

6. Cover the entire system with a suitable plastic tarp. (Do not seal.)

2. Long Term Breadboard System Storage

If immediate reuse is not anticipated or if shipment to another facility is to be accomplished, the following procedures are recommended:

1. Insure that the engine is at BDC and safety wire or tape the flywheel in this position.

2. Turn off the $GN_2$ purge pressures by closing Valves V-3 and V-4 and disconnect the propellant supply system from the breadboard system.

3. Flush and fill the breadboard propellant systems with high quality Freon solvent.

4. Drain the oil tank (Open the fitting at the system low point).

5. Drain the cooling system (Open the fitting at system low point).

6. Secure the accumulator hand pump handle.

7. Secure the starter and governor cables.

8. Secure the exhaust pipe plugs.

9. Replace the shipping case cover and secure.

3. Propellant System Storage

Because the propellant system is required for short term storage of the breadboard unit to supply $GN_2$, no other precautions need be taken. However, if long term storage or shipment is anticipated, the unit should be unloaded. A reverse filling procedure can be used. If shipment is required, the tanks must be flushed and partially filled with Freon solvent.

# VIII. LEM INSTALLATION STUDY

## A. General Considerations

In order to orient development efforts of the Space Power Unit toward the Lunar Module (LM) application, initial contacts were made with NASA and the Grumman Aircraft Engineering Corporation to discuss this installation of the Space Power Unit.

Discussions at Grumman were reassuring in that no major problems exist or are anticipated in installing this powerplant. The structural configuration of the LM provides a number of candidate locations. It appears unwarranted and inadvisable to make a firm selection of a location at this time due to the possible shifting of the LM first flight. A structural drawing was obtained which shows that support of the powerplant can be established at these candidate locations. Preliminary installation drawings are included herein as Figures 24, 25, and 26. Locations under consideration are discussed below.

## B. Scientific Equipment Bay Installation

Structural floor members existing in this bay afford a choice of floor or wall mounting (See Figure 24). The Aerozine 50 and $N_2O_4$ tanks are located on either side of this bay and the propellant lines are accessible. The panel enclosing the bay could supply the required radiator surface. It will be necessary to rotate the panel radiator to seek a north-south orientation. Since there is no obstruction through an arc of 170°, this orientation can easily be achieved. The engine is accessible but it does not require monitoring (See operation below). Heat shielding of the exhaust lines may be accomplished by selective positioning or by insulation or shields.

## C. External Installation at the Landing Gear Struts

The landing gear struts of the locations shown in Figures 25 and 26 are fixed and provide an accessible external envelope both at the launch and landing configuration for the Space Power System and/or radiator. Service lines can be plumbed to the bulkhead of these panels for system operation either on the vehicle or for lunar surface operation. Installation at any of the four landing gear strut locations provides, by utilizing the struts, good structural strength and minimum interference with initial flight components. Accessibility is excellent and operation on the lunar surface could be accomplished with less expenditure of effort than with the scientific bay installation. The radiator could be the same as the scientific bay panel or it could be erectable on the lunar surface or a foldout radiator attached to the struts.

## D. Engine Operation

The engine system is designed to provide the following features:

1. Astronaut safety
2. Reliability
3. Starting without LM electrical power availability
4. No monitoring requirements
5. SPC of 5.8 lbs/KW-hr or less at the design point

The operating sequence requires the following Astronaut action:

1. Orientation of the radiator facing north-south
2. Opening of the oxidizer and fuel valves to tank pressure
3. Opening of the exhaust valve to vacuum ambient pressure
4. Release of the accumulator pressure to the hydraulic starting motor

Ignition will occur and the engine will come up to operating speed where it will accept loading or it can be placed on the LM line. The governor will maintain control to accept loads without adjustment. Stopping will be accomplished by placing governor control on stop position and, after coasting to a stop, the exhaust system will automatically seal against the lunar zero pressure. The engine is then in the "ready to start" condition.

## IX. CONCLUSIONS

During the time period covered by this report, a complete breadboard space power system was designed, fabricated, and successfully tested. Testing was organized to demonstrate component and system functions. Experience gained in testing system components in previous phases of the program was utilized in the selection or design of supporting hardware for the breadboard system. The completely self-contained system delivered to the NASA Manned Spacecraft Center at Houston, Texas is capable of generating a nominal electrical power output of 2.0 KW at a specific propellant consumption of 10.5 lbs/KW-hr or less.

In addition to testing of the system, several component evaluations were made. These tests proved the following:

1. Cast iron material is not suitable for use in the combustion sections of the SPU engine.

2. Quality control surveillance of outside vendor chrome plating techniques must be improved.

3. The expansion ratio of 10:1 provides a gain in performance over higher ratios.

4. Three methods of propellant pressurization are available, namely, the initial pump system, the modified initial pump system, and the alternate pump system using isolation diaphragm units with a Bosch injection pump. However, only the latter system appears feasible for final development.

The Phase III activities functionally demonstrated the hypergolic propellant reciprocating SPU system sufficiently for evaluation for the LM application of extending the lunar staytime. A final design and development effort would produce a system meeting the desired parameters of performance, weight, size, and reliability and which would be suitable for installation at several candidate locations on the LM vehicle.

## X. RECOMMENDATIONS

With the accumulation of over 427 hours of engine operation of which one run was 90 continuous hours, and with the successful operation and delivery of a breadboard system, the feasibility of this prime mover and all system components has been demonstrated. With the degree of success encountered in the last phase of the subject program no major problem areas or technology advances are required to develop and qualify the Hypergolic Reciprocator Space Power System. A basis has been established to enter final development to qualify this system.

Accordingly the following recommendations are made:

1. The engine contractor and the government should establish a program plan with the ultimate goal of delivering a qualified Space Power System that will contribute significantly to the exploration of the lunar surface.

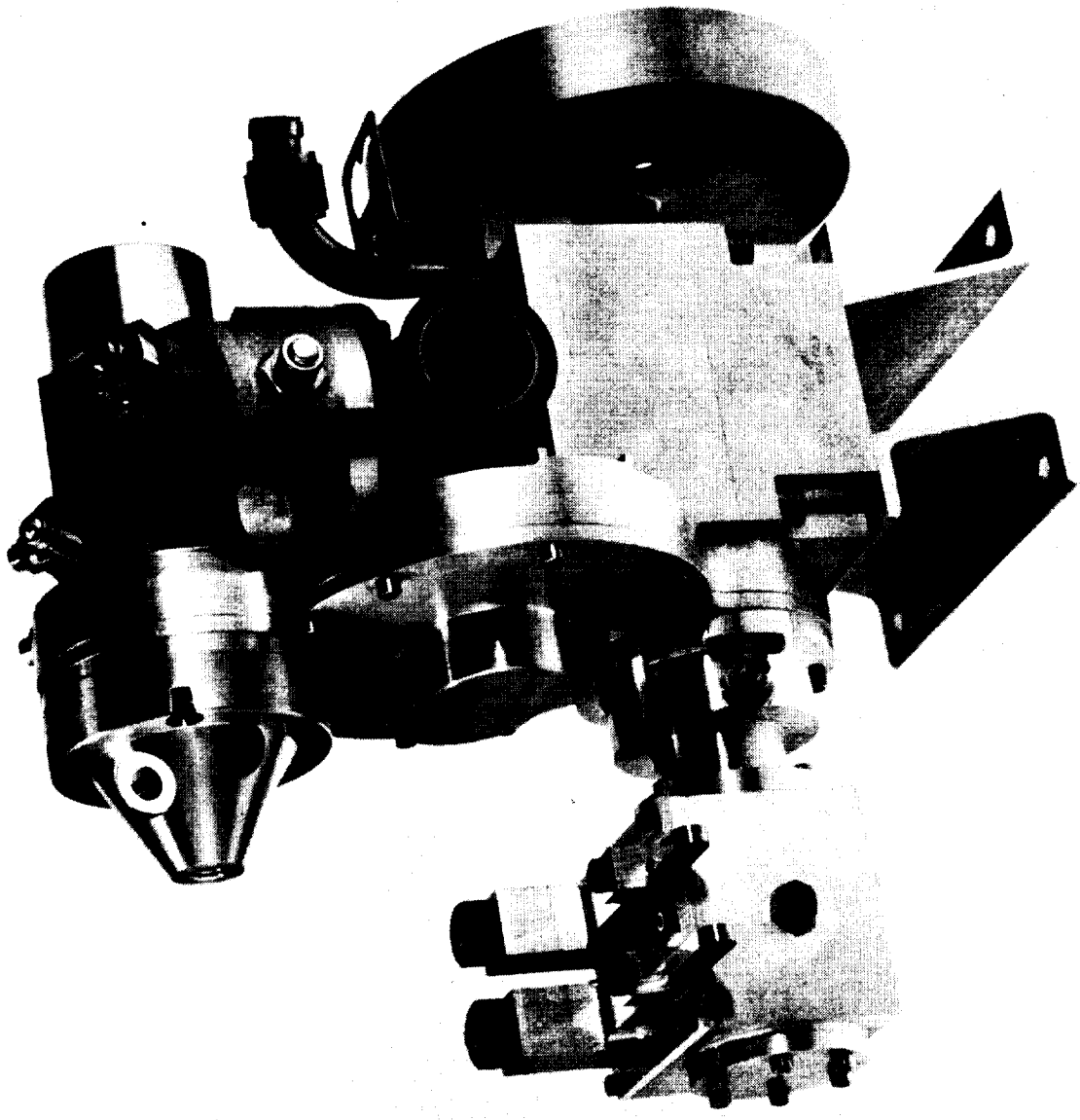
2. Long lead time items should be identified and their procurement should be initiated without delay.

3. The development program should be implemented in a timely manner for incorporation into the LM program.

## XI. REFERENCES

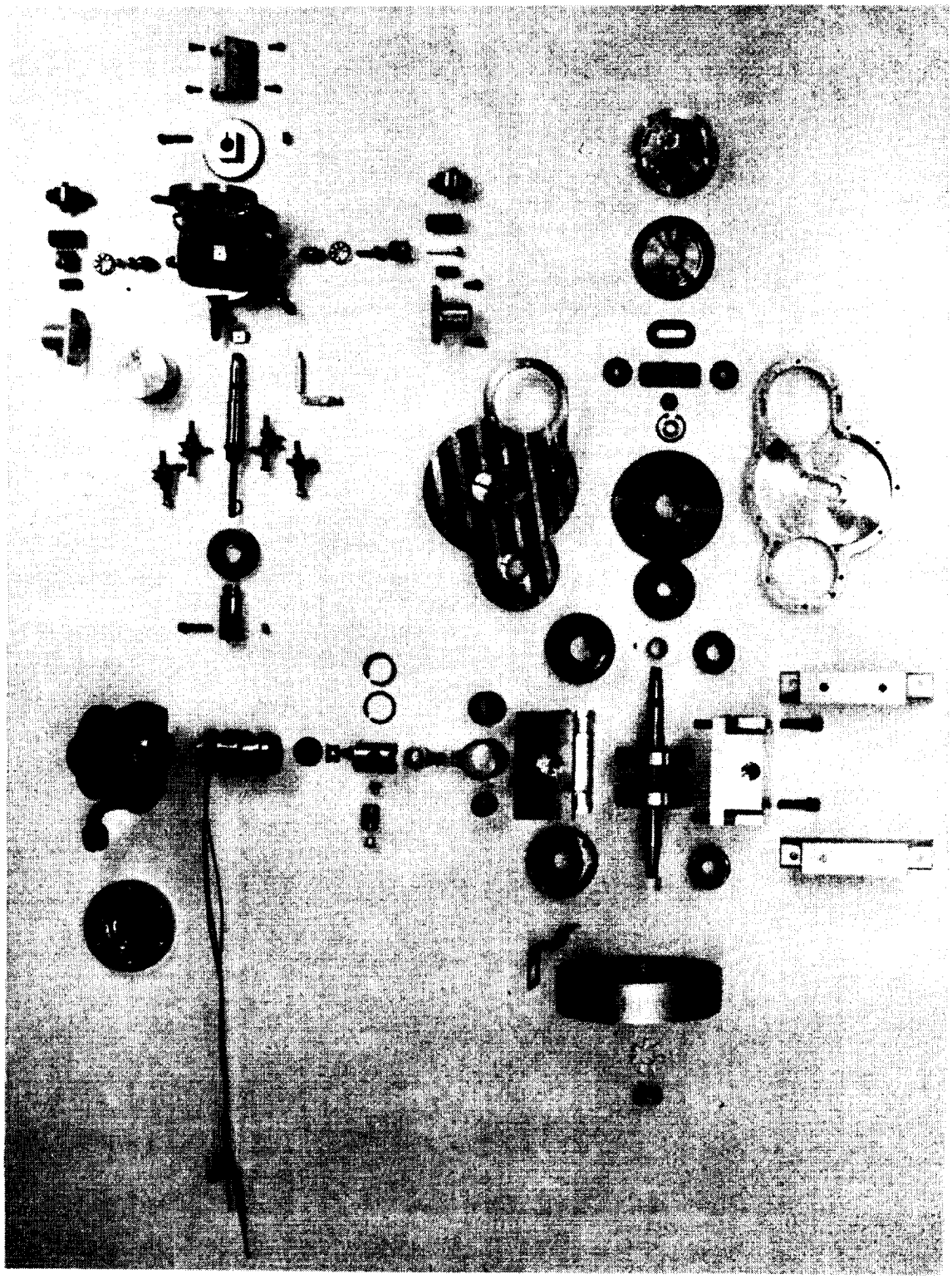
1. Marquardt Report 6076, "(Unclassified Title) Feasibility Study for Development of a Hypergolic Engine Space Power System. Phase I: Final Report", 25 September 1964. UNCLASSIFIED.

2. Marquardt Report 6098, "(Unclassified Title) Design Study and Evaluation of a Hypergolic Engine for a Space Power System. Final Report for Phase II and Phase II Modification I for the Period 1 July 1964 to 10 February 1966", 28 February 1966. UNCLASSIFIED.



5140-24

FIGURE 1. External Configuration of the Marquardt SPU-3 Hypergolic Reciprocating Engine



T5140-15

FIGURE 2. Disassembled View of the SPU-3 Hypergolic Reciprocating Engine

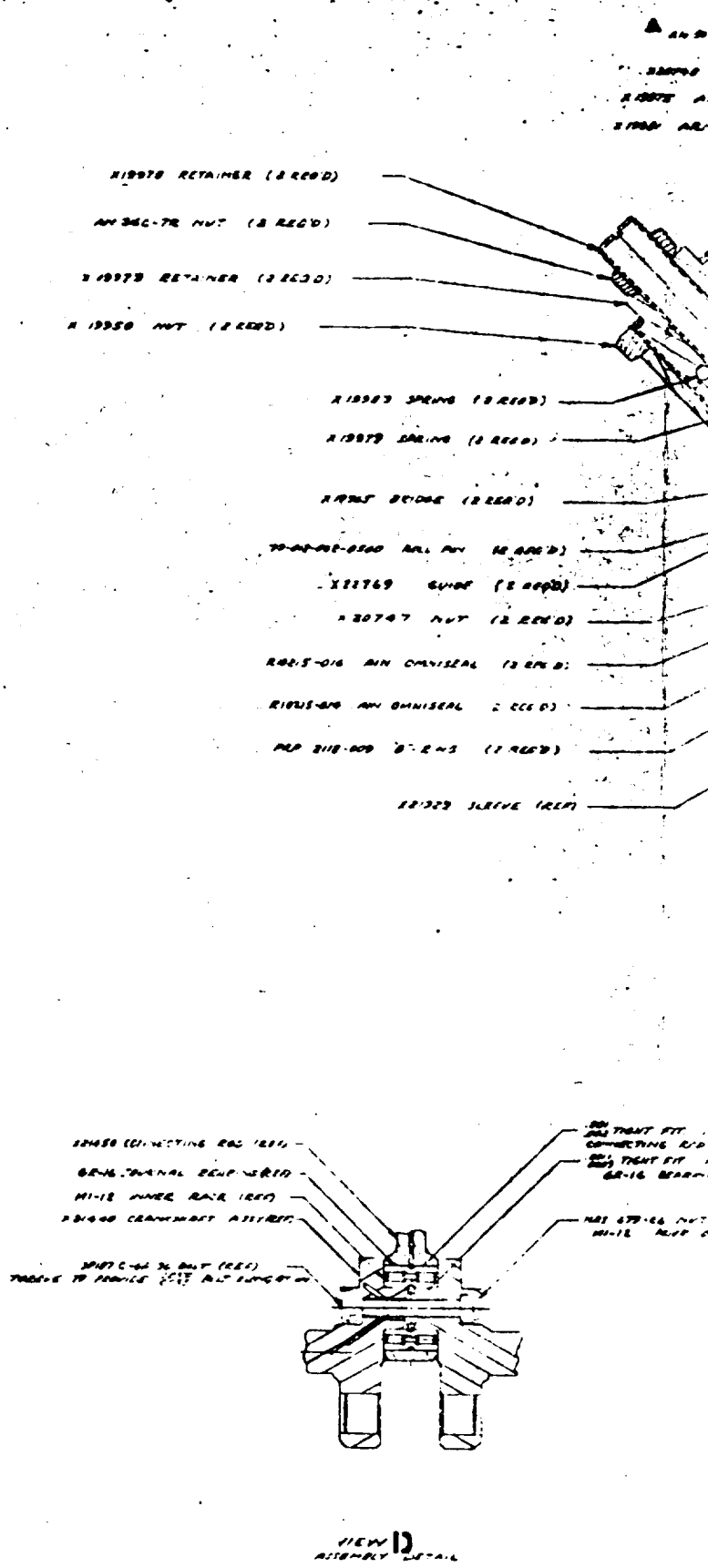
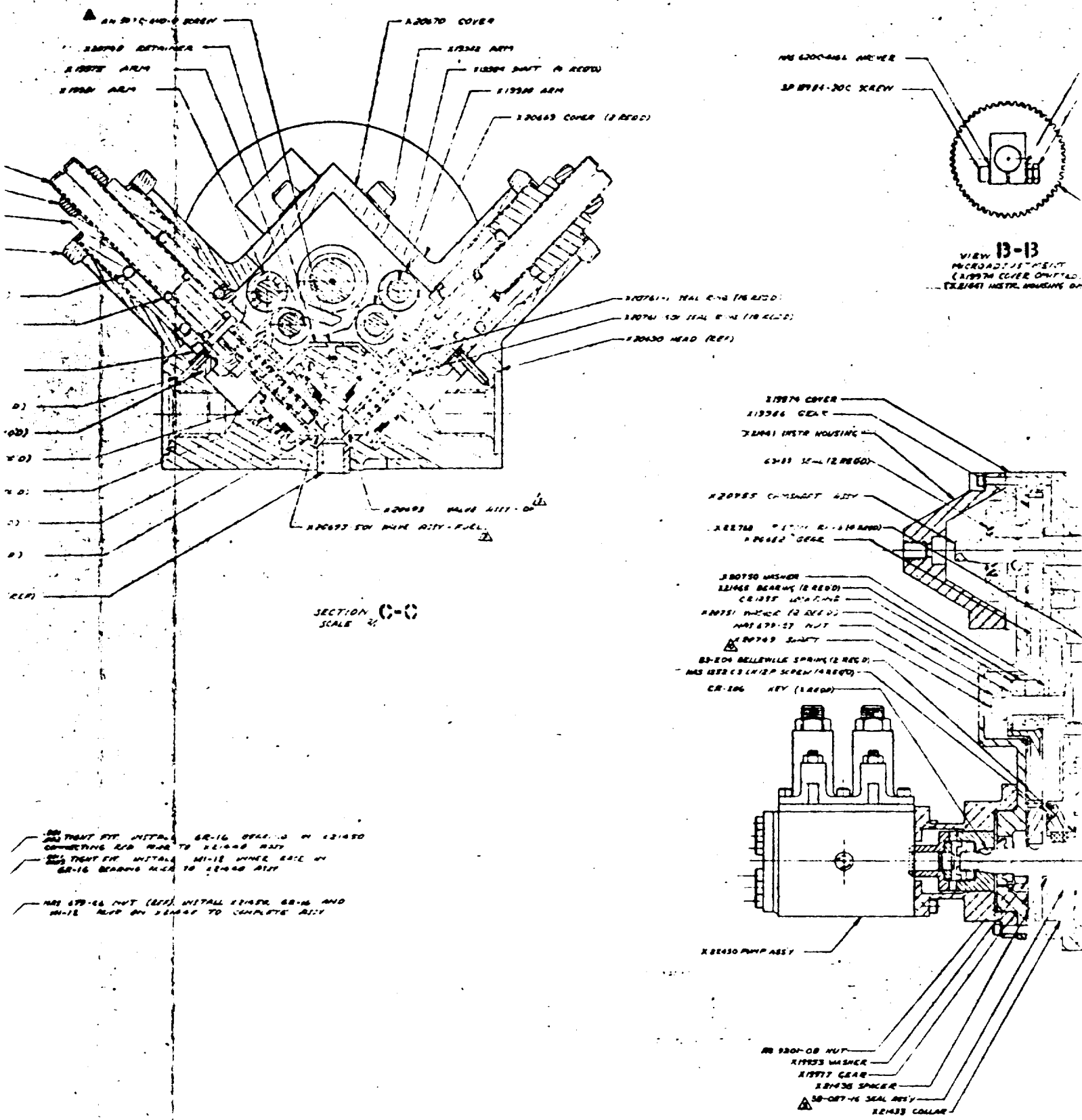

X19978 RETAINER (2 REQ'D)
AN 36C-7R NUT (2 REQ'D)
X19973 RETAINER (2 REQ'D)
X19950 NUT (2 REQ'D)
X19983 SPRING (2 REQ'D)
X19979 SPRING (2 REQ'D)
X19965 BRIDGE (2 REQ'D)
X22769 GUIDE (2 REQ'D)
X20747 NUT (2 REQ'D)
R10215-016 AIN OMNISEAL (2 REQ'D)
R10215-014 AIN OMNISEAL (2 REQ'D)
PRP 2118-009 "O"-RING (2 REQ'D)
X21329 SLEEVE (REF)
X21450 CONNECTING ROD (REF)
GR-16 JOURNAL BEARINGS (REF)
MI-12 INNER RACE (REF)
X21440 CRANKSHAFT ASSY (REF)
TIGHT FIT
CONNECTING ROD
TIGHT FIT
GR-16 BEARING
MI-12 RACE
VIEW D
ASSEMBLY DETAIL



FIG 3 - 1



X20670 COVER
X20669 COVER (2 REQ'D)
X20630 HEAD (REF)
X20693 VALVE ASSY - OP
X20693-501 VALVE ASSY - FUEL
SECTION C-C
SCALE
VIEW B-B
X19974 COVER
X19966 GEAR
X21441 INSTR HOUSING
X20755 CAMSHAFT ASSY
X20750 WASHER
X21465 BEARING (2 REQ'D)
X20749 SHAFT
X22430 PUMP ASS'Y
X19953 WASHER
X19977 GEAR
X21436 SPACER
X21433 COLLAR


FIG 3 - 2

9 8 7

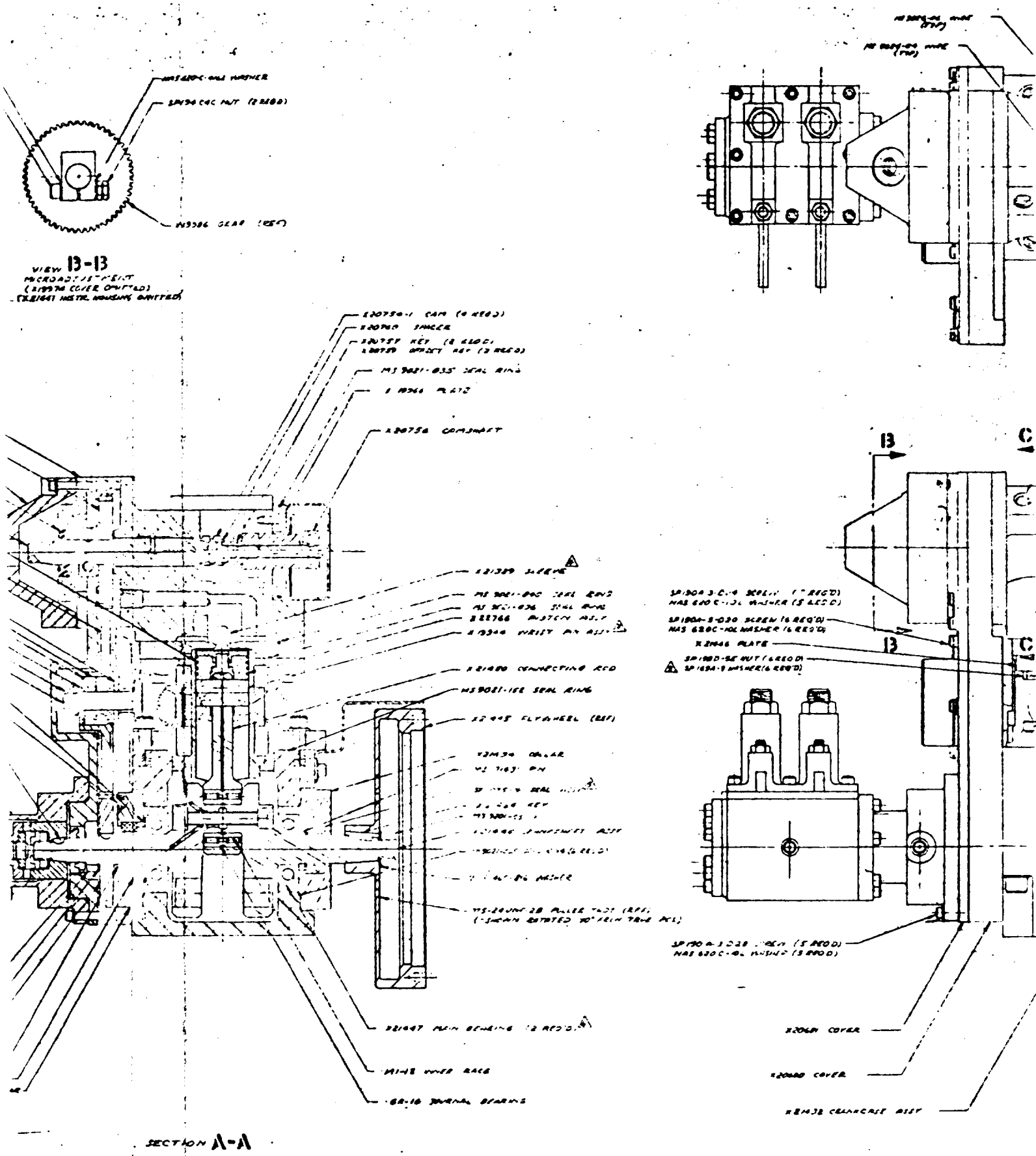

VIEW B-B
SECTION A-A
B
C
X20756 CAMSHAFT
X21389 SLEEVE
X21480 CONNECTING ROD
MS9021-152 SEAL RING
X21446 PLATE
X20681 COVER
X20680 COVER
X21432 CRANKCASE ASSY

FIG. 3

3

7 6 5

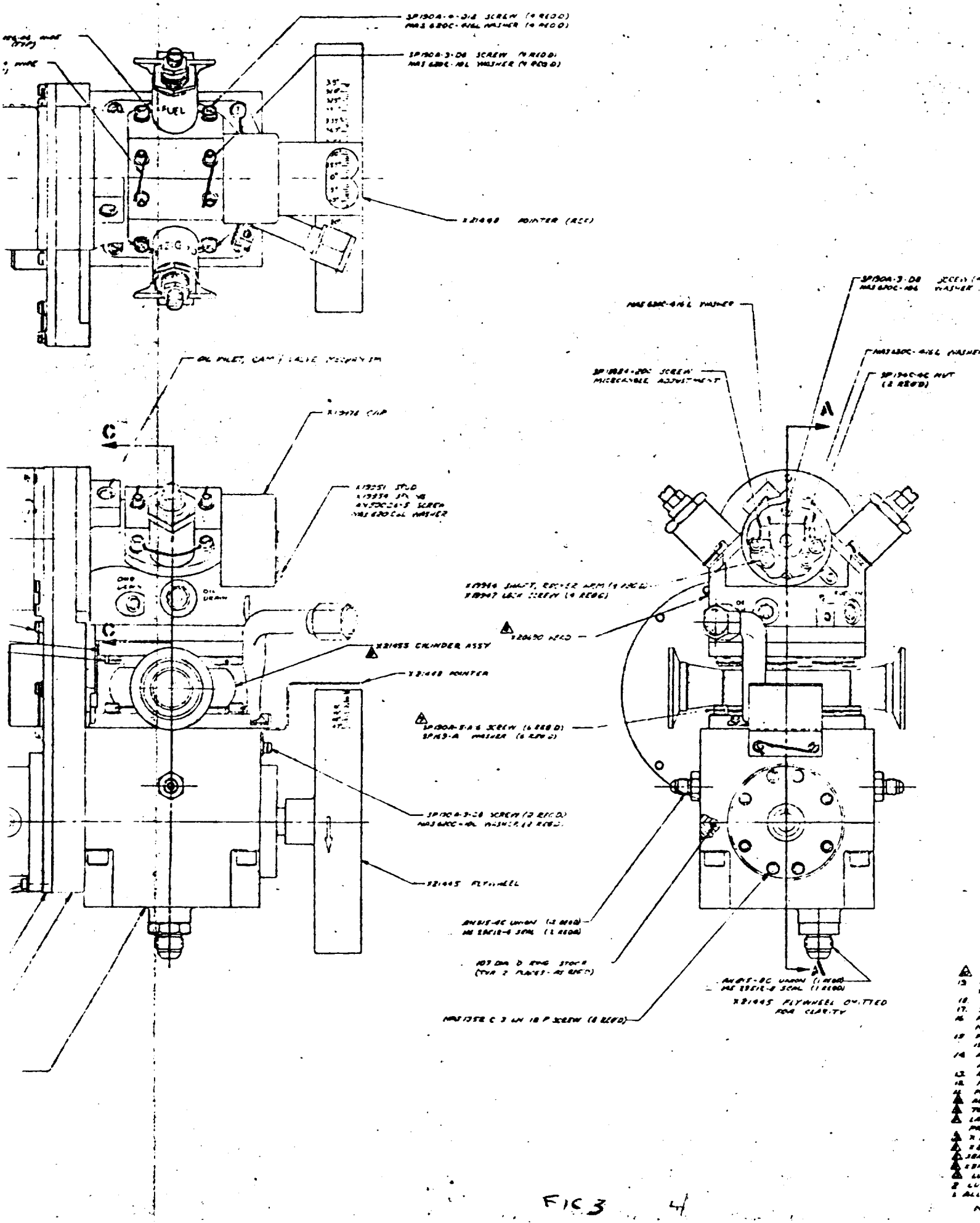

FUEL
X21448 POINTER (REF)
OIL INLET, CAM & VALVE MECHANISM
X19976 CAP
X19251 STUD
X19954 SPRING
AN500C6-5 SCREW
NAS 620C6L WASHER
OIL DRAIN
X21455 CYLINDER ASSY
X21448 POINTER
SP190A-3-D8 SCREW (2 REQ'D)
NAS 620C-10L WASHER (2 REQ'D)
X21445 FLYWHEEL
NAS 620C-416L WASHER
SP190A-3-D8 SCREW
NAS 620C-10L WASHER
SP1884-20C SCREW
MICROCABLE ADJUSTMENT
SP190C-4C NUT
(2 REQ'D)
X19964 SHAFT, ROCKER ARM (4 REQ'D)
X19947 LOCK SCREW (4 REQ'D)
X20690 HEAD
SP190A-5-A6 SCREW (6 REQ'D)
SP169-A WASHER (6 REQ'D)
AN815-4C UNION (2 REQ'D)
MS 29512-4 SEAL (2 REQ'D)
107 DIA D RING STOCK
(THR 2 PLACES - AS REQ'D)
AN815-8C UNION (1 REQ'D)
MS 29512-8 SEAL (1 REQ'D)
X21445 FLYWHEEL OMITTED
FOR CLARITY
NAS 1352 C 3 LH 18 P SCREW (8 REQ'D)
A
C

FIG 3 4

| | | | |
|---|---|---|---|
| 1 | A | TOTAL CHG REL | |
| 2 | B | RE ARRANGED & REDRAWN | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| 1 | | MS9821-152 | SEAL RING | 68 | |
| 1 | | MS29512-8 | SEAL, UNION | 83 | |
| 2 | | MS29512-6 | SEAL UNION | 84 | |
| 1 | | MS171431 | PIN, ROLL | 86 | |
| 1 | | MS9300-08 | NUT | 87 | |
| 1 | | MS9300-05 | NUT | 86 | |
| 1 | | MS9821-040 | SEAL RING | C7 | |
| 1 | | MS9821-036 | SEAL RING | C7 | |
| 3 | | MS9821-038 | SEAL RING | C7 | |
| AR | | MS9826-04 | WIRE, SAFETY | | |
| AR | | MS9826-04 | WIRE, SAFETY | | |
| 1 | | AN815-8C | UNION | 83 | |
| 2 | | AN815-6C | UNION | 84 | |
| 1 | | AN3070-6A5-4 | SCREW | C9 | |
| 1 | | AN960-D6-5 | SCREW | C9 | |
| 2 | | AN340-7R | NUT | C9 | |
| | | | | | |
| | | | | | |
| | | | | | |
| 12 | | MS35751-D6A-4R | SCREW, SELF-LOCKING | | |
| 1 | | MS17875-C7 | NUT | C7 | |
| 8 | | MS9300-06L | WASHER | | |
| 26 | | MS15200-10L | WASHER | | |
| 1 | | MS15200-6L | WASHER | C4 | |
| 1 | | MS15203-8L | WASHER, TAB | 86 | |
| 1 | | CR-E06 | KEY | 87 | |
| | | | | | |
| | | | | | |
| 2 | | | PIN, ROLL | C9 | |
| 2 | | 63-8B | SEAL | | |
| | | | | | |
| 1 | | SS-OFT-16 | SEAL ASSY | 87 | |
| 1 | | SS-OFS-16 | SEAL ASSY | 86 | |
| | | 103 DIA | BRASS STOCK | 83 | |
| 2 | | E-RTS-016 | OMNI-SEAL | C9 | |
| 2 | | E-RTS-014 | OMNISEAL | 69 | |
| 2 | | MPD-2-009 | SEAL RING | C9 | |
| 1 | | CR 1885 | LOCK RING | 87 | |
| 2 | | B304 | SPRING, BELLEVILLE | 87 | |
| | | | | | |
| | | | | | |
| 6 | | SP190 D5E | NUT | 87 | |
| 4 | | SP190 C6E | NUT | | |
| 6 | | SP190A-D-D6 | SCREW | 87 | |
| 4 | | SP190A-D-D12 | SCREW | C5 | |
| 5 | | SP190A-3-D08 | SCREW | 83 | |

| | | | | | |
|---|---|---|---|---|---|
| 5 | | SP190A-3-D09 | SCREW | 83 | |
| 6 | | SP190A 3-D09 | SCREW | 83 | |
| 3 | | SP190A 3-D8 | SCREW | | |
| 2 | | SP190A-3-D8C | SCREW | | |
| 18 | | SP1694-9 | WASHER | 83 | |
| | | | | | |
| | | | | | |
| 2 | | X 21769 | GUIDE-BRIDGE | 3C | |
| 2 | | X 21665 | BEARING, IDLER | 87 | |
| 1 | | X 21466 | KEY, PTO-SEL | 8- | |
| 1 | | X 21456 | CHAMBER ASSY | 8- | |
| 1 | | X 21456 | CONNECTING ROD | 87 | |
| 1 | | X 21440 | POINTER, TIMING | 8- | |
| 2 | | X 21447 | MAIN BEARING | 83 | |
| 1 | | X 21461 | PLATE, CYLINDER HEAD | C | |
| 1 | | X 21465 | FLYWHEEL | 8- | |
| 1 | 91156 | GR-16 | JOURNAL BEARING | 8- | |
| 1 | 91156 | MR-16 | MAIN RACE, JOURNAL BEARING | 87 | |
| 1 | | X 21461 | MOUNTING, OIL INJECTION | 8- | |
| 1 | | X 21440 | CRANKSHAFT ASSY | 87 | |
| 1 | | X 21435 | SPACER | 87 | |
| | | X 21434 | COLLAR, PTO-SEL SIDE | 8- | |
| 1 | | X 21433 | COLLAR, SEAL SIDE | 87 | |
| 1 | | X 21432 | CRANKCASE ASSY | 8- | |
| | | | | | |
| 1 | | X 21389 | SLEEVE | 87 | |
| 8 | | X 20760-001 | SEAL, OUTER VALVE | 8- | |
| 16 | | X 20760-1 | SEAL, INNER VALVE | 8- | |
| 1 | | X 20760 | SPACER | 87 | |
| 8 | | X 20759-1 | KEY, OUTER | | |
| 8 | | X 20759 | KEY | 83 | |
| 1 | | X 20756 | CAMSHAFT | | |
| 1 | | X 20755 | CAMSHAFT | | |
| 4 | | X 20754-1 | CAM | | |
| 8 | | X 20751 | WASHER, TIMING GEAR | 87 | |
| 1 | | X 20750 | WASHER, TIMING GEAR | 87 | |
| 1 | | X 20749 | SHAFT, TIMING GEAR | 87 | |
| 1 | | X 20748 | RETAINER, OUTER SPRING VALVE | C9 | |
| 8 | | X 20747 | NUT, SPRING, VALVE | C9 | |
| 6 | | X 20746 | RING, PISTON | 87 | |
| 1 | | X 20630 | PUMP ASSY | 87 | |
| 1 | | X 20633-30 | VALVE ASSY, INJECTION, FUEL | C9 | |
| 1 | | X 20633 | VALVE ASSY, INJECTION, DIVIDER | 8- | |
| 1 | | X 20590-1 | HEAD, CYLINDER | C9 | |
| 1 | | X 20582 | GEAR, TIMING, IDLER | 87 | |
| 1 | | X 20581 | GEAR, TIMING GEAR, FRONT | 83 | |
| 1 | | X 20580 | COVER, TIMING GEAR, BACK | 83 | |
| 1 | | X 20566 | PISTON ASSY | 87 | |
| 1 | | X 20470 | HEAD COVER | 8- | |
| 8 | | X 20469 | HEAD COVER | C9 | |
| 1 | | X 19986 | GEAR, TIMING, CAMSHAFT | C7 | |
| 4 | | X 19984 | SHAFT, ROCKER ARM | C9 | |
| 8 | | X 19983 | SPRING, OUTER VALVE | C9 | |
| 1 | | X 19982 | ARM, ROCKER, FUEL, OUTER VALVE | C9 | |
| 1 | | X 19981 | ARM, ROCKER | C9 | |
| 1 | | X 19980 | ARM, ROCKER, FUEL, INNER VALVE | 8- | |
| 8 | | X 19979 | SPRING, INNER VALVE | C9 | |
| 8 | | X 19978 | RETAINER, SPRING, VALVE CAP | C9 | |
| 1 | | X 19977 | GEAR, TIMING, CAMSHAFT | 87 | |
| 1 | | X 19976 | CAP, END CAMSHAFT | C9 | |
| 1 | | X 19975 | ARM, ROCKER, DIDGEE CUT | C9 | |
| 1 | | X 19974 | COVER PLATE, GEAR, CAMSHAFT | C5 | |
| 8 | | X 19973 | RETAINER, SPRING VALVE CAP | C9 | |
| 1 | | X 19966 | PLATE, CAMSHAFT END | C7 | |
| 8 | | X 19965 | BRIDGE, SPRING OUTER VALVE | C9 | |
| 1 | | X 19954 | SPRING, CAP RETAINER | C4 | |
| 1 | | X 19953 | WASHER, TAB | 87 | |
| 1 | | X 19951 | STUD, CAP RETAINER | | |
| 2 | | X 19950 | NUT, RETAINER SPRING VALVE CAP | C9 | |
| 4 | | X 19947 | LOCK SCREW, ROCKER ARM SHAFT | C3 | |
| 1 | | X 19946 | INLET PIN ASSY | C- | |

| QTY REQD | CODE IDENT | PART OR IDENTIFYING NO. | NOMENCLATURE OR DESCRIPTION | SPECIFICATION | MATERIAL OR NOTE | FONC | NO. |
|---|---|---|---|---|---|---|---|

USE OF MATERIALS OR PARTS LIST

UNLESS OTHERWISE SPECIFIED

Marquardt

ENGINE ASSEMBLY SPU-3

CODE IDENT NO. 88845 | SIZE R | X 21431

SCALE

- STAKE AN570C-440-4 SCREW TO X20760 RETAINER.
- 13 PISTON RING END GAP TO BE 2.20 WHEN FULLY COMPRESSED AND 2.8 WHEN INSTALLED IN X21456 CYLINDER.
- 16. ENGINE ROTATION IS COUNTER-CLOCKWISE, FACING ENGINE FROM FLYWHEEL SIDE.
- 17. SAFETY WIRE PER MS33540
- 18 PRESSURE CHECK COOLANT PASSAGE WITH 10 MICRON FILTERED GASEOUS NITROGEN AT 25±5 PSI. NO LEAKAGE ALLOWED.
- 19 PRESSURE CHECK HEAD ASSY WITH 3 MICRON FILTERED GASEOUS NITROGEN AT 100±10 PSI. NO LEAKAGE ALLOWED THROUGH VALVE SEAT 1 PSI DROP ALLOWED IN ASSY.
- 14 ADJUST CAMSHAFT TIMING AND INJECTOR DWELL BY LOCKING SP194 NUTS AND REMOVING SP194 SCREW
- 12. ROCKER ARM TO CAM-LOBE OPERATING CLEARANCE TO BE .003 MIN.
- 18. PRELOAD BOTH X19983 SPRINGS 6½ TURNS OF X19973 RETAINER
- 14 PRELOAD BOTH X19979 SPRINGS 4½ TURNS OF X19978 RETAINER
- ADJUST X20749 SHAFT TO PROVIDE .005 IN BACKLASH IN EACH GEAR
- TORQUE TO 240±10 IN-LB
- LAP SLIDE SERRATIONS IN X21466 CYLINDER ASSY AND X20590 HEAD, AT ASSY, TO PROVIDE FULL CONTACT WITH X20496 PLATE SEAL AREAS.
- X19954 DOWEL PIN TO BE .000-.002 IN LOOSE FIT IN X19950 CONNECTING ROD.
- X19947 BEARING TO BE PRESSED (.000-.002 IN TIGHT FIT) ON X21440 CRANKSHAFT ASSY.
- SEAL ASSY TO BE PRESSED (.000-.002 IN TIGHT FIT) INTO HOUSING.
- X21389 SLEEVE TO BE PRESSED (.000-.002 IN TIGHT FIT) INTO X20590 HEAD
- LUBRICATE X20693-1 AND X20693-30 VALVES INTERNALLY WITH POWER OR BRUSH.
- 2 LUBRICATE ALL THREADS WITH "DRI-LUBE" (REF MPS 1100)
- 1 ALL PARTS ARE TO BE CLEANED PER MPS 204-8 PRIOR TO ASSY.

NOTE 4: (UNLESS OTHERWISE SPECIFIED)

2



FIGURE 3

FIG 3 5

T5169-11

FIGURE 4. Cast Iron Cylinder Liner After Test 5169-12 with the SPU-3 Engine

T5169-10

FIGURE 5. Chrome Plated 440-C Piston Rings after Test 5169-12 with the SPU-3 Engine

SPU-3 ENGINE
VARIATION OF BRAKE MEAN EFFECTIVE PRESSURE AND
SPECIFIC PROPELLANT CONSUMPTION WITH EXPANSION RATIO

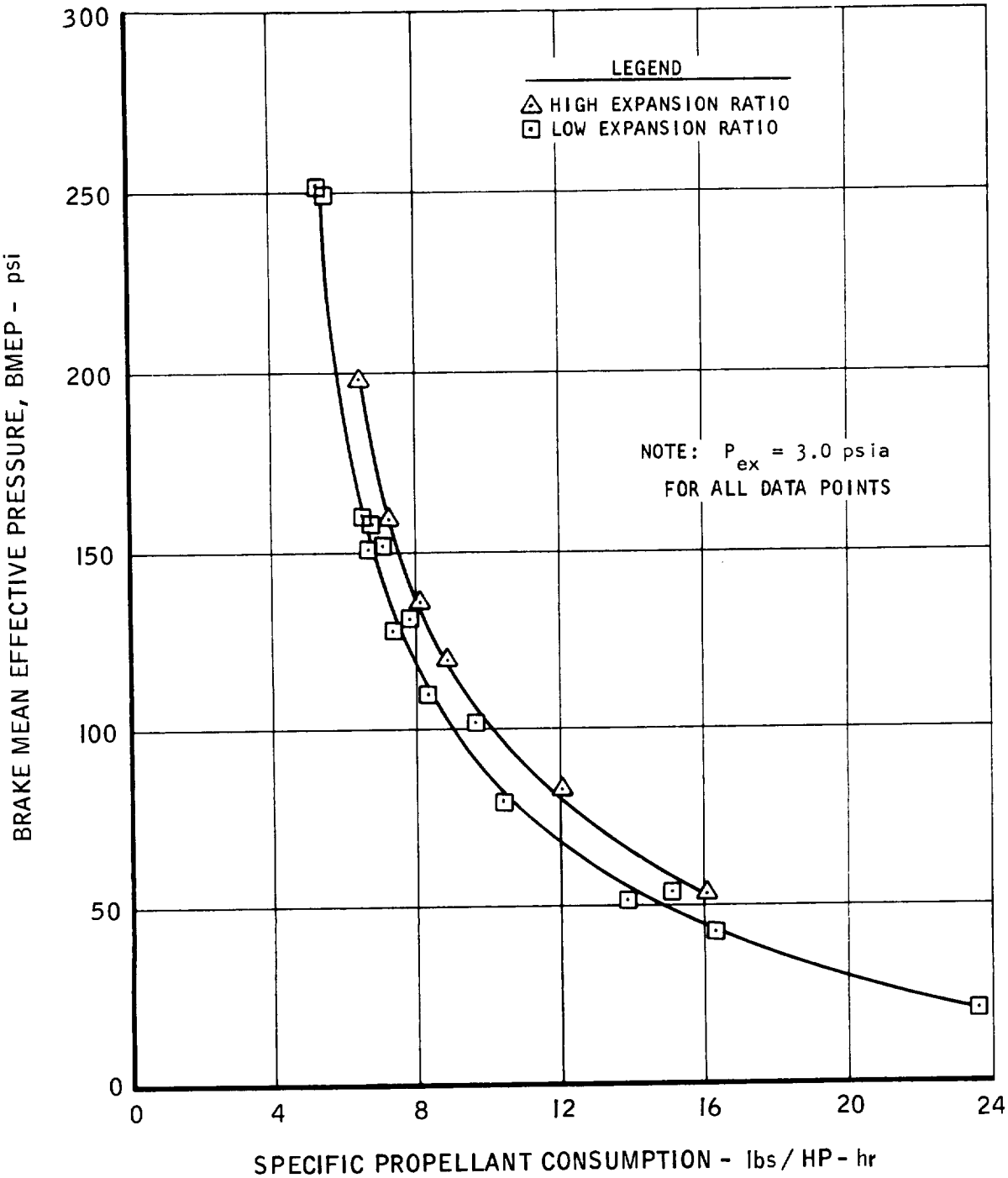



FIGURE 6

# SPU - 3 ENGINE
## SCHEMATIC OF INITIAL PROPELLANT PUMP SYSTEM

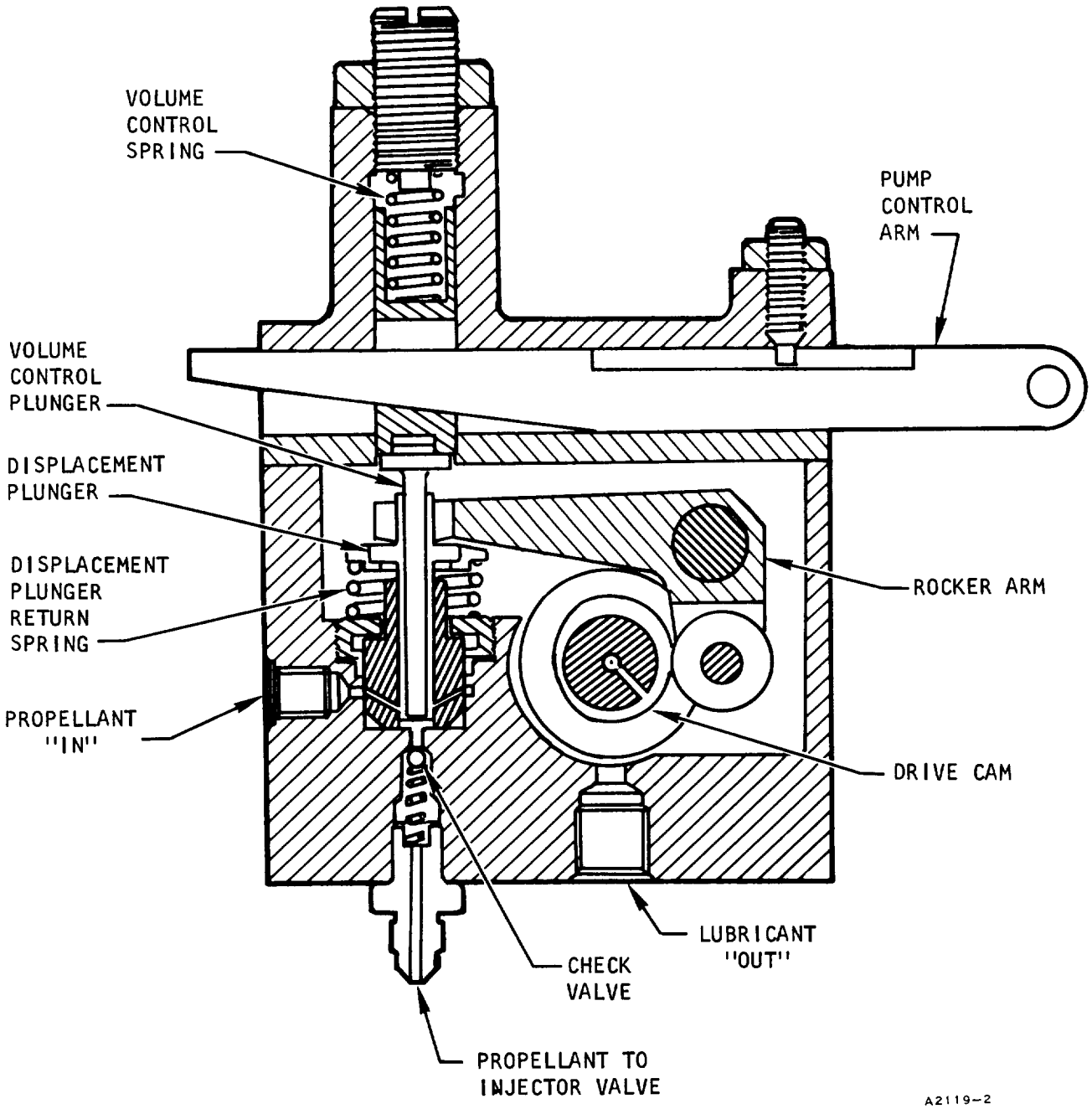



FIGURE 7

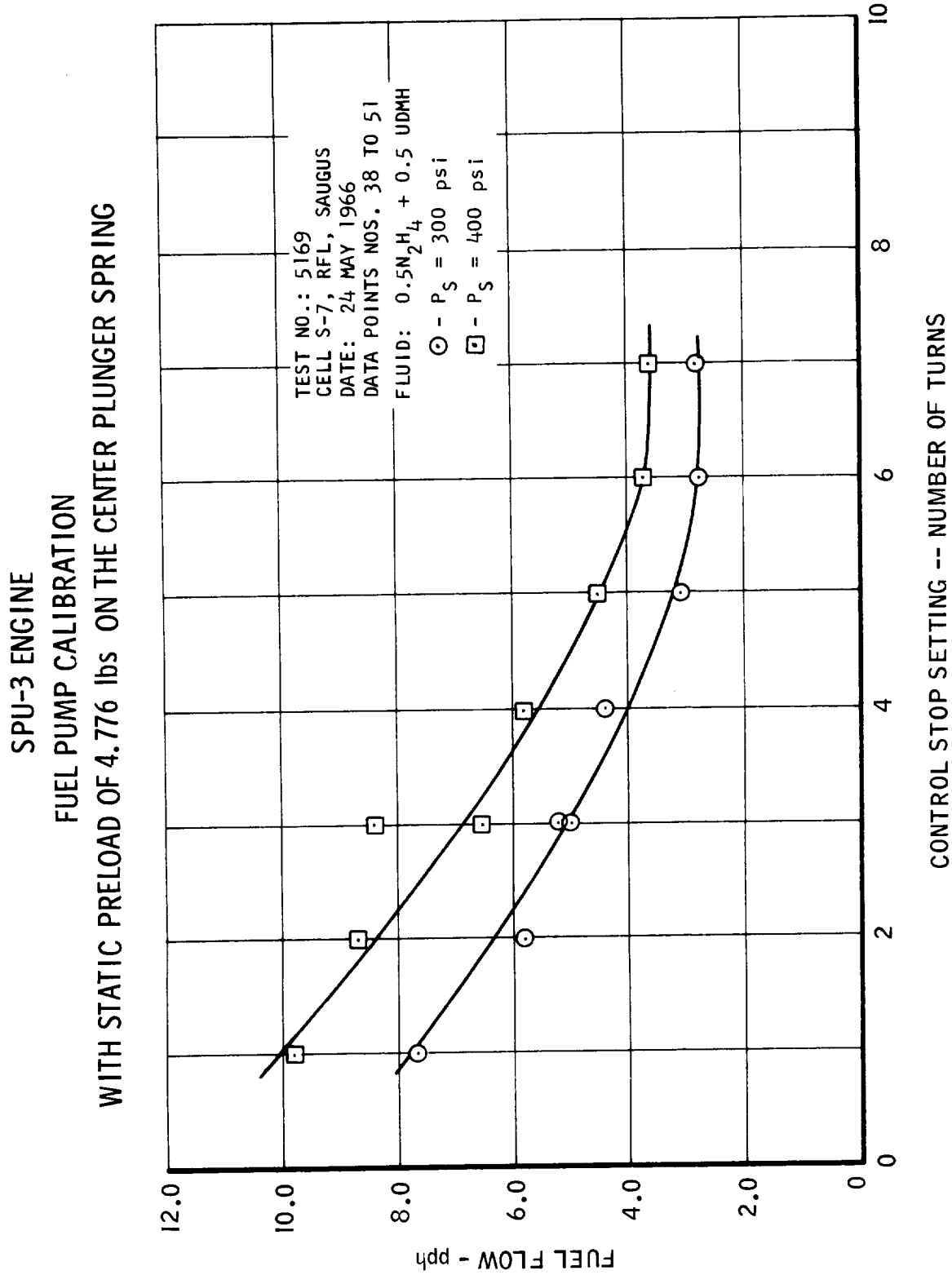

SPU-3 ENGINE
FUEL PUMP CALIBRATION
WITH STATIC PRELOAD OF 4.776 lbs ON THE CENTER PLUNGER SPRING
TEST NO.: 5169
CELL S-7, RFL, SAUGUS
DATE: 24 MAY 1966
DATA POINTS NOS. 38 TO 51
FLUID: 0.5N2H4 + 0.5 UDMH
⊙ - PS = 300 psi
⊡ - PS = 400 psi
FUEL FLOW - pph
12.0
10.0
8.0
6.0
4.0
2.0
0
0
2
4
6
8
10
CONTROL STOP SETTING -- NUMBER OF TURNS

FIGURE 8

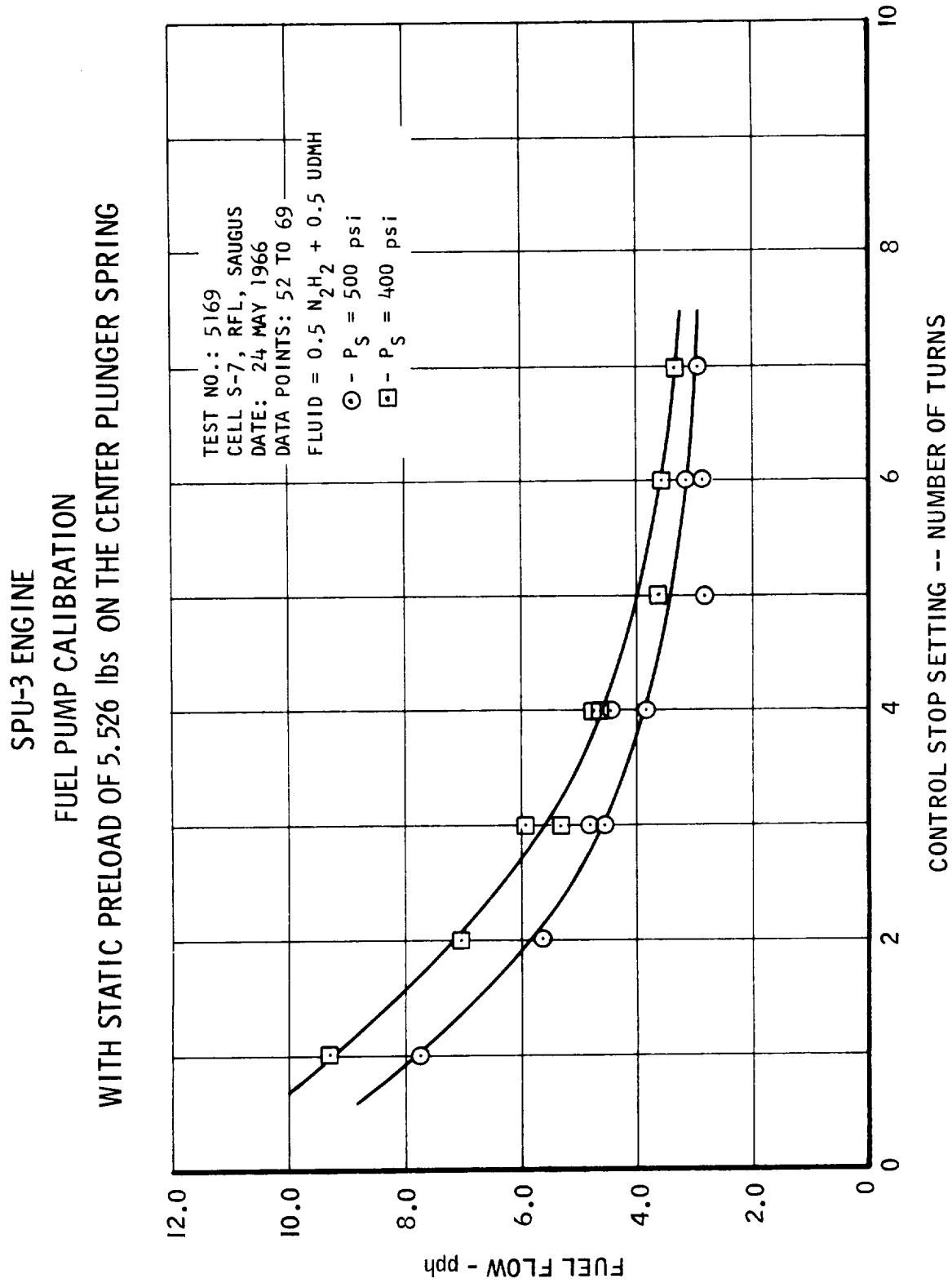

SPU-3 ENGINE
FUEL PUMP CALIBRATION
WITH STATIC PRELOAD OF 5.526 lbs ON THE CENTER PLUNGER SPRING
TEST NO.: 5169
CELL S-7, RFL, SAUGUS
DATE: 24 MAY 1966
DATA POINTS: 52 TO 69
FLUID = 0.5 $N_2H_2$ + 0.5 UDMH
⊙ - $P_S$ = 500 psi
⊡ - $P_S$ = 400 psi
FUEL FLOW - pph
12.0
10.0
8.0
6.0
4.0
2.0
0
0
2
4
6
8
10
CONTROL STOP SETTING -- NUMBER OF TURNS

FIGURE 9

SPU - 3 ENGINE
SCHEMATIC OF FUEL SIDE OF ALTERNATE PROPELLANT ISOLATION PUMP

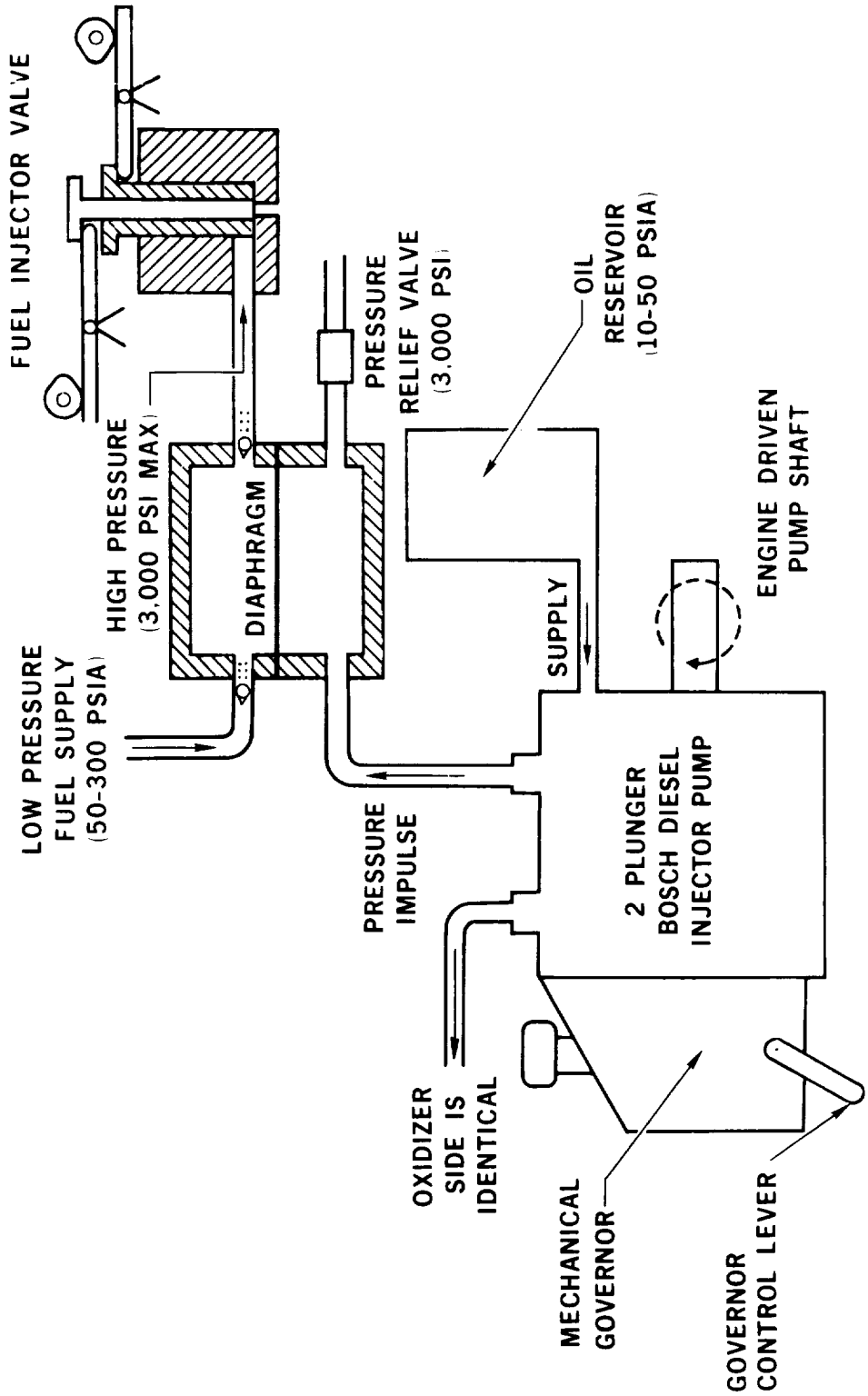
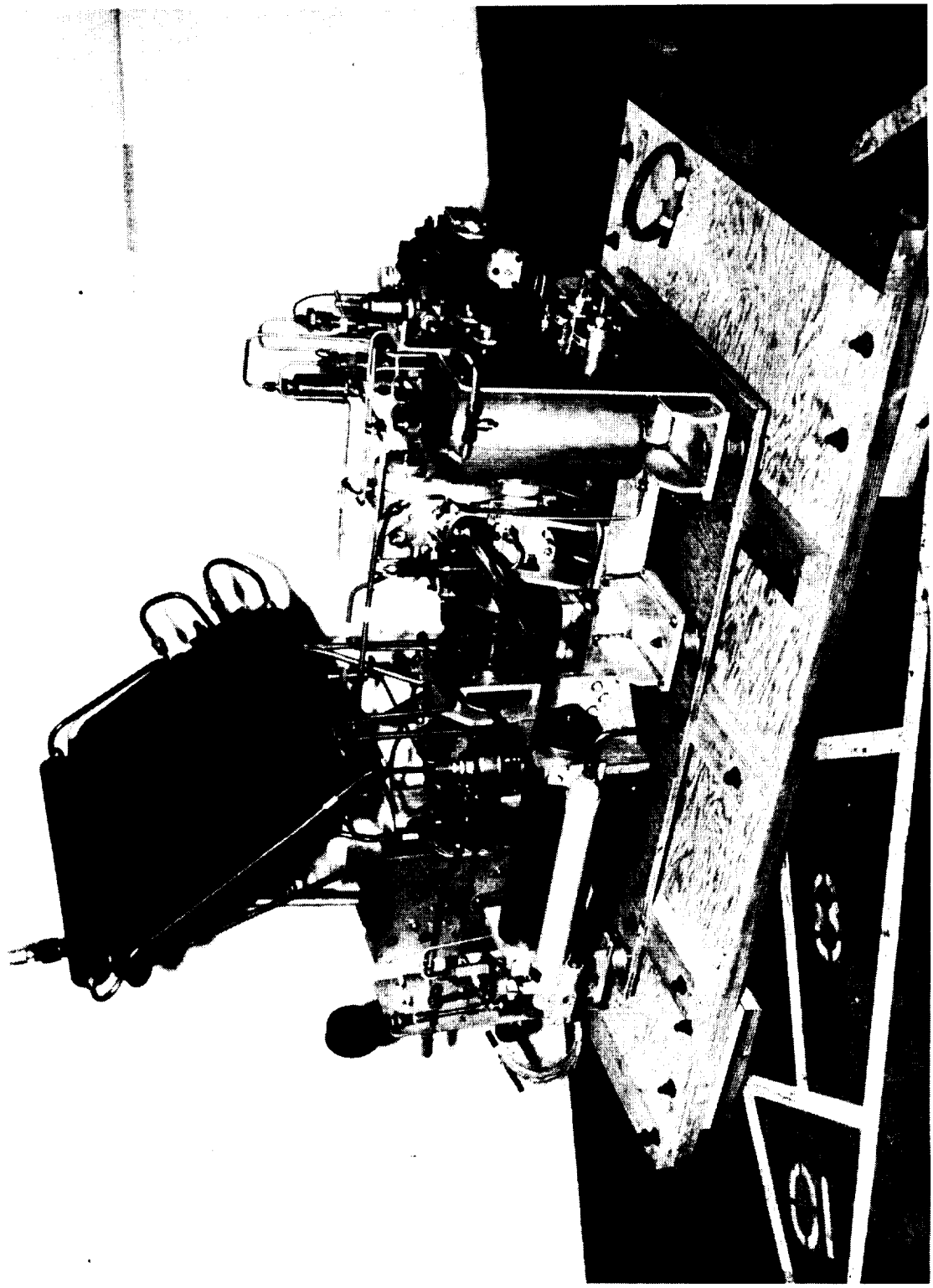
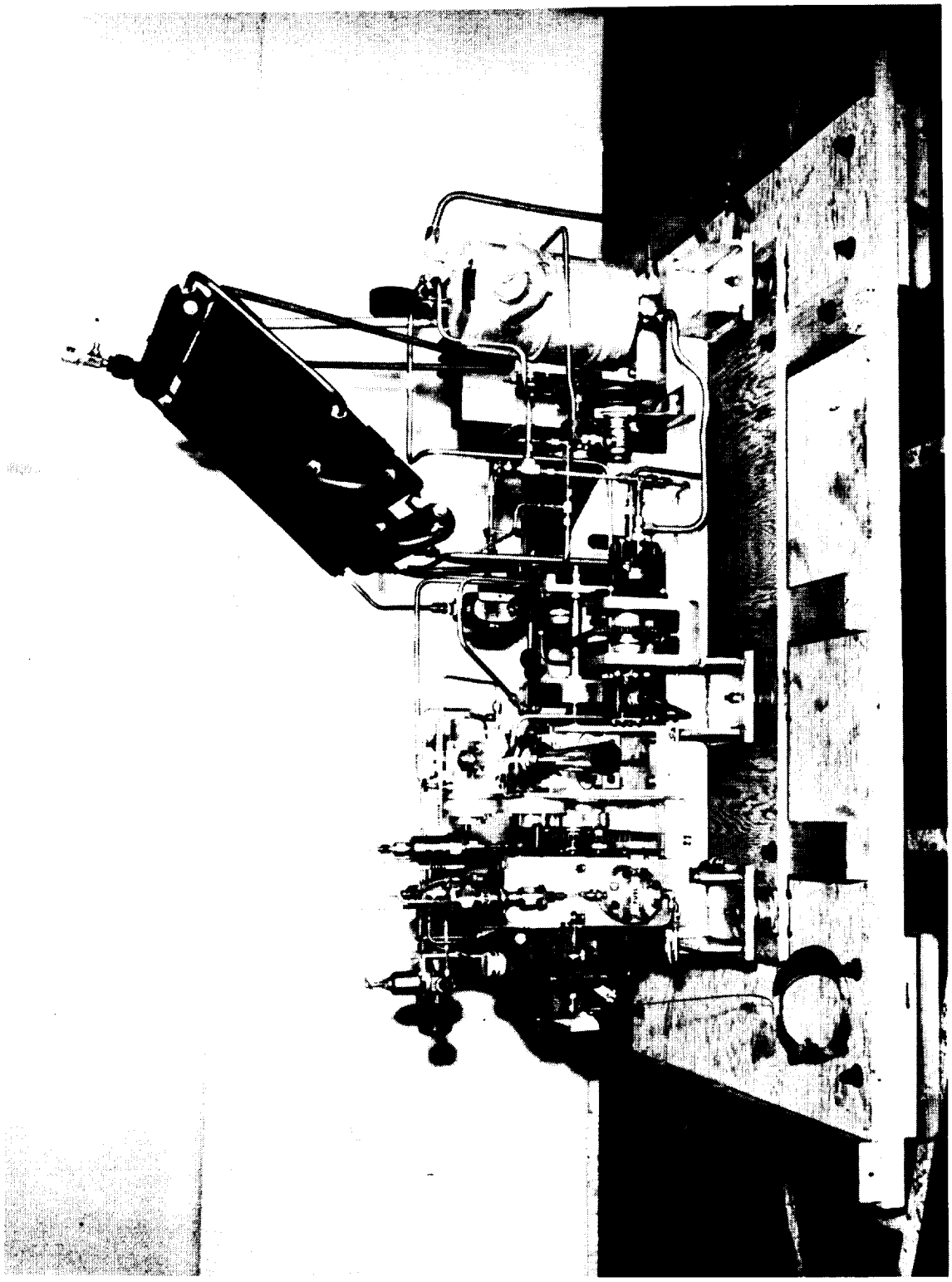



FIGURE 10



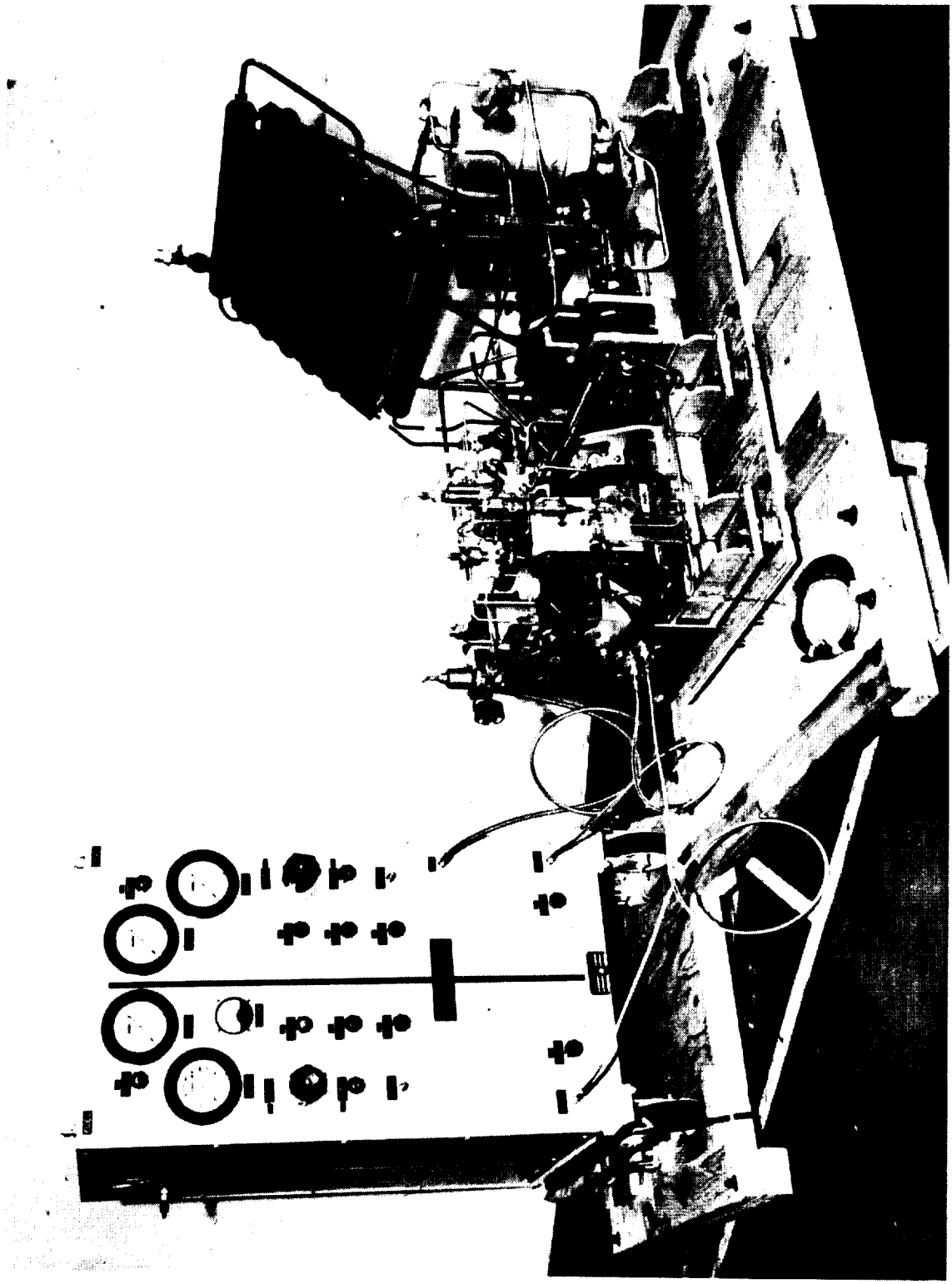
T5169-20

FIGURE 11. View of Space Power Unit Breadboard System



T5169-24

FIGURE 12. View of Space Power Unit Breadboard System



T5169-26

FIGURE 13. View of Space Power Unit Breadboard System with Propellant Supply Subsystem Installed

SPU-3 ENGINE

SCHEMATIC OF SPACE POWER UNIT BREADBOARD SYSTEM

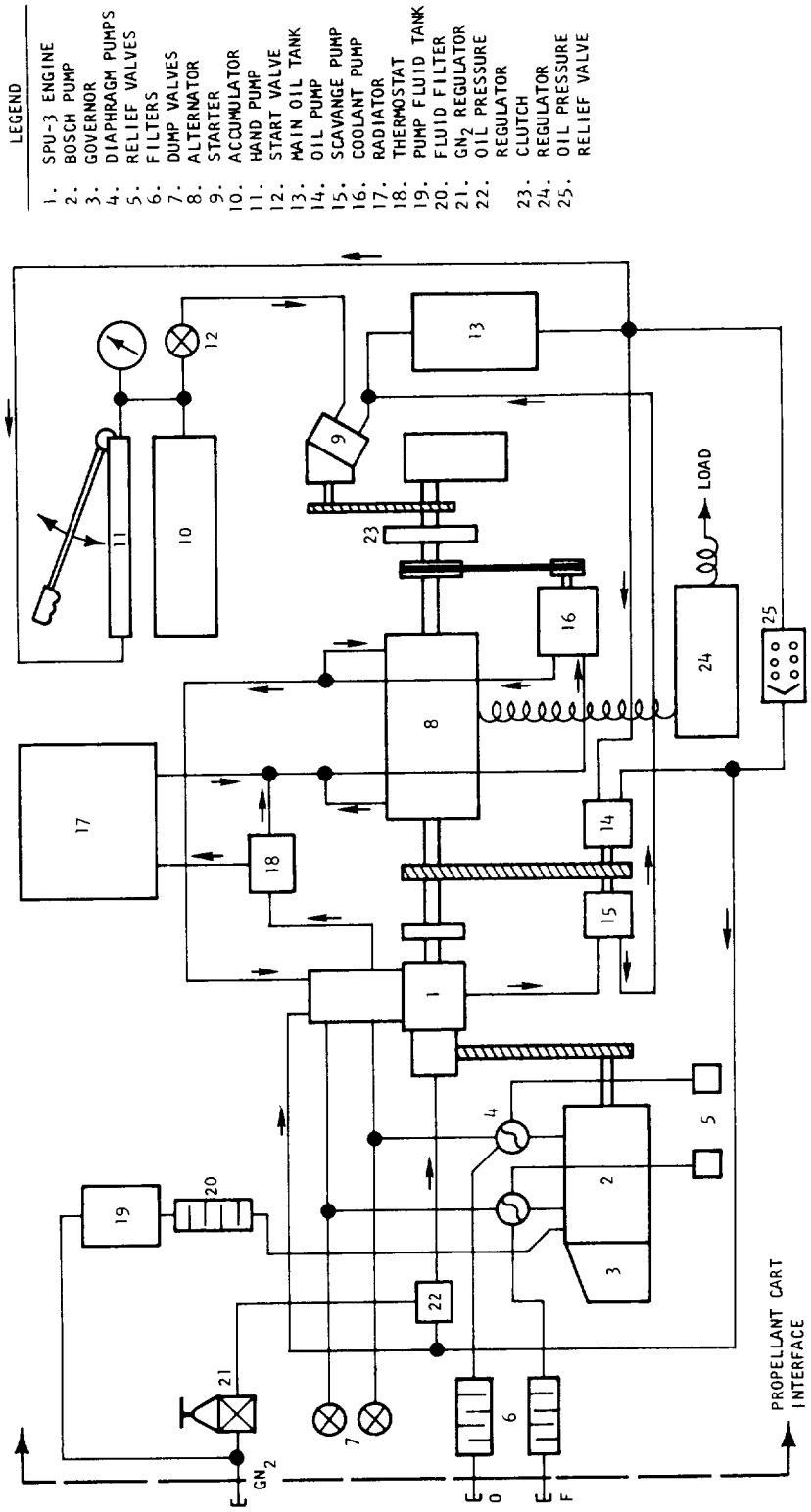



FIGURE 14

SPU-3 ENGINE

CALIBRATION OF GAST 8AM AIR MOTOR

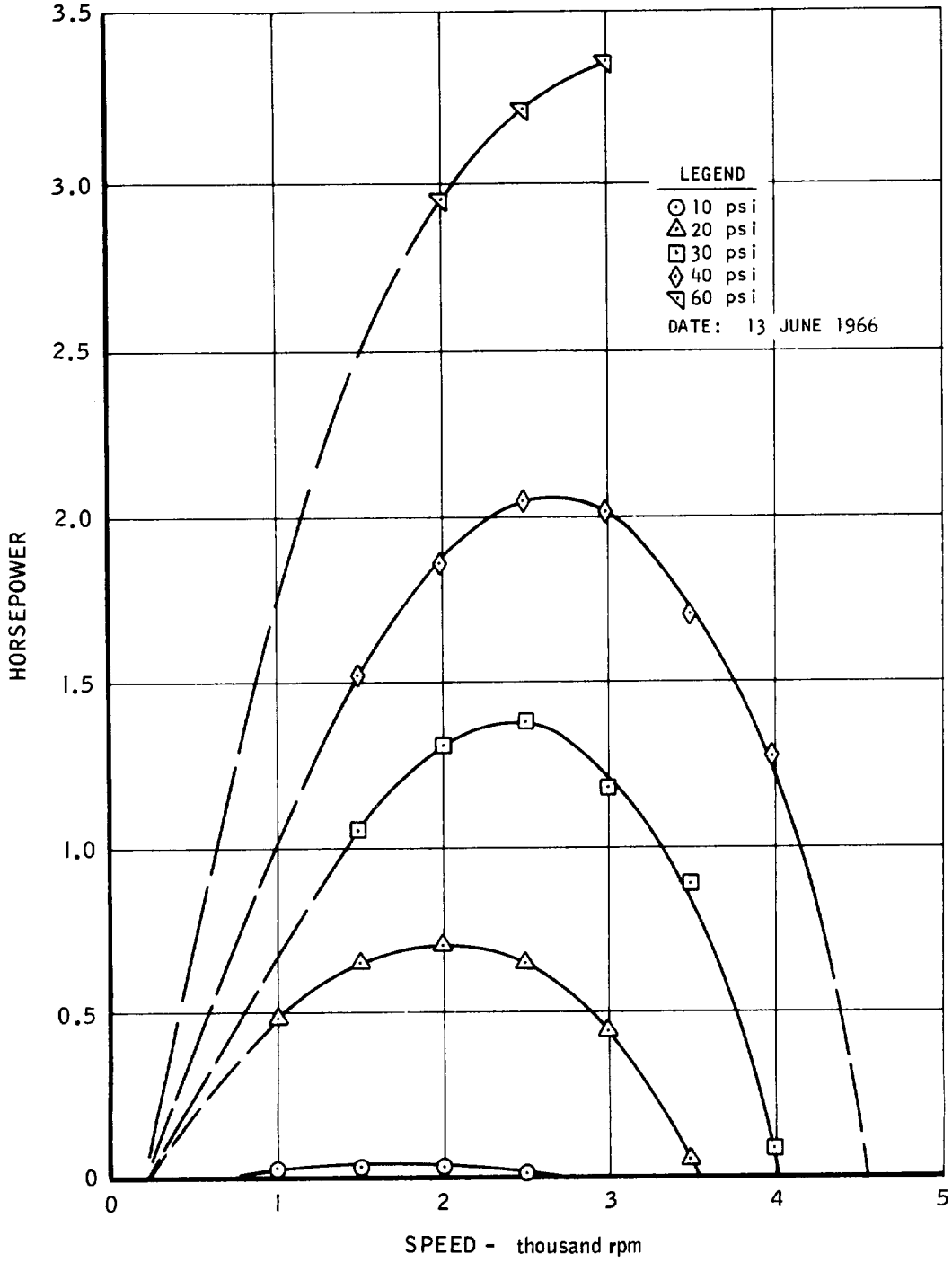



FIGURE 15

SPU-3 ENGINE

RESULTS OF COOLANT PUMP PERFORMANCE TESTS

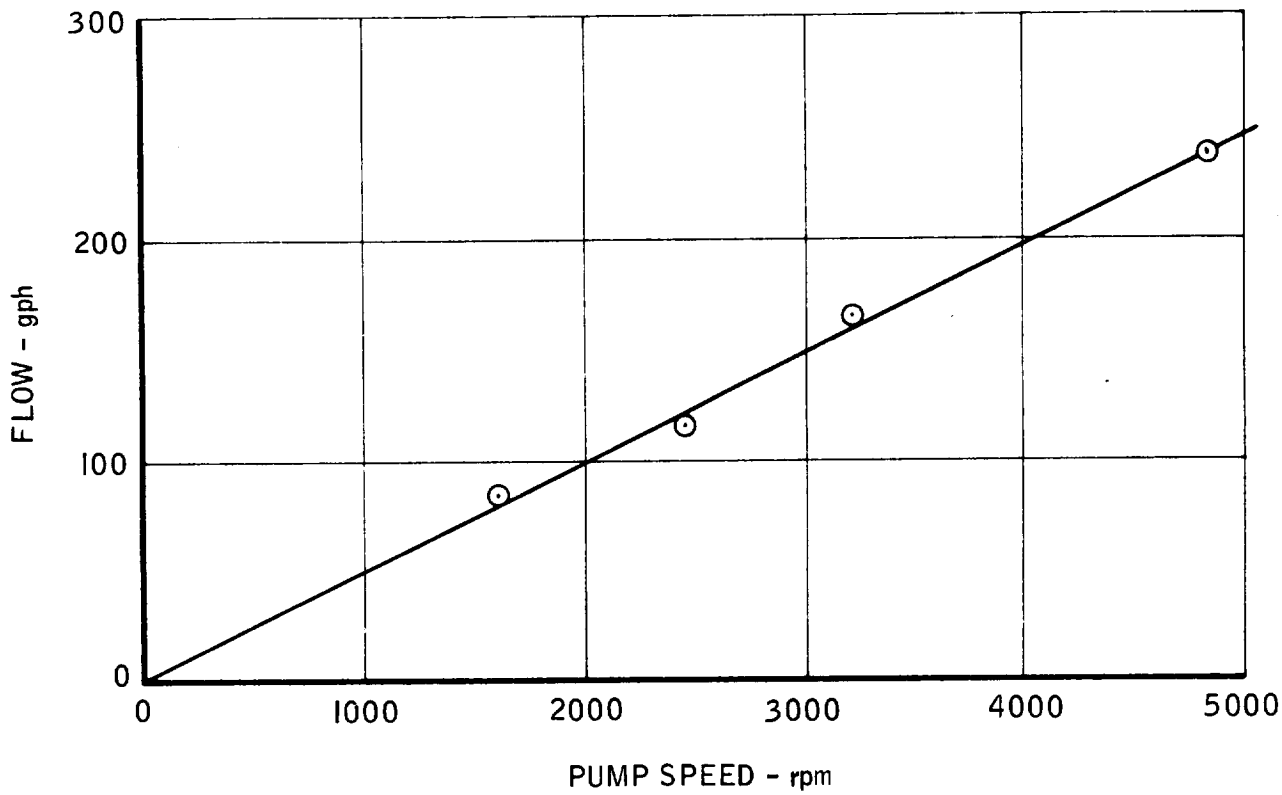
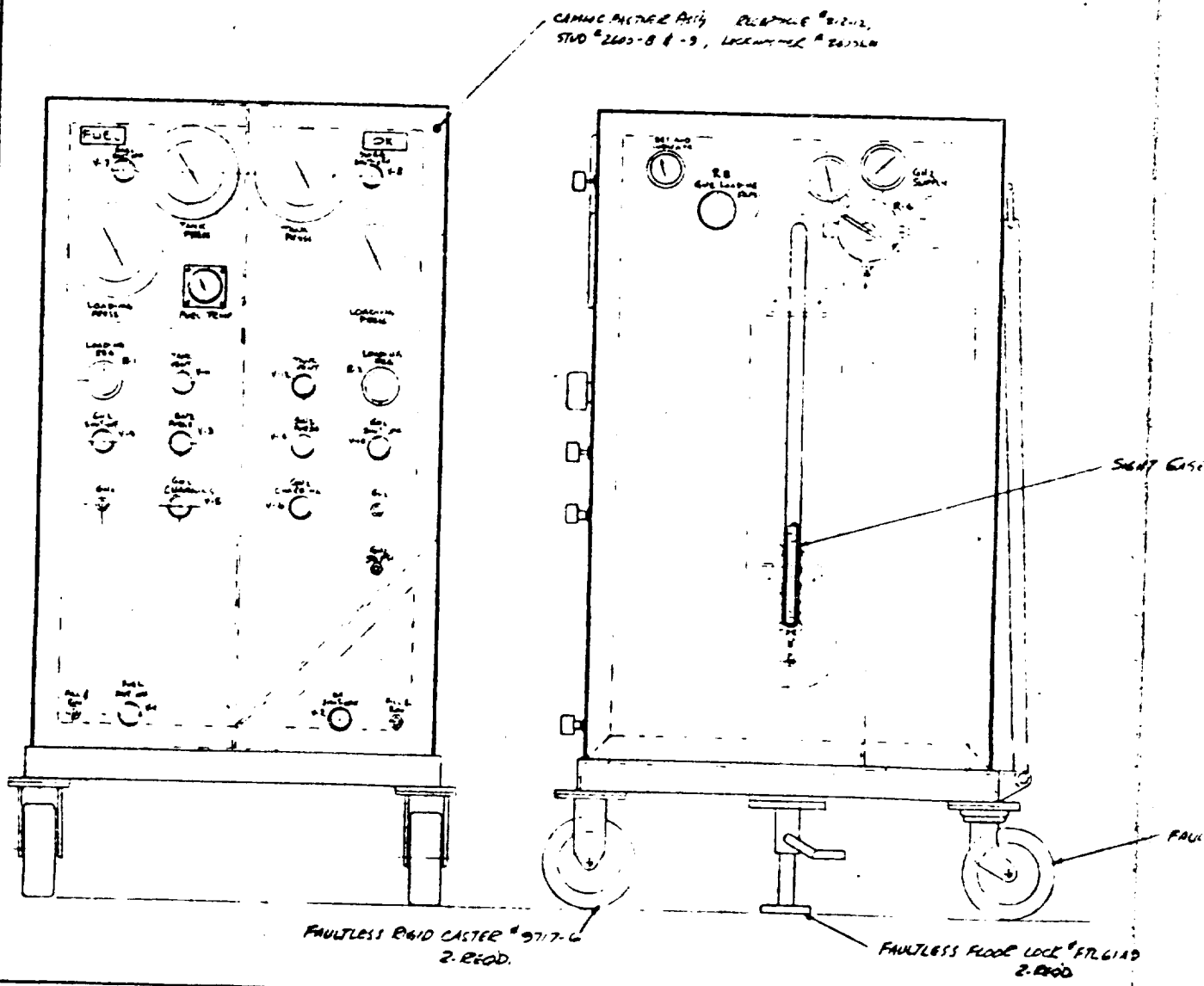


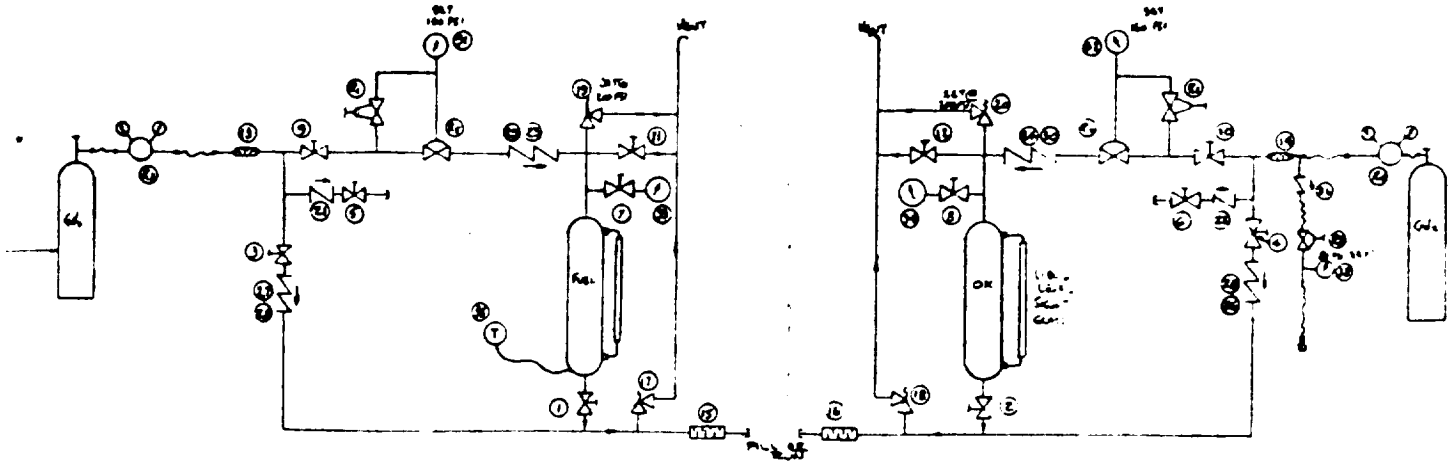

FIGURE 16




NOTES:

1. PRIME & PAINT BLUE
2. CLEAN COMPONENTS PER MIPS-209, EXCEPT EXPLOSIVES & GAS FILTERS
3. SYSTEM OPERATING PRESSURE = 160 PSIG
4. LEAK CHECK SYSTEM AT 300 PSIG, THEN FUNCTIONAL CHECK @ 160 PSIG

UNCLASSIFIED



PROPELLANT SYSTEM SCHEMATIC

ISE (EW)

JUSTLESS SWIVEL CASTER #917-6
2-REQ'D.

| | |
|---|---|
| 38 | PRESS. GAGE ANHW 1½ [illegible] 0-100 PSI RANGE |
| 36 | KEPNER CHECK VALVE - ¼ - #1304-D-3 |
| R8 | LOADING REGULATOR - GRIVE #96W (#[illegible]) [illegible] 60 PSI OUT |
| 35 | AMBIENT TEMP GAGE. LEWIS [illegible] #2082 [illegible] |
| 33-34 31-32 | PRESS. GAGE, ASHCROFT 4½" DIAL #137755 STAIN. STL. TUBE [illegible] ⅛" NB BACK CONN. 0-400 PSI |
| 29-30 27-28 | KEPNER CHECK VALVE #1304-D-3 |
| 25-26 23-24 21-22 | KEPNER CHECK VALVE #1304-D-3 |
| 19-20 17-18 | EBLOW VALVE EBURSLIC #[illegible]KB-4-4T SET @ 200 PSI |
| 14 15 | WESTERN FILTER #28-1-1651-0-5 5 MICRON NOMINAL |
| 10 13 | PERMANENT FILTER #20233A-10 10 MICRON NOMINAL |
| 11-12 9-10 7-8 5-6 3-4 1-2 | NEEDLE VALVE, DRISCO #SP-4034 LT STAIN. STL., ANDIDSO-4 PART |
| R6 R5 | PRESS. REDUCING REGULATOR - GRIVE #94W FIG. 1095-1-02-6 |
| R4 R3 | VICTOR GAS PRESS. REG. #[illegible]E-250-PMT W/GAGES, 0-2000 PSI INLET, 0-250 PSI OUTLET, ⅛" NPT PORTS |
| R2 R1 | PRESS. LOADING REGULATOR - GRIVE MID #15-5 0-3000 PSI INLET, 0-300 PSI OUTLET, ⅛ NPT PORTS |

REF. DWGS.

705549 - PROPELLANT TANK ASS'Y
705550 - SIGHT GAGE ASS'Y
705573 - FRAMING ASS'Y.
705574 - PANEL DETAILS

| REV | DESCRIPTION |
|---|---|
| A | [illegible] |

The Marquardt Corporation — TEST ENGINEERING

PROPELLANT CART ASS'Y. - SPU -

SCALE [illegible]

705548 A

FIGURE 17

SPU-3 ENGINE
SCHEMATIC OF SPU BREADBOARD TESTING SYSTEM

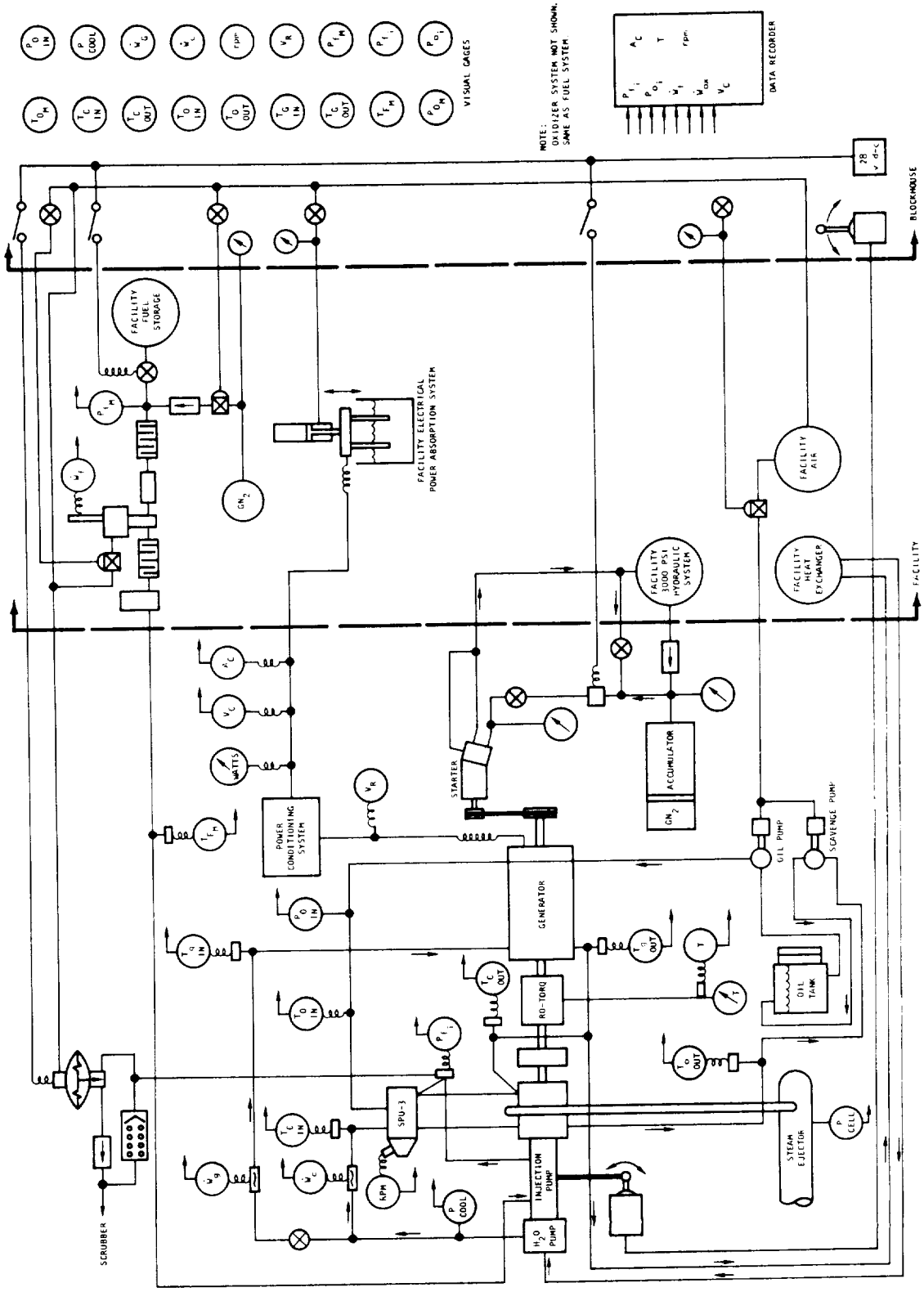
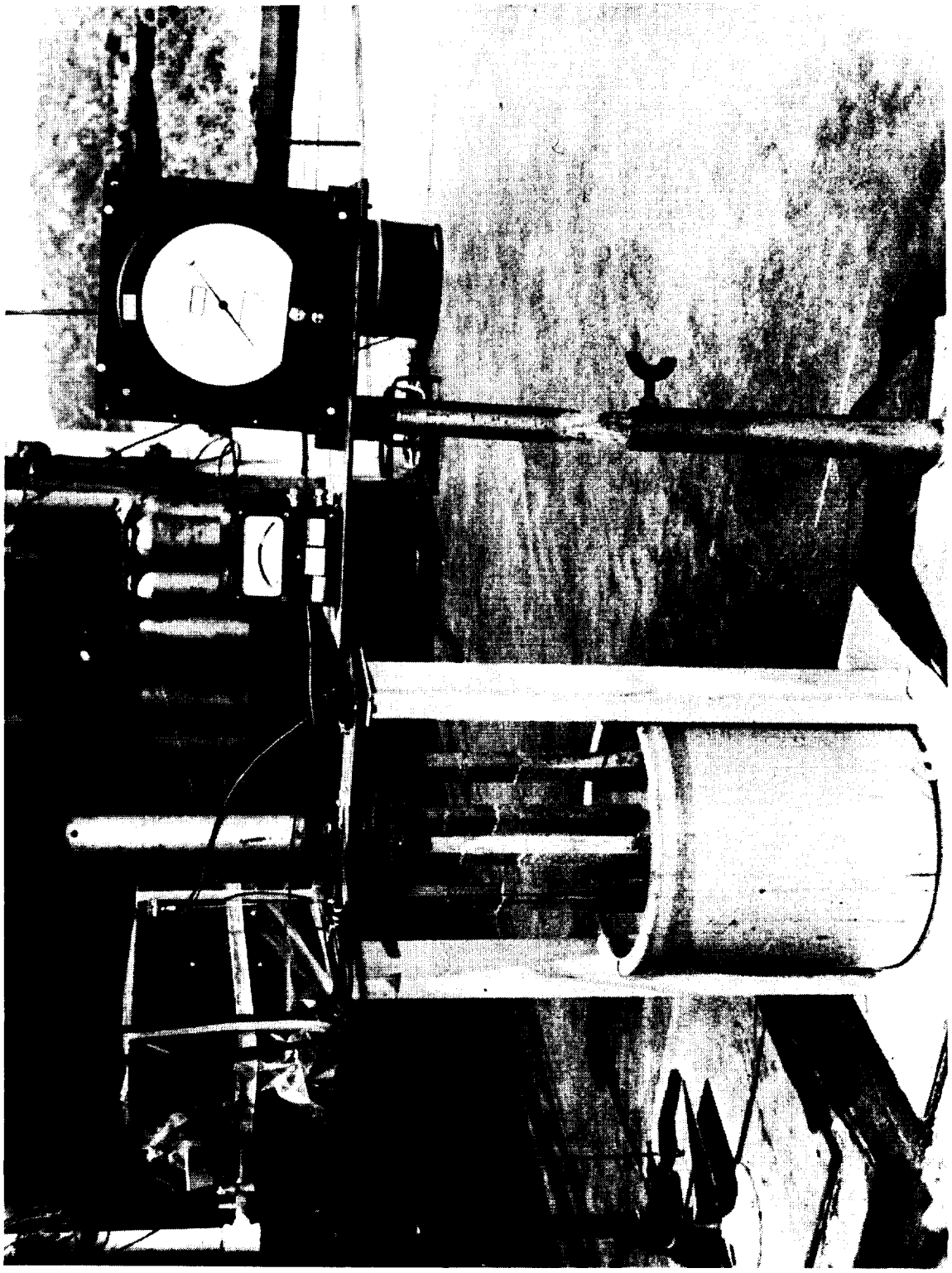



FIGURE 18



T5169-3

FIGURE 19. Electrical Power Absorption Unit (Water Rheostat)

SPU-3 ENGINE
RESULTS OF POWER TRAVERSE TEST
SPECIFIC PROPELLANT CONSUMPTION vs. KW OUTPUT

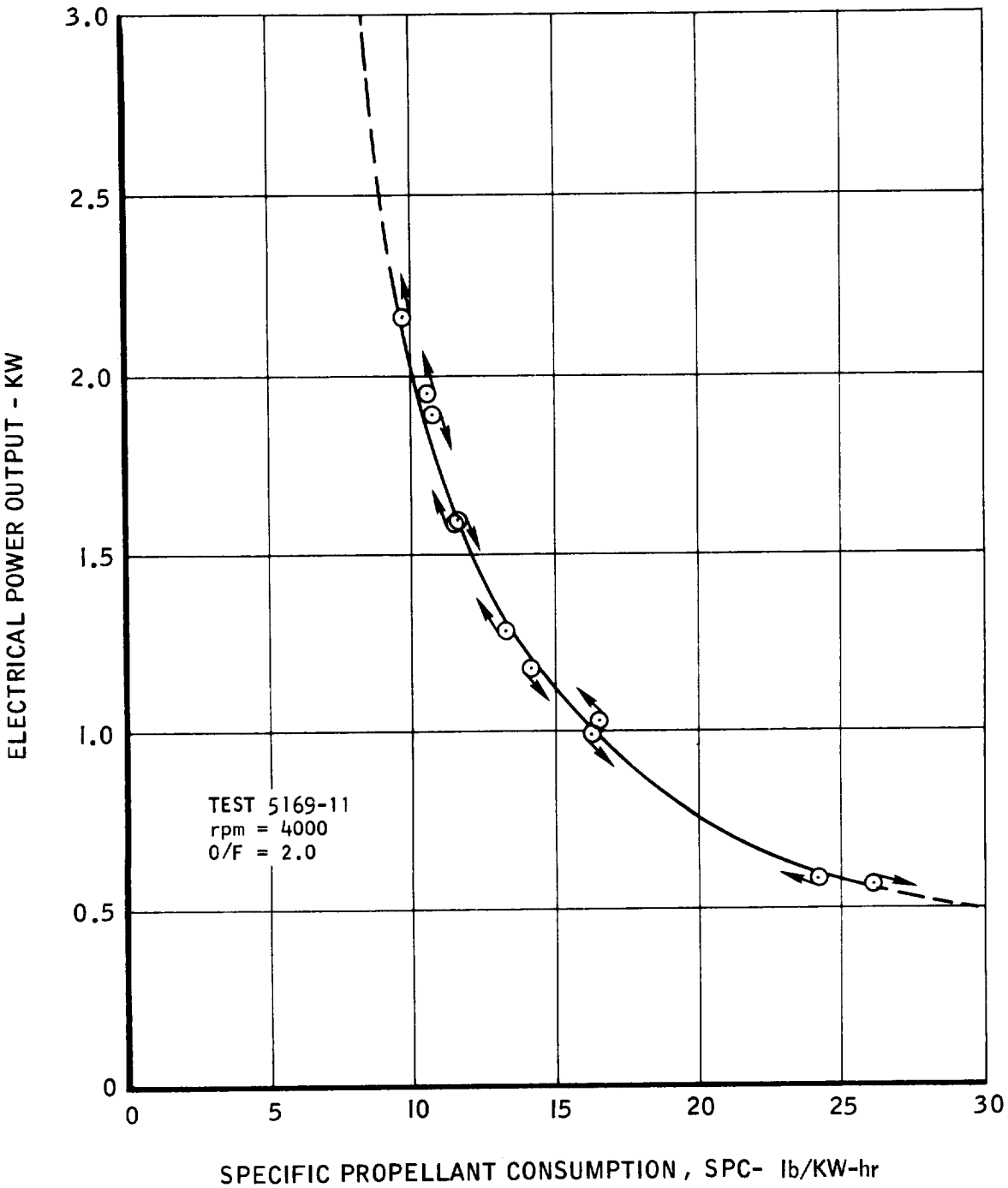



FIGURE 20

SPU-3 ENGINE

RESULTS OF POWER TRAVERSE TEST

INJECTION PRESSURE VS. KW OUTPUT

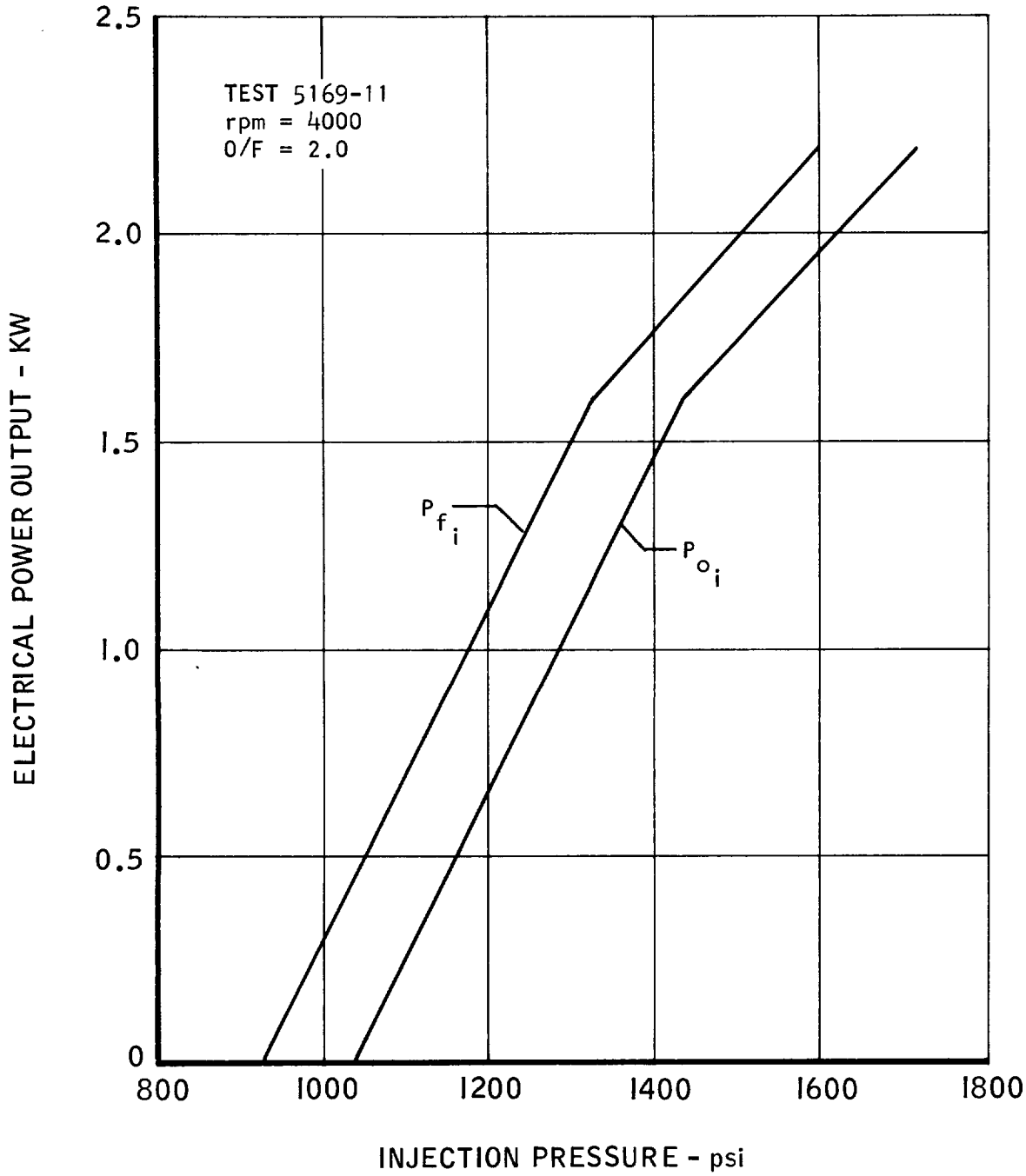
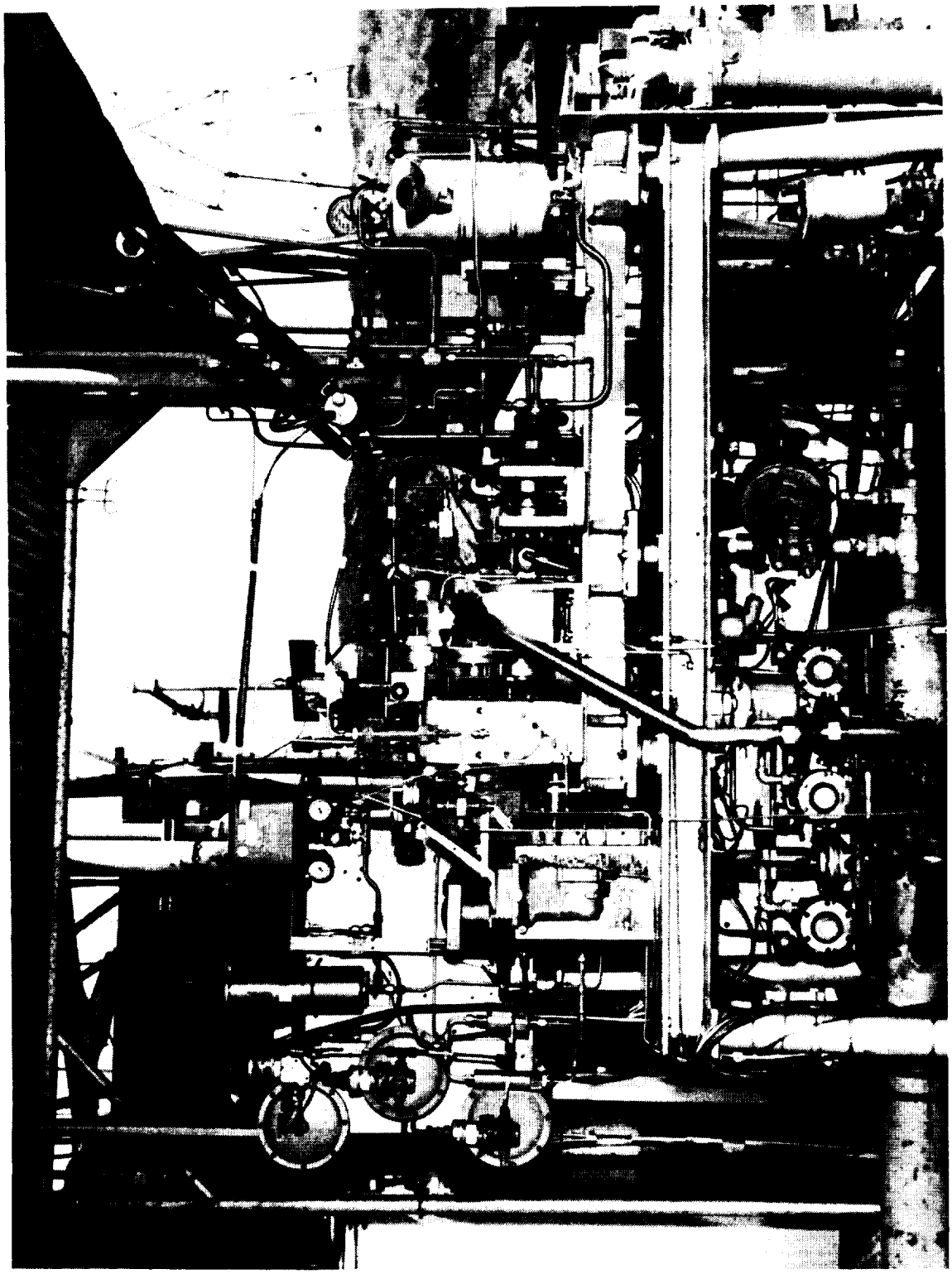
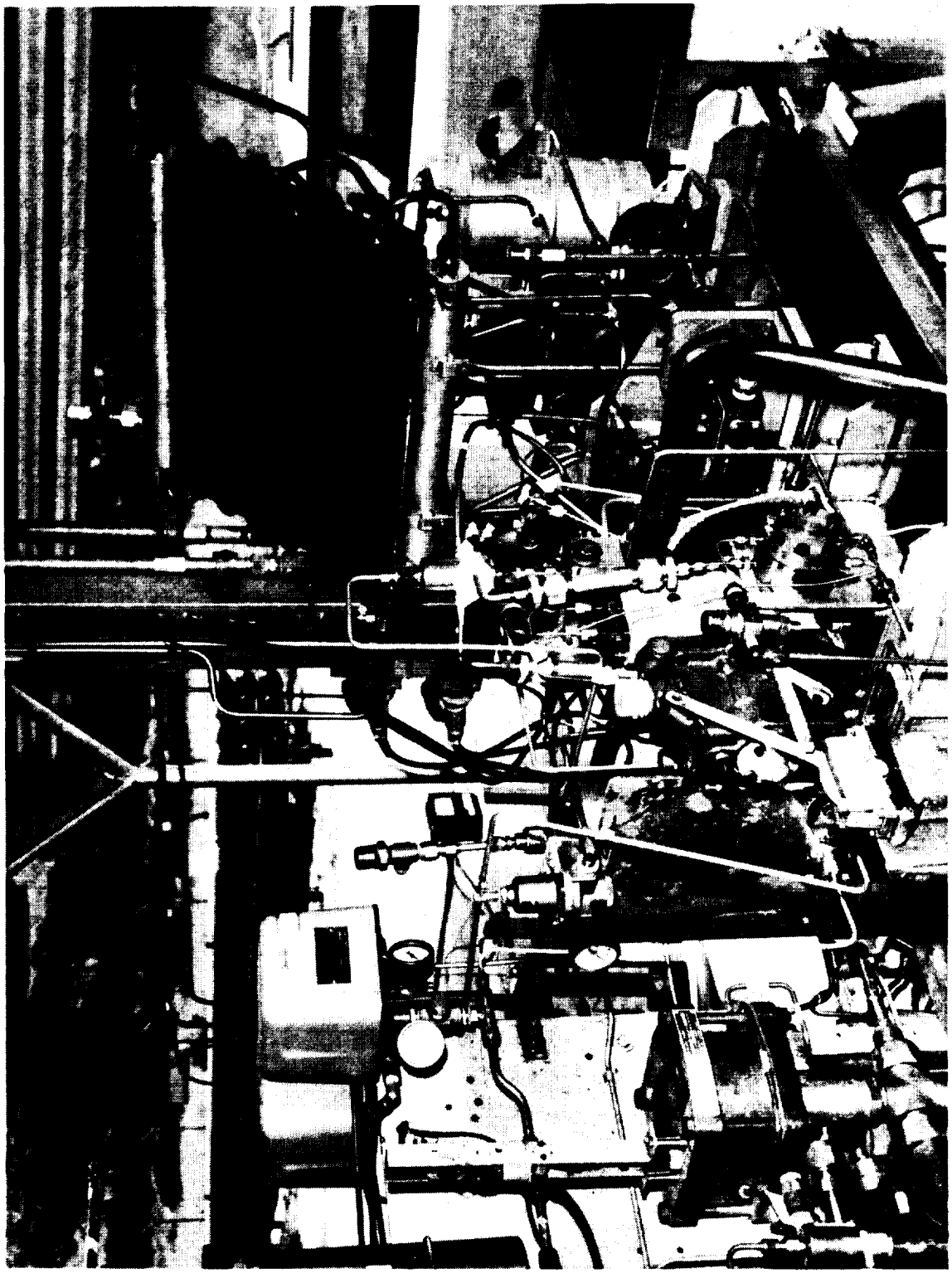



FIGURE 21



T5169-15

FIGURE 22. Installation of Complete SPU-3 Breadboard System in Test Cell S-7 at RFL, Saugus



T5169-14

FIGURE 23. Installation of Complete SPU-3 Breadboard System in Test Cell S-7 at RFL, Saugus

# TYPICAL SPACE POWER SYSTEM INSTALLATION

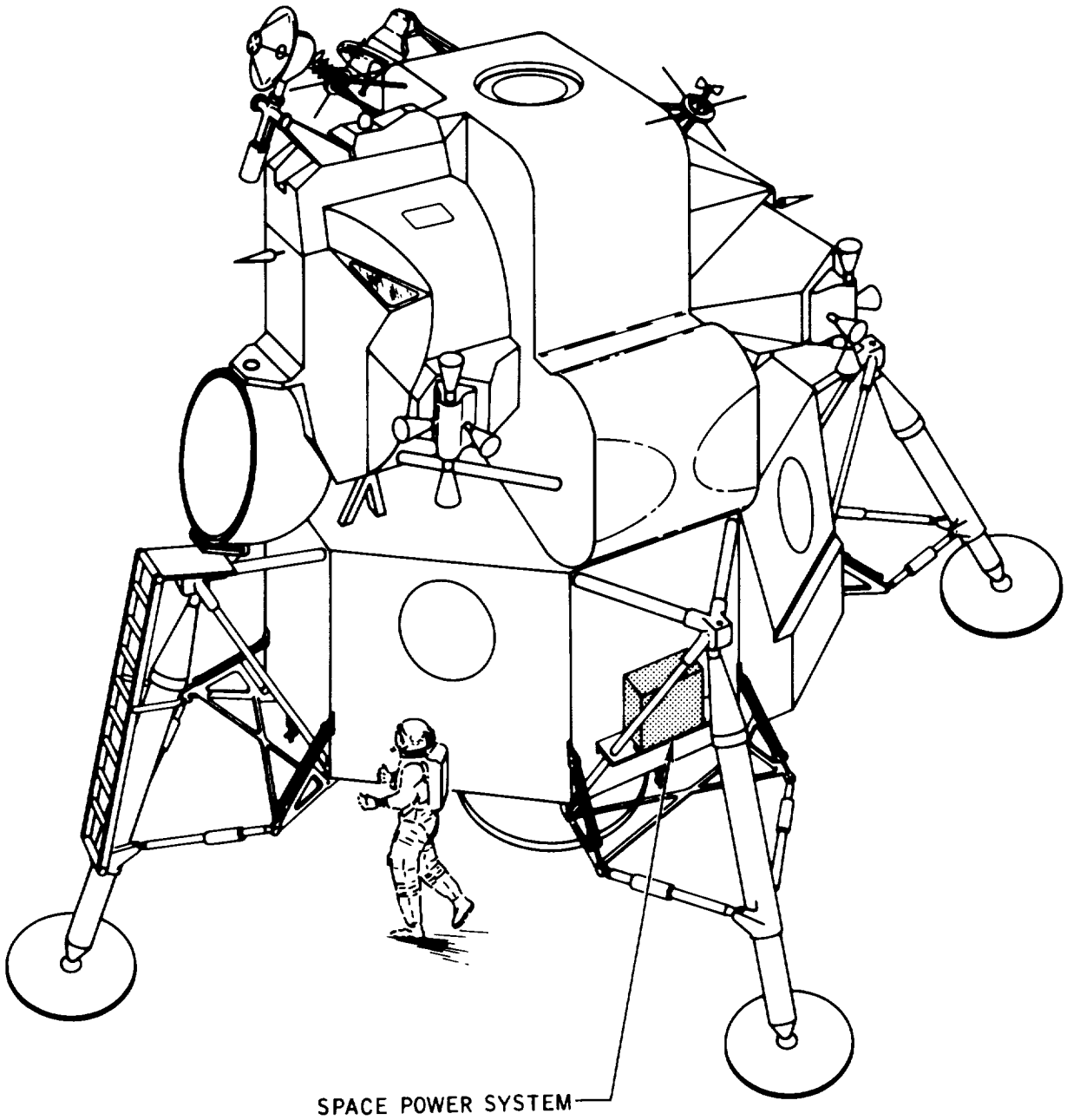
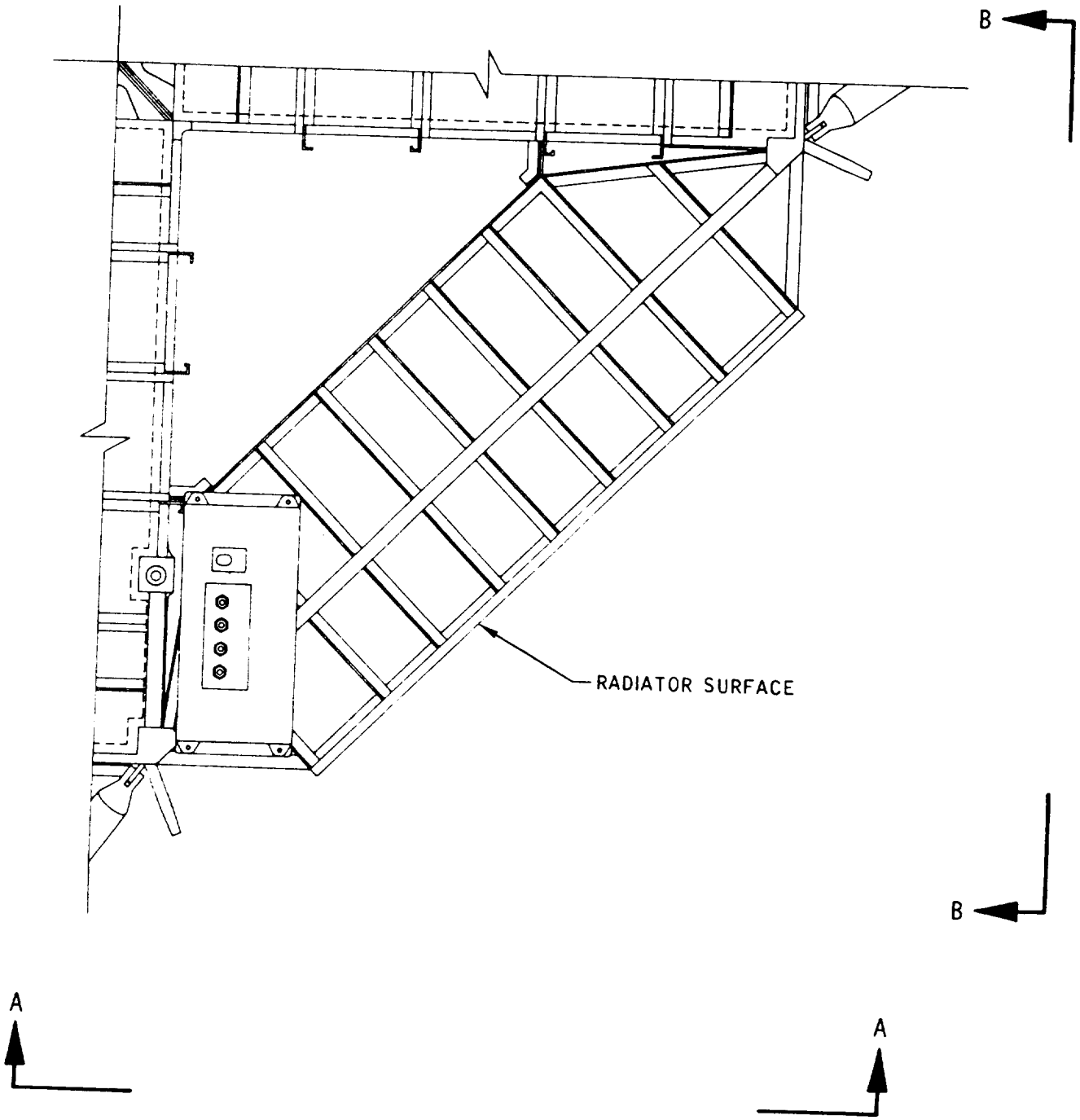
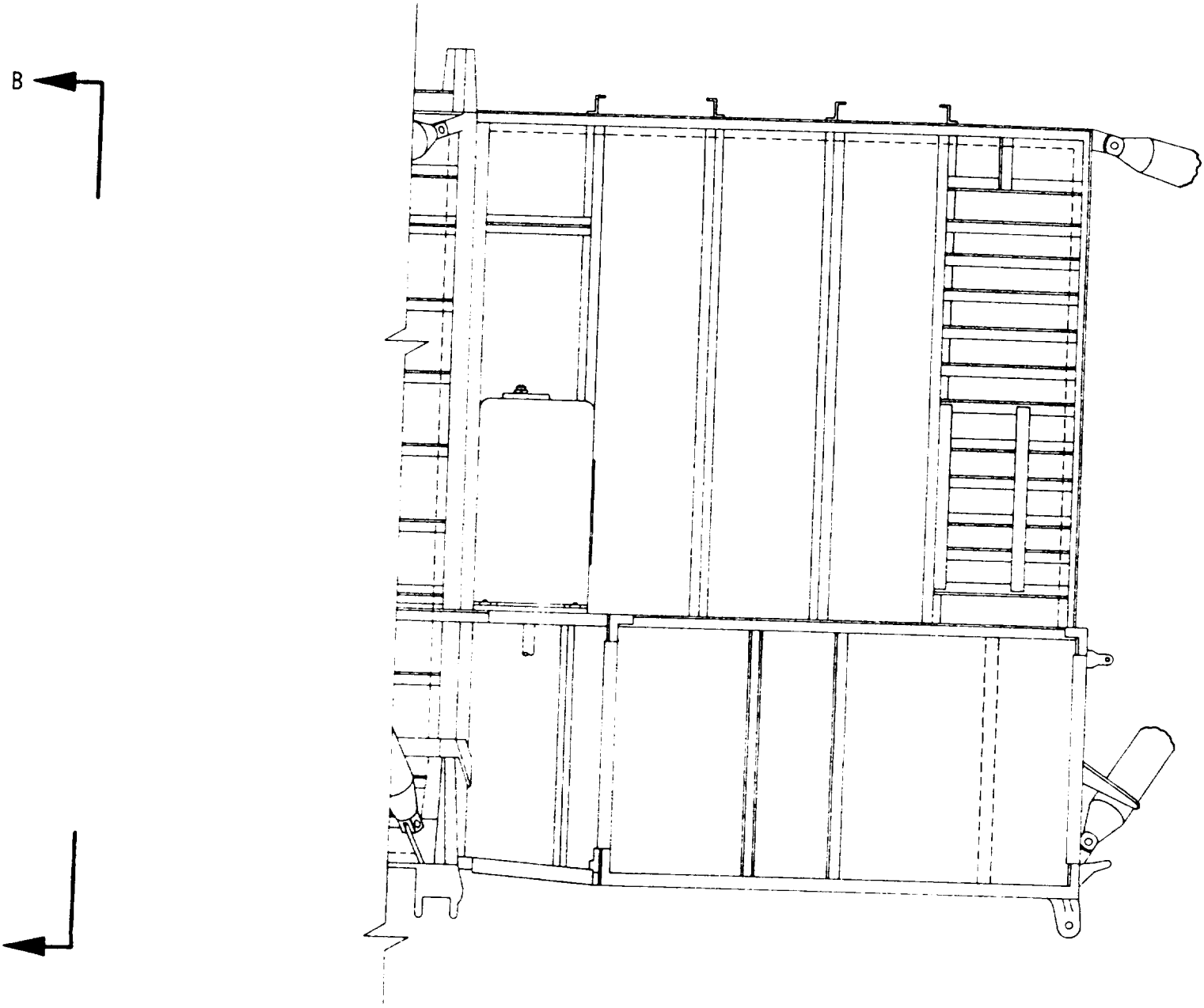


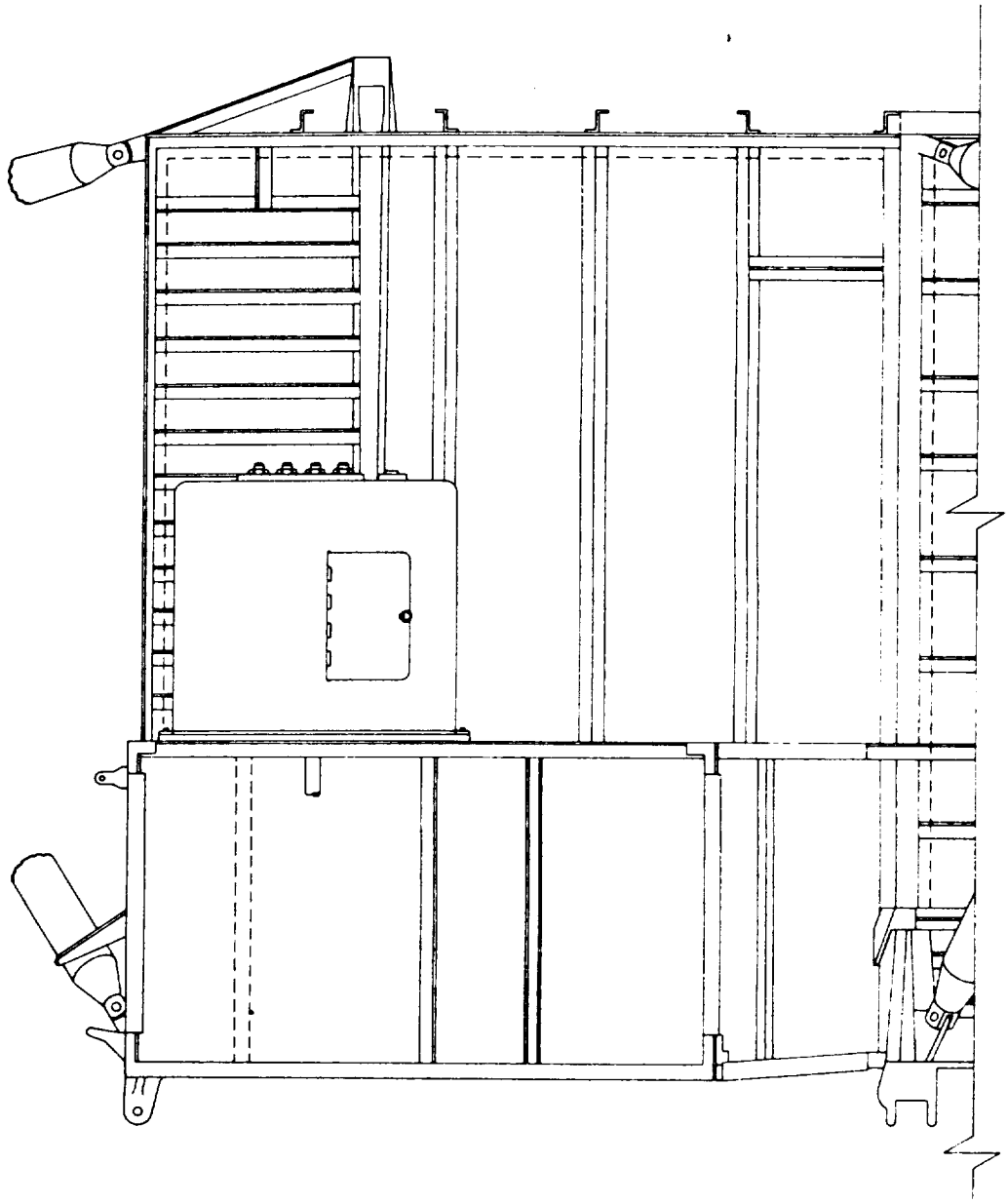

FIGURE 24


B
B
RADIATOR SURFACE
A
A

# SCIENTIFIC BAY INSTALLATION




VIEW A-A



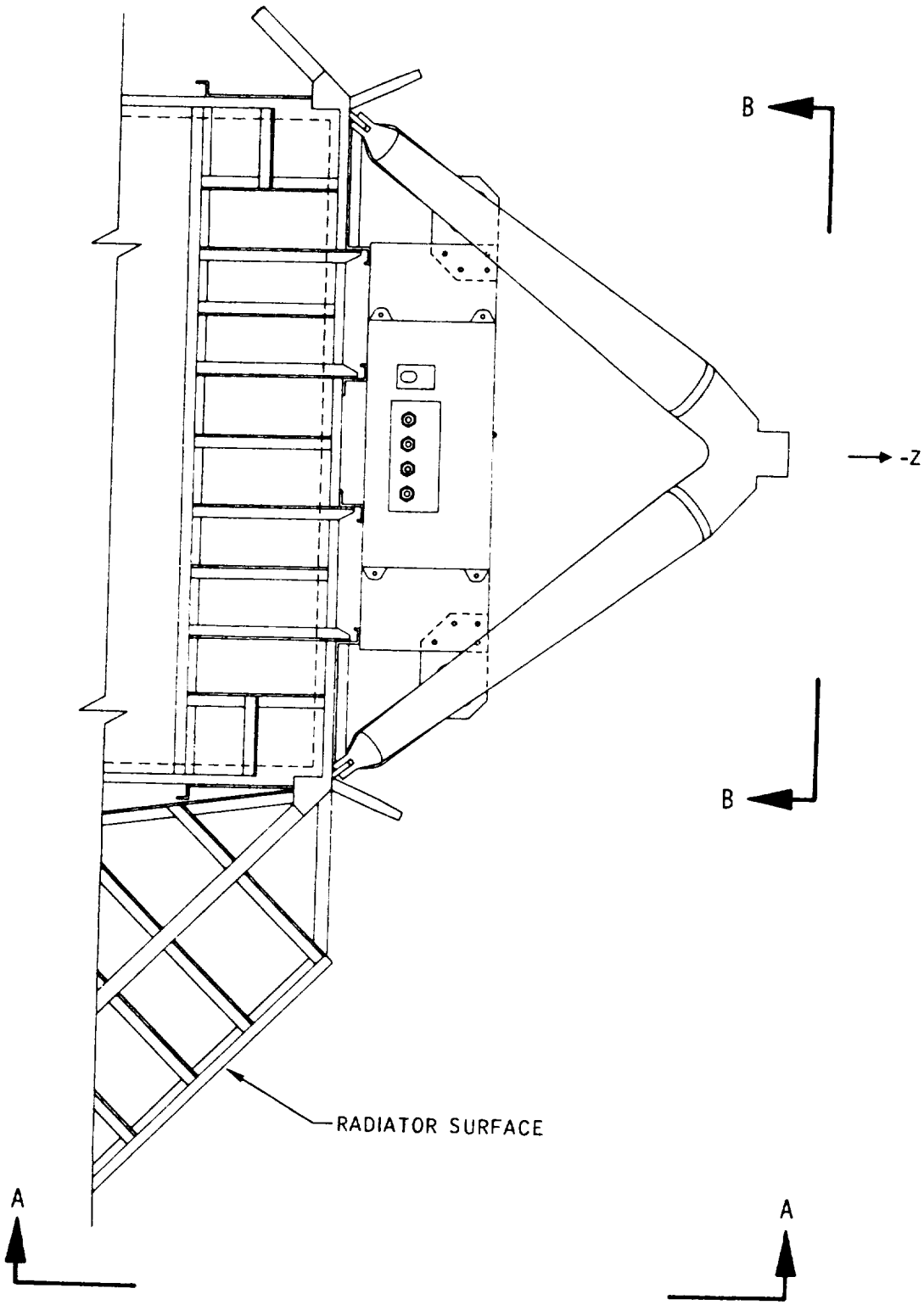
0 10 20
SCALE - INCHES

VIEW B - B
(ROTATED 90° CW)

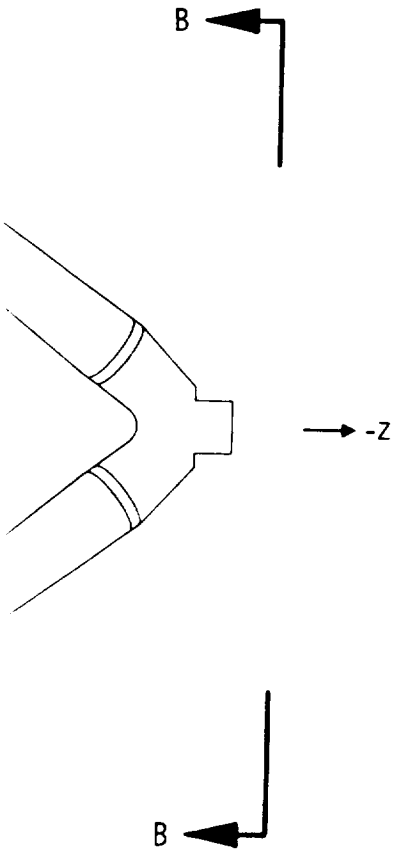
65-3

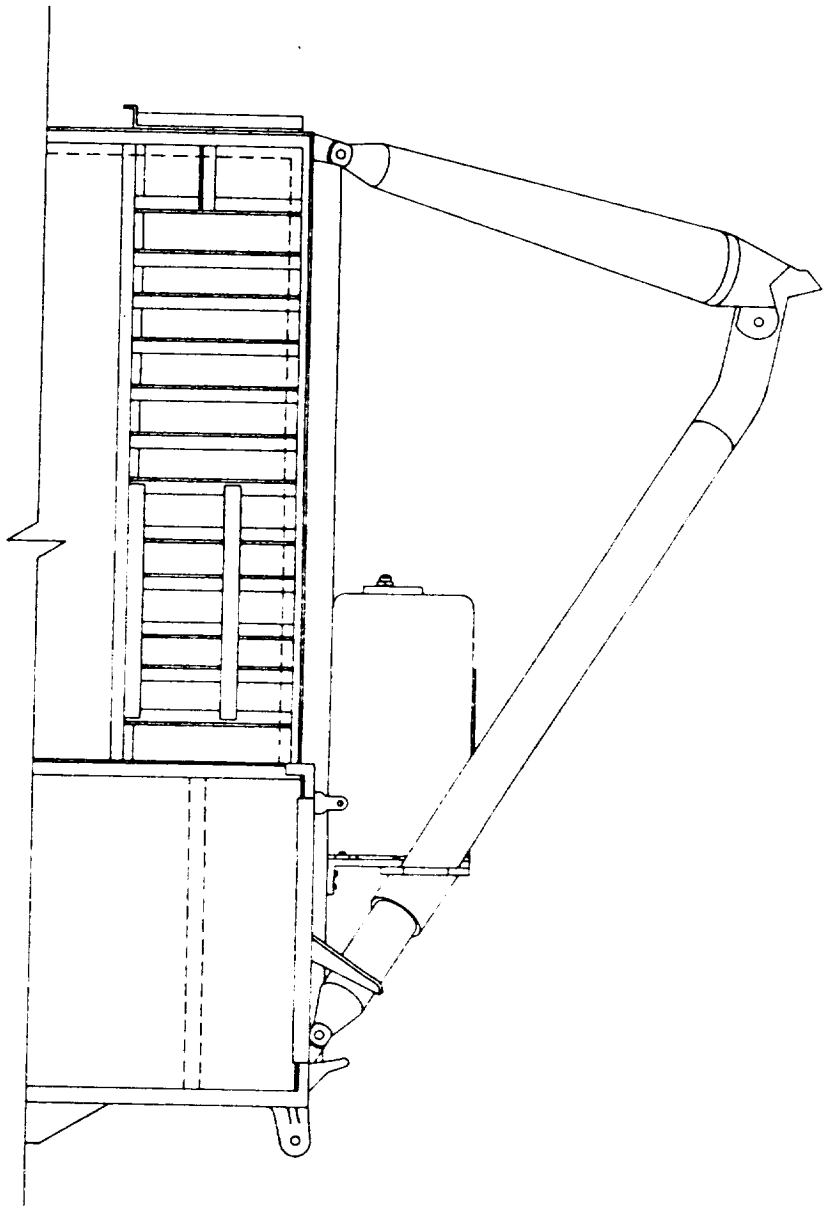


FIGURE 25

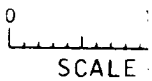

B
B
-Z
RADIATOR SURFACE
A
A

# LANDING GEAR STRUT INSTALLATION

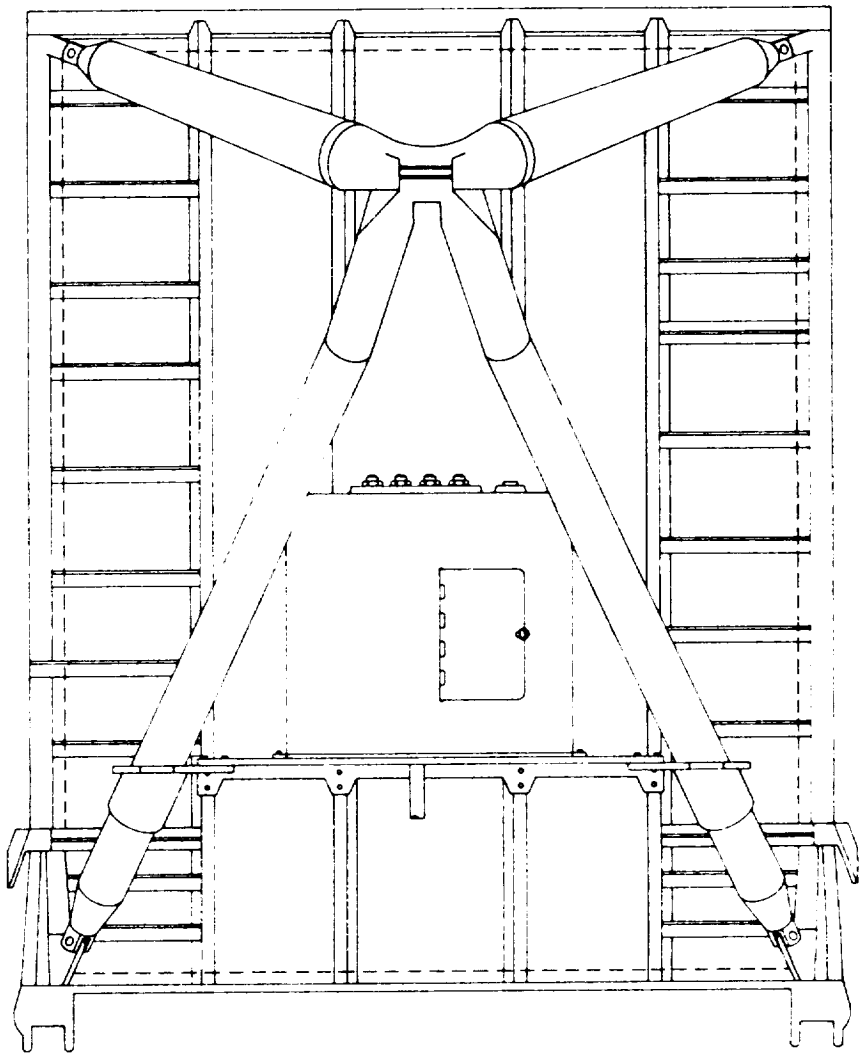


VIEW A-A




FIED



VIEW B - B
(ROTATED 90° CW)

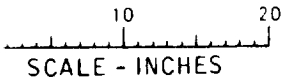



 FIGURE 26