

LM

PROPULSION AND RCS

COURSE NO. 30217

S T U D Y G U I D E

OBSOLETE

FOR TRAINING PURPOSES ONLY

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LM Training

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Preface

This document is designed to support  
the Propulsion and RCS Familiarization  
Course 30217



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Descent Engine Characteristics Report  
8438-6021-SC000

Ascent Engine Support Manual  
8258-954001

RCS Training Manual L1026

Miscellaneous Engine and Component  
Specifications and Data Sheets



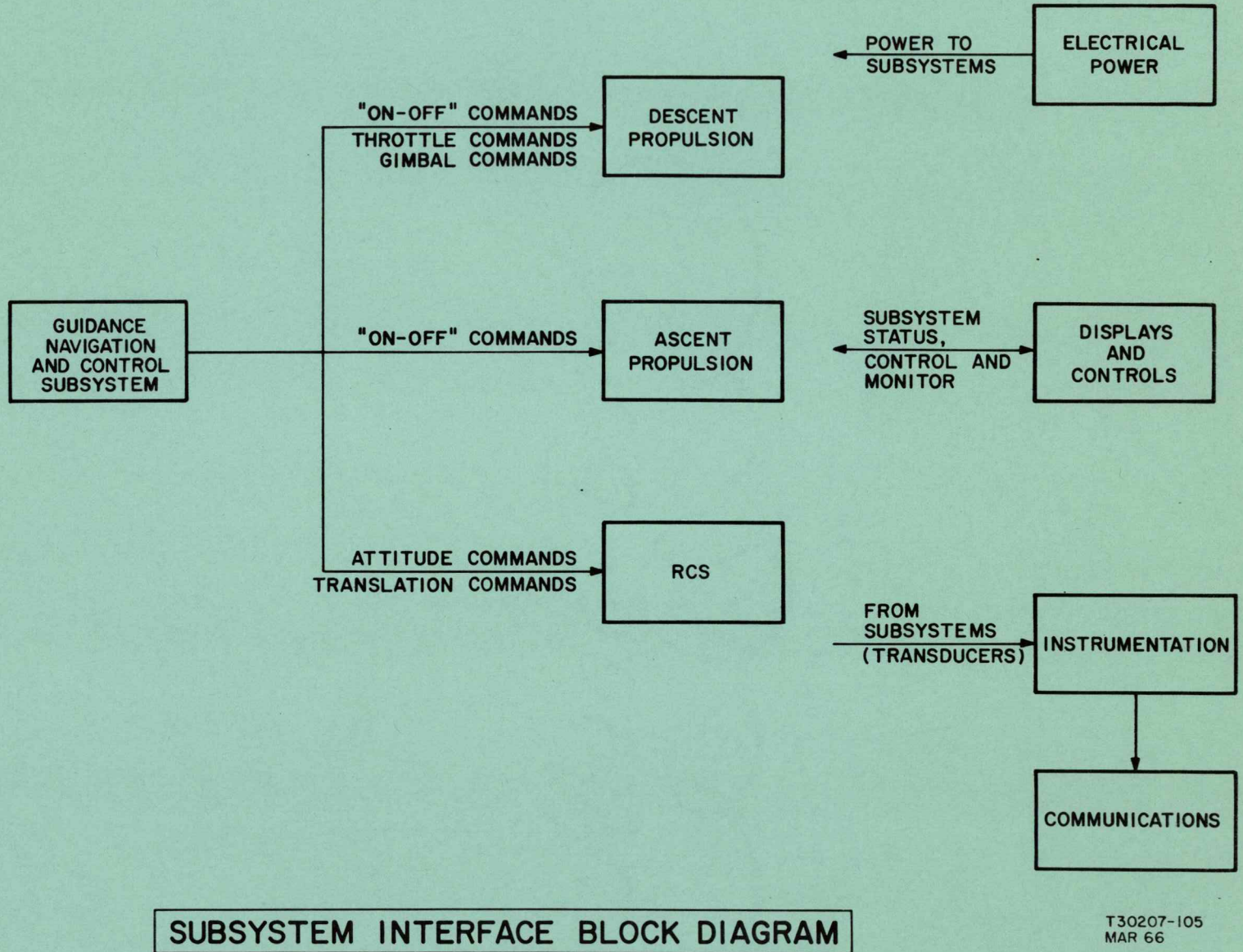
## Introduction

This study guide provides an operational description of the LM Descent Propulsion Subsystem, the LM Ascent Propulsion Subsystem and the LM Reaction Control Subsystem. It also includes chapters on the propellants, the control system and the ground support equipment used in conjunction with the above mentioned subsystems.

Each subsystem of the LM is functionally related to one or more of the other subsystems. A block diagram is presented showing the major relationships between the subsystems described in this study guide, and other subsystems. (See Figure 1.)

The information contained herein is for orientation and indoctrination purposes only. The scope of coverage provides an understanding of the functional operation of the Propulsion and RCS Subsystems. It is not intended to provide the latest, detailed engineering information.







## Chapter I

### LM Propellants

#### Introduction

The principal purpose of propellants is to impart motion to an object. Of the literally hundreds of oxidizer/fuel combinations that are possible, most are disqualified because they do not possess the specialized characteristics that would make them compatible with the demands of the LM mission. Indeed, no single propellant combination possesses all of the desirable properties and it was necessary to select those with properties that most closely met the requirements of the mission.

Primary characteristics demanded of LM propellants are: high performance per weight unit; storeability over long periods without undue vaporization or pressure build-up; hypergolicity for easy, closely spaced engine starts; no shock sensitivity; freezing and boiling points within controllable extremes; and chemical stability.

Nitrogen tetroxide, hydrazine and unsymmetrical dimethyl hydrazine possess all of these properties and were selected to be the LM propellants. (See Figure 2.)

#### Oxidizer

The oxidizer used with all the LM engines is nitrogen tetroxide ( $N_2 O_4$ ). It has a minimum purity of 99.5% and a maximum water content of 0.1%.

The color varies from yellow at the freezing point to red-brown at the boiling point. The vapors vary in color from orange to red-brown and have a sharp, pungent odor.

$N_2 O_4$  is a powerful oxidizing agent as it contains 70% oxygen by weight. It is not shock sensitive in its pure state, but does become shock sensitive when contaminated with organic substances. It is hypergolic with a number of fuels. It may be stored for an indefinite period without deterioration. Pure  $N_2 O_4$  (water content under 0.1%) is not corrosive, however water reacts with the  $N_2 O_4$  to form nitric acid, and whenever the water content exceeds 0.4% it becomes very corrosive.

The freezing point of nitrogen tetroxide is 12°F; the boiling point is 70°F.



## Fuel

The fuel used with all the LM engines is a blend of hydrazine ( $N_2 H_4$ ) and unsymmetrical dimethyl hydrazine, abbreviated to UDMH ( $(CH_3)_2 NNH_2$ ). This blend is obtained commercially by the name of Aerozine 50. The proportions of the blend are approximately: hydrazine 51.5%; UDMH 47.5%; water 1% maximum.

The color varies from colorless to a clear yellow and the vapors are colorless. The odor is like ammonia or "fishy."

Aerozine 50 is extremely flammable. It is hypergolic with nitrogen tetroxide and will ignite spontaneously if contaminated with metallic oxides. It is not shock sensitive and may be stored for indefinite periods without deterioration. However it is extremely hygroscopic and if exposed to air will deteriorate rapidly.

The freezing point of Aerozine 50 is  $21^\circ F$  and the boiling point is  $170^\circ F$ .

## Handling and Safety

Most of the regulations and precautions pertaining to handling and safety of the oxidizer also pertain to the fuel and vice versa. Therefore, unless otherwise stated, the following list should be taken to pertain to both propellants.

## Hazards

1. These propellants are very corrosive to body tissues. Even short exposure to  $N_2 O_4$  can cause severe acid burns and the fuel can penetrate the skin and cause severe systemic affects.
2. Contact with the eyes will cause severe irritation; temporary or permanent blindness.
3. First aid consists of flushing the affected areas with large amounts of water. Contaminated clothing should be removed. The eyes should be treated by flushing with water for 15 minutes. Then obtain medical attention.
4. The propellants are extremely toxic. Short exposure to the fumes can cause severe illness. Longer exposure can lead to death. Symptoms of exposure are cough, nausea, chest pain, shortness of breath. Persons exposed to the



fumes should be carried from the area and kept quiet and under medical observation. If breathing stops apply artificial respiration and administer oxygen.

5. In case of fire promptly shut off the flow of propellants and apply large quantities of water. If the fire cannot be promptly controlled, evacuate the area.

### Safety

1. All operations involving propellant handling should be performed by 2 or more persons (Buddy system).
2. Guard against spills, splashes and vapor inhalation.
3. Wear approved type protective clothing and goggles. If a dangerous concentration of fumes is present wear a self contained air supply source. (The canister type mask is of limited value only.)
4. Do not work on a pressurized system. (Remember that  $N_2 O_4$  boils at  $70^\circ F.$ ) Work from above or the side; never work below a propellant line.
5. Check safety showers and eye wash fountains regularly for proper operation.

### Transfer & Storage

1. Storage tanks and shipping containers will usually be made of stainless steel.
2. The recommended sealing material is teflon.
3. Only special lubricants should be used. (Do not use regular oils or greases.) Degrease all parts before exposing them to the propellants.
4. Oxidizer storage tanks should be vented to prevent internal pressure build-up.
5. Storage facilities should be diked or separated by distance. (Never store oxidizer and fuel containers together.)
6. All electrical equipment should be vapor proof.



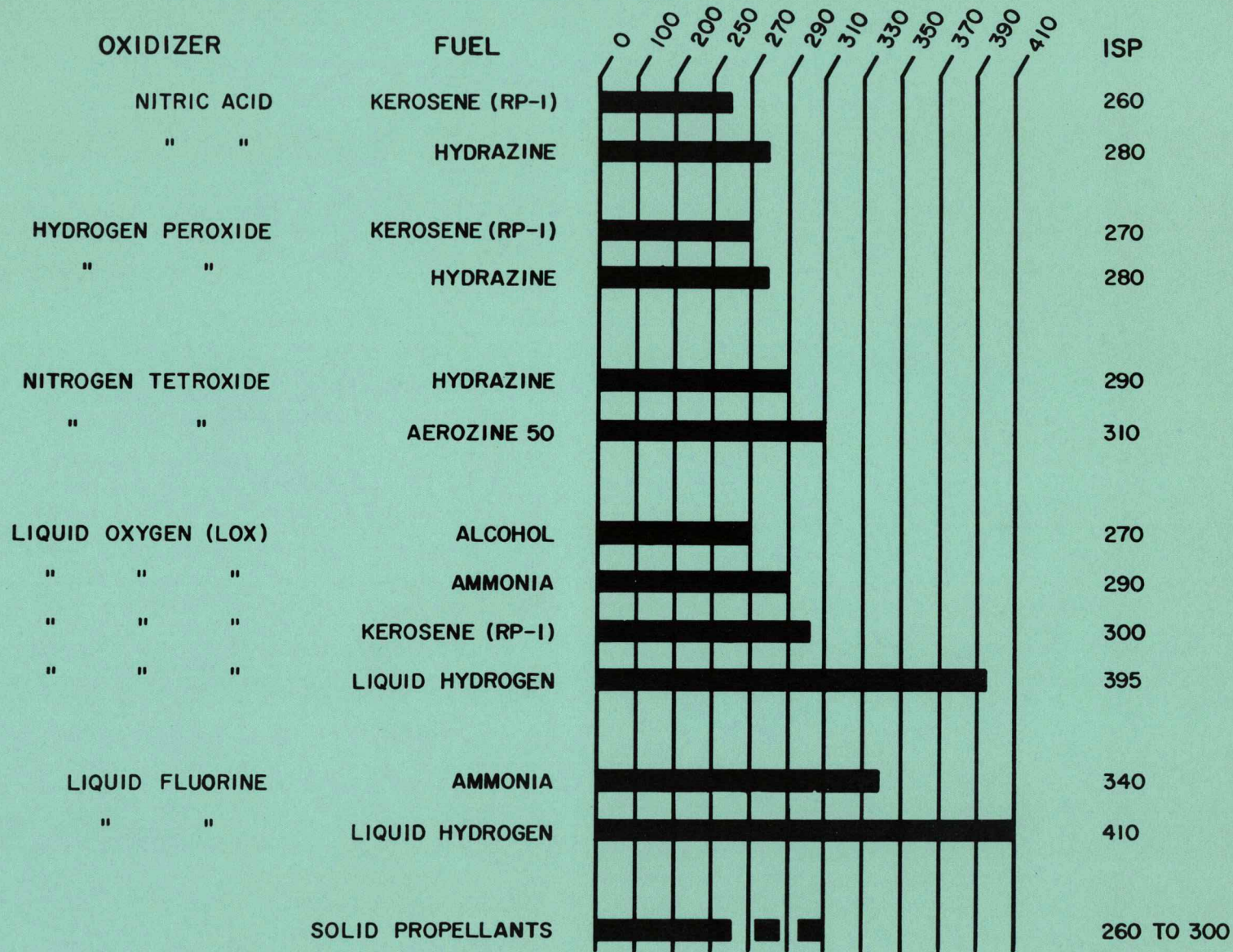
7. All storage and handling equipment for the fuel should be grounded to prevent build-up of static electricity.
8. An alarm system should be provided to give warning if the vapor concentration reaches the MAC. (Maximum acceptable concentration.)
9. Spills should be flushed away with large quantities of water. (Small oxidizer spills may be permitted to boil off naturally if the area is well ventilated.)
10. Storage and transfer of the fuel should be accomplished under a nitrogen blanket to prevent water absorption and reduce the fire hazard.

#### Summary

There are many propellant combinations, each with its own characteristics and performance level. The LM propellants, nitrogen tetroxide and Aerozine 50 are particularly suitable for the purpose for which they were selected, but hazards inherent in their use demand special care in handling.

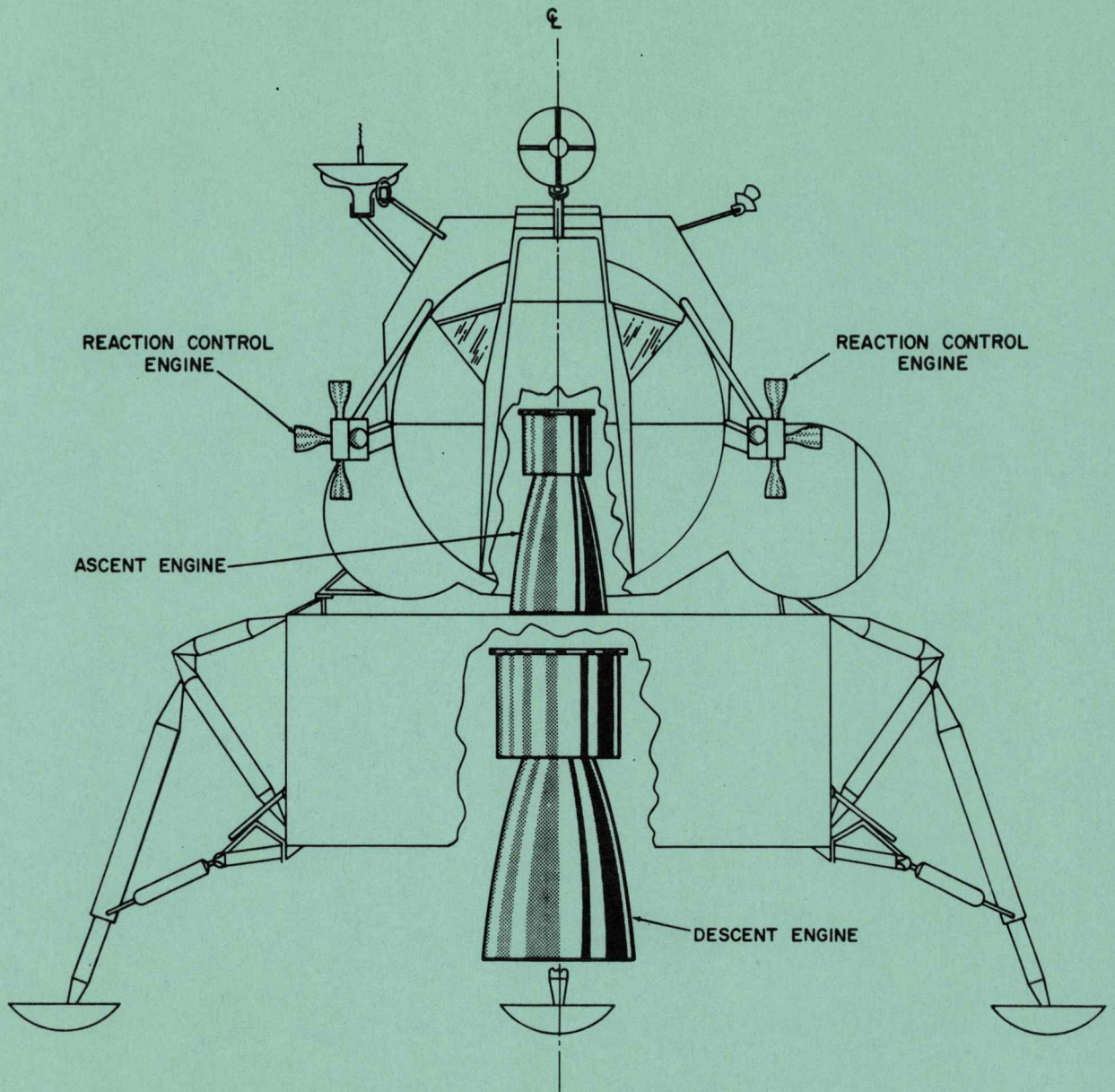
These propellants are hypergolic, and corrosive and toxic to body tissues. The ever constant hazards of fire and severe personnel injury demand strict adherence to safety precautions.





**PROPELLANT COMBINATIONS**

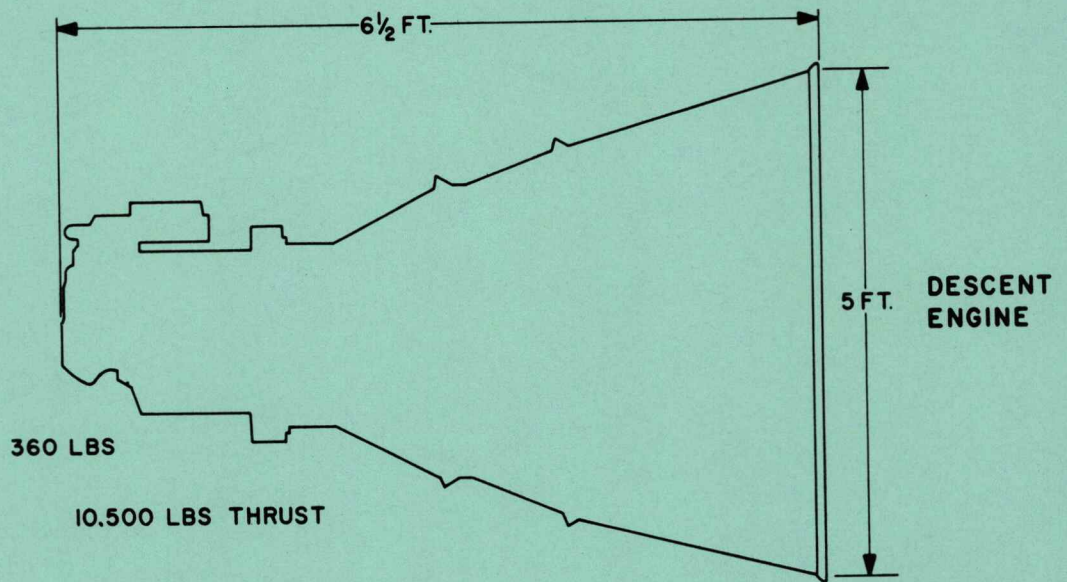
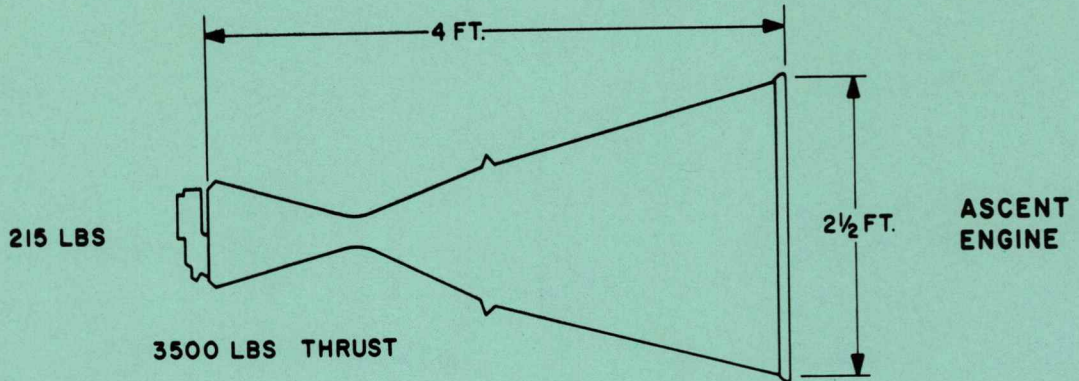
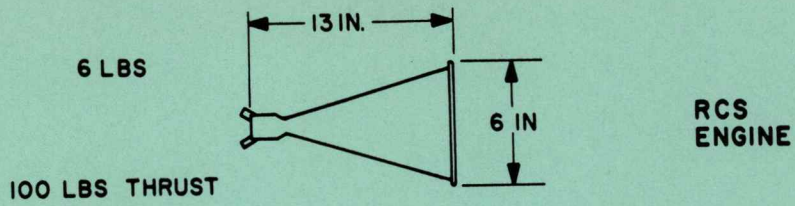




LM ENGINE LOCATIONS

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**LM ENGINE COMPARISONS**

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## Chapter II

### LM Propulsion Subsystems

#### Introduction

The LM uses separate descent and ascent propulsion subsystems, each of which is complete and independent of the other and consists, basically, of a liquid propellant rocket engine with its propellant storage, pressurization and feed components. The descent propulsion subsystem is wholly contained in the descent stage and uses a throttleable - gimballed engine which serves the following purposes:

1. Provides the thrust to move the LM from an 80 mile circular lunar orbit to an elliptical coasting descent transfer orbit.
2. Provides the thrust to control the rate of descent from 50,000 ft. to the lunar surface.

The ascent propulsion subsystem is wholly contained in the ascent stage and uses a fixed, constant thrust engine which serves the following purposes:

1. Provides the thrust for a powered ascent from the lunar surface and insertion into an 80 mile circular lunar orbit.
2. Provides the thrust for any orbit adjustments that may be necessary for successful rendezvous with the command/service module.

In addition, the ascent propulsion subsystem provides back-up propellant to the RCS.

In case of a mission abort the LM can be placed into a rendezvous trajectory with the Command/Service Module from any point in the descent trajectory. The choice of engine or engines to be used depends on the cause for abort and the amount of propellant remaining in the descent stage.

#### Propulsion Subsystem Components

Because of their functional similarity, descent and ascent subsystem components will be described in one grouping.



1. Helium Storage Tanks. (Ascent Subsystem) Gaseous helium is stored under high pressure (3500 psi) in two spherical titanium storage tanks. This helium is used as a pressurant to expel the propellants from the propellant storage tanks during periods of engine operation.
2. Helium Storage Tanks. (Descent Subsystem) Supercritical helium is stored in a double walled cryogenic storage container. It consists of an inner spherical tank with an outer jacket; the void between the tank and its jacket is filled with aluminized mylar insulation and evacuated to minimize heat transfer. The material used is titanium. The tank has associated fill and vent ports and a pressure relief device consisting of two burst discs, in series. Inside the inner tank is a helium/helium heat exchanger constructed of titanium tubing. A separate storage tank is used by the descent subsystem to provide pressurization of the propellant tanks and the complete filling of the ullage space prior to the initial engine start. This is a spherical titanium tank containing gaseous helium at intermediate pressure. (about 1600 psi)
3. Fuel/Helium Heat Exchanger. (Descent Subsystem) The helium flows through this heat exchanger and absorbs heat from the engine fuel which flows from the tanks and through the heat exchanger before its ultimate delivery to the engine. It is a two pass unit, that is, helium from the supply tank flows through the first pass and back to the supply tank internal heat exchanger to pre-heat the helium supply. It then makes a second pass through the fuel/helium heat exchanger and is brought to a desirable operating pressure.
4. Helium Isolation Valve. A normally closed, explosively operated squib valve isolates the helium supply in its tanks until propellant tank pressurization is required. These valves are opened by an electrical signal. They are one shot valves, once opened they cannot be closed again. (See Figures 5 and 6.)
5. Helium Filter. Contaminants from the helium storage tanks or debris generated by the actuation of the isolation valve are trapped by the filter to prevent contamination of downstream components. (See Figure 7.)
6. Regulator Shut-off Valves. There are two latching type shut-off valves, one for each regulation leg. They are



used to shut off helium flow through their respective leg should the pressure regulation component in the leg fail open. In the descent subsystem the shut-off valves are one normally open and one normally closed; in the ascent subsystem both valves are normally open. (See Figures 8 and 9.)

7. Pressure Reducing Regulators. (Descent Subsystem). There are two regulators in parallel, one in each regulating leg. Normally only one regulator leg is used, but should a failure occur the parallel redundant leg is available. Each regulator contains a pilot valve and seat assembly which modulates inlet pressure to control the opening of a main poppet valve and seat assembly, and has the ability to reduce the upstream pressure to that required to provide correct propellant tank pressurization. (Ascent subsystem) This regulating system is functionally similar to the one used with the descent subsystem, except that four regulators are used in a series-parallel arrangement, two regulators in each leg. This arrangement provides the overall regulation system with added redundancy. (See Figures 10 and 11.)
8. Quad Check Valves. This assembly consists of four check valves arranged in a series - parallel configuration. The purpose is to prevent the mixing of propellants or propellant fumes in the upstream pressurization manifold. (See Figure 12.)
9. Relief Valve Assy. This assembly is installed to prevent propellant tank damage in case of an open failure of the pressure reducing regulators, with resulting system overpressurization. A burst disc isolates the relief valve from the helium pressurization system during normal operation and so prevents helium loss through a possibly leaking relief valve. If overpressurization occurs the burst disc will rupture and excess helium will be dumped overboard through a thrust neutralizer which eliminates thrust generated by the escaping gas. When the pressure drops below the nominal setting the relief valve closes preventing further helium loss and permitting a resumption of normal operation. A normally open vent valve, located between the burst disc and the relief valve, will prevent any pressure build up in this area, should the burst disc leak. Following any system overpressurization and burst disc rupture this vent valve will close. (See Figures 13 and 14.)



10. Propellant Storage Tanks - (Descent Subsystem). There are four propellant storage tanks in the descent subsystem. Two for oxidizer and two for fuel. All four tanks are identical insofar as size and construction are concerned. They are cylindrical and have hemispherical ends; the material used in their fabrication is titanium. These tanks have a total capacity of approximately 18,000 lbs of propellant. Each tank is equipped with a helium diffuser at the inlet to provide even pressurization at the helium/propellant interface. A series of vanes are arranged at the tank outlet to prevent propellant swirling in the out-line. A negative "G" can is also installed at the outlet of each tank. These devices allow unrestricted propellant flow from the tank to the engine under normal pressurization, but will not allow reverse flow of propellant from the outlet line back into the tank under zero "G" conditions, or even at the maximum negative "G"s expected. Thus, helium can never enter the outlet line and the possibility of engine malfunction due to helium infusion is eliminated. The tanks are not baffled. A probe is installed in each tank for the propellant quantity gaging system. (See Figure 15.) Ascent Subsystem: There are two propellant storage tanks in the ascent subsystem, one for oxidizer and one for fuel. These tanks are spherical and have a combined capacity of approximately 5,000 lbs of propellant. They are identical, made of titanium and each contains, as do the descent subsystem tanks, a helium diffuser, anti-swirl device and negative "G" can. They are not baffled, and have a low level warning device installed at the tank bottom. (See Figure 16.)
11. Explosive Safety Valves. (Descent Subsystem) Located between the quad check valve assembly and the propellant tanks in each leg is a single, normally closed, squib valve. This valve serves the purpose of forming a positive seal and makes it impossible for any propellant fumes to reach the quad check valves during the period from propellant tank servicing prior to earth launch until just prior to descent engine operation. It is a one shot valve. After it has been opened, and during subsequent periods of descent engine shutdown, the quad check valve assemblies will be depended upon to prevent propellant fume leakage. (Ascent Subsystem) Functionally, the explosive safety valves serve the same purpose in this subsystem as they do in the descent subsystem. The only difference is that two valves, arranged in parallel, are used in each leg to provide redundancy.



12. Actuator Isolation Valves. Because of the possibility of fuel leakage at the ascent engine propellant shut-off valve actuators actuator isolation valves have been installed in the fuel line between the fuel tanks and these actuators. These valves will be opened immediately prior to engine start, simultaneously with the engine shut-off valves. To provide redundancy, two valves are used, in a parallel arrangement.
13. Trim Orifices. These orifices are placed in both propellant lines downstream of the tanks. Their function is to meter the propellants and so insure engine interface pressure requirements for proper propellant utilization.
14. Propellant Filters.| The function of the filters is to trap contaminants originating in the propellant tanks and so prevent contamination of downstream components. (See Figure 17.)
15. Depressurization Valves. (Descent Subsystem Only) An explosive squib valve and a solenoid shut off valve are placed in series up-stream of each propellant tank pair. Subsequent to lunar landing the propellant tanks can be safely depressurized by opening the squib valves and selectively opening and closing the solenoid valves. The helium and propellant vapors thus released will be discharged through the thrust neutralizers.
16. Flexible Couplings. On the descent engine only, flex couplings are used in each propellant line close to the engine mounting. Their function is to permit relative motion during engine gimbaling.
17. Plumbing. All helium supply lines and propellant feed lines are made of stainless steel. Brazed connectors are used throughout.

Functional Description of the Descent Helium Pressurization and Propellant System Operation. (See Figures 18 and 19.)

Supercritical helium can be stored at a much higher density (about 3 times as high) as ambient helium. Therefore, the use of this type of pressurization system will result in a considerable weight saving. The cryogenic storage tank is initially vented and loaded with liquid helium. Then the vent is closed and a pressure head of gaseous helium, at a higher temperature than that of the liquid helium, is forced into the tank. As this occurs, the temperature transfer causes the liquid helium to evaporate into a high density gas, that is, it becomes supercritical.



A normally closed explosive valve isolates the helium supply until the valve is fired at the initial engine start. When the squib is fired, helium initially passes through the first loop of a two-pass fuel/helium heat exchanger, where it is permitted to absorb heat from the engine fuel, which has been circulated from the fuel tanks directly to the heat exchanger, before its ultimate delivery to the engine. The warmed helium is then routed back through the internal heat exchanger inside the storage vessel; the resultant heat transfer to the remaining gas in the vessel maintains the continuing pressure required to expel the helium throughout the entire period of operation. After passing through the internal heat exchanger, the helium is routed back through the second loop of the fuel/helium heat exchanger and postheated for temperature conditioning before delivery to the pressure reducers.

The helium in the storage tank is loaded to a pressure of 100 psia at a temperature of about  $-455^{\circ}\text{F}$ . Due to heat transfer across the wall of the tank there will be a gradual pressure rise of about 10 psi/hr.

After the squib valve is blown and the system put into operation the tank pressure will stabilize in the 1200-1600 psia range and the temperature at about  $-400^{\circ}\text{F}$ . During system operation the tank pressure will, of course, gradually decrease. Helium temperature, after the second pass through the fuel/helium heat exchanger will be about  $-35^{\circ}\text{F}$ .

Should excessive heat transfer across the tank walls occur internal pressures will increase beyond the burst pressure of the protective burst discs and the entire helium supply will be lost.

Downstream of the fuel/helium heat exchanger the helium flow continues through a filter which is designed to trap any debris originating in the squib valves. It will protect downstream components from contamination.

After the filter the pressurization section divides into two flow paths. Each path contains a latching type solenoid shut-off valve and a pressure regulator. Normally, one shut-off valve is open and the other one is closed. Helium, flowing through the open shut-off valve, will have its pressure reduced by the downstream pressure regulator and will then continue downstream to pressurize the propellant tanks. Nominal regulator pressure setting is 245 psi. Should an open or closed failure of the pressure regulator occur the pressure at the downstream manifold will either increase or decrease beyond acceptable limits and a warning light on



the cockpit display panel will come on. Crew action is now required to close the shut-off valve in the malfunctioning leg and to open the shut-off valve in the redundant leg, restoring normal propellant tank pressurization.

In addition both shut-off valves will be kept closed during coast periods of descent to prevent inadvertent helium loss due to possible leakage through the pressure regulators.

The primary and redundant helium flow paths merge downstream of the regulators to form a common pressurization manifold. From this manifold the pressurization section again divides into two flow paths, one path leading to the oxidizer tanks; the other leading to the fuel tanks. Each path incorporates a quad check valve assembly in a series - parallel arrangement designed to prevent backflow of propellants or fumes from the propellant tanks into the common helium pressurization manifold, after initial propellant tank pressurization and descent engine usage.

Downstream of the quad check valves in each flow path is a single-normally closed, explosive operated valve. These valves will be opened just prior to initial propellant tank pressurization, a brief time before the first descent engine start. The purpose of these valves is to form a positive seal upstream of the propellant tanks, eliminating the possibility of regulator corrosion or hypergolic propellant fume mixing in the upstream helium manifold, prior to initial propellant tank pressurization.

Just prior to reaching the fuel and oxidizer storage tanks, each flow path contains safety provisions to insure propellant tank integrity in case of overpressurization. The fuel and oxidizer tank sets each incorporate an overboard relief capability if supply pressures exceed designated safety margins. The relief valves will vent overpressure through a thrust neutralizer which eliminates unwanted thrust generated by the escaping gas and will reseal the system after expulsion of the overpressure. To prevent possible leakage through a faulty relief valve during normal system operation, a burst disc isolates the relief valve from the rest of the system. This burst disc will rupture at a pressure slightly below the relief valve setting.

The helium is introduced into the tanks and acts directly on the surface of the fluids to force them into the propellant feed lines. Each pair of tanks is manifolded into a common discharge line that contains a filter and trim orifice from which oxidizer is piped directly to the engine, and fuel is piped directly to the



fuel/helium heat exchanger, and then to the engine. Both fuel and both oxidizer tanks are also interconnected by a double crossfeed piping arrangement to maintain positive pressure balances across the upper (helium) portions and lower (propellant) portions of each pair.

The filter prevents any debris originating at the squib safety valve or in the propellant tank from contaminating downstream components.

The trim orifices are designed to provide engine interface pressure requirements for proper propellant utilization.

An additional flow path branches off at a point just downstream of the outlets of the fuel tanks. It leads to two solenoid valves, arranged in parallel for purposes of redundancy, and from there to the four engine shut off valve actuators. The purpose of these valves is to prevent possible fuel loss through leakage at the actuator pilot valves prior to initial engine operation and during periods of engine shut-down. These solenoid valves, called actuator isolation valves, are opened or closed simultaneously by the arming or disarming of the descent engine.

During normal system operation freeze up of the fuel/helium heat exchanger is not an area of concern. At any thrust level of engine operation the fuel flow rate and the helium flow rate are such that the heat exchanger wall temperatures are above the fuel freezing point. (See Figure 20.)

However, prior to the initial engine start it will be necessary to pressurize the propellant tank ullage space to normal operating pressure. These tanks are partly pressurized prior to earth launch, but full pressurization at this time, particularly of the oxidizer tanks, is not desirable because of the possibility of stress corrosion. If the in-flight pressurization were to be achieved using supercritical helium, then the high helium flow rate without any corresponding fuel flow could probably result in a freeze up of the fuel/helium heat exchanger. To avoid this, the in-flight pressurization is accomplished using ambient helium.

The installation consists of a small tank containing gaseous helium, a squib valve and a filter. When in-flight pressurization is required the squib valve is opened releasing the helium, which flows through the filter and enters the main system at a point between the normally closed solenoid valve and the pressure regulator. The helium that had been contained in the tank at about 1600



psia thus passes through the regulator, has its pressure reduced to about 245 psia and continues on to pressurize both propellant tanks. Now the engine bi-propellant valves can be opened and the engine will start. A propellant flow, in particular, a fuel flow through the heat exchanger is established. A second or two after the opening of the bipropellant valves, an automatic signal will open the isolating squib valve downstream of the supercritical helium tank and supercritical helium flow is initiated. Because a corresponding fuel flow has already been established there will be no danger of a heat exchanger freeze up.

During any subsequent engine start there will be no danger of a heat exchanger freeze up, because the propellant tank pressure will already be at the normal operating value and there will be no helium surge to fill up the ullage space. Opening the engine bi-propellant valves will establish a simultaneous flow of supercritical helium and fuel through the heat exchanger that is within the normal operating range.

Subsequent to lunar landing it will be necessary to depressurize both propellant tanks to preclude the possibility of an untimely opening of the tank relief assemblies, caused by a pressure build up inside the tanks due to engine heat soak back. To achieve this, an explosive valve and a solenoid operated shut-off valve are installed upstream of the propellant tanks, parallel with the burst disc and relief valve assembly. There will be one such valve pair upstream of the oxidizer tanks and one upstream of the fuel tanks. Operation calls for simultaneous operation of the explosive valves and selective operation of the solenoid shut-off valves. The helium and propellant fumes will be discharged overboard through the thrust neutralizers downstream of the relief valve assemblies.

#### Propellant Quantity Gaging System. (See Figure 21.)

A capacitance type quantity gaging system is used to provide propellant quantity information to the crew. The system will be in operation from the start of descent braking until the lunar touchdown. The PQGS will be a continuous gaging system with capabilities for gaging propellants in each descent stage tank between 95% of propellants remaining and one inch of the tank bottom. Quantity information is displayed in the cockpit on two 2 place digital displays. In addition the PQGS will provide a discrete signal when the propellant level is a predetermined distance from the tank bottom. This low level signal will provide a warning 2 minutes prior to propellant depletion, when the engine is operating at a 24% thrust level.



## Probes

A double walled probe is installed in each of the propellant tanks. Each probe has a 20 VDC input and the varying resistance, caused by the decreasing propellant quantity, will cause the output signal to vary from 5 VDC down to zero VDC. The signal strength is in direct proportion to the propellant quantity. These output signals, processed through the probe circuitry are sent directly to the control unit.

## Control Unit

The control unit performs a data processing function, converting the output signals of the detector probes into a usable form. It has the following functions:

1. Provides propellant quantity information (fuel and oxidizer) for each of the descent stage propellant tanks through a selector switch on demand from the crews, to a digital display in the cockpit.
2. Provides conditioned signals, corresponding to propellant quantities in each of the four tanks, to the telemetry registers.
3. Provides a warning signal on the appropriate panel when the propellant level in any of the four tanks reaches a pre-determined level.

## Descent Engine

### General Description

The descent engine consists primarily of an ablative lined thrust chamber with a crushable, radiation cooled nozzle extension; a variable area injector; a pair of flow control valves; four electromechanical flow control actuators; and eight propellant shut-off valves. (See Figure 22.)

The engine is throttleable over a 10:1 range and develops 10,500 pounds of thrust in a vacuum at full throttle and 1,050 pounds minimum thrust.

It is mounted in the center compartment of the descent stage and is pivoted at the throat of the combustion chamber on a gimbal ring that is an integral portion of the engine assembly. The ring is suspended in the structure, pivoted in a line 90 degrees opposite to the engine pivots, so that the engine is capable of being gimbaled  $\pm 6$  degrees in any direction by means of vehicle mounted gimbal actuators. (See Figures 23 and 24.)



The nozzle extension is designed as a crushable skirt that can collapse a distance of 28 inches on lunar impact to prevent the descent engine from being torn from its mounts, should it contact the lunar surface upon landing. The engine also has instrumentation sensors to measure fuel and oxidizer inlet pressures and temperatures, injector inlet pressures, thrust chamber pressures, valve positions, vibration, and exterior surface temperatures.

The mechanical throttling scheme (See Figure 25.) utilizes variable-area, cavitating venturi correction, flow control valves mechanically linked to a variable area injector in order to separate propellant flow control and propellant injector functions so that each may be optimized without compromising the other, and to ensure that propellant flow rates are made insensitive to downstream pressure variations in the injector and combustion chamber. The injector consists basically of a face-plate and fuel manifold assembly outfitted with a coaxial oxidizer feed tube and movable metering sleeve. Oxidizer flows through the center tube and out between a fixed pintle and the bottom of the sleeve, while the fuel orifice is an annular opening between the sleeve contour and injector face. The design of the sleeve is such that the propellant orifices increase in area as the sleeve is moved upward, away from the fixed pintle. The areas of the throats in the flow control valves are regulated by close-tolerance, contoured metering pintles that are linked directly to the injector sleeve. The linkage is, in turn, operated by a single actuator. Thrust is thus regulated by movement of the actuator to simultaneously adjust the pintles in the flow control valves and the movable sleeve in the injector. The fuel and oxidizer are thereby injected at velocities and angles compatible with variations in weight flow.

At maximum thrust, operation is conventional. As the engine is throttled the pintles in the flow control valves are moved to decrease the flow control area in the venturis so that the pressure drop across the valve balances out the differential between engine inlet and injector inlet pressures.

At the same time, injector orifice areas are decreased so that injection velocities and impingement angles of fuel and oxidizer are maintained at optimum conditions for combustion efficiency.

At approximately 70% of maximum thrust, cavitation commences in the valve throats. From this level down to minimum thrust, the valve functions as a cavitating venturi. Once cavitation begins, the propellant metering function is entirely removed from the injector; flow is controlled entirely by the cavitating venturi valves. (Flow control valves.)



The mechanical linkage connecting the valve pintles and injector sleeve is pivoted about a fulcrum attached to the injector body; the throttle control is an electromechanical linear servo actuator with redundant DC motors that operate to position the linkage in response to electrical input signals. At maximum thrust, the actuator positions the linkage to set the flow control valves and injector apertures to the full open position. As thrust is reduced, the actuator reduces the flow at the control valves and moves the injector sleeve to reduce the apertures. (See Figure 26.)

Fuel and oxidizer are introduced to the engine through flex inlet lines located near the gimbal ring at the engine throat, from where they are piped directly into the flow control valves. After flowing through the venturis, the propellants pass to a series-parallel shutoff valve assembly. (See Figure 25.) The shutoff valves are fuel pressure-actuated ball valves; fuel is introduced to the valve actuators through solenoid operated pilot valves, all of which are energized simultaneously during engine startup. During the start, the solenoids unseat the caged balls from the actuator inlet ports and seat them against the overboard vent ports. Fuel enters the actuator cavities; the actuator pistons connected to rack-and-pinion linkages twist the ball valves 90 degrees to the open position, permitting flow to the injector. The series parallel redundancy in the valve arrangement provides for positive start and cutoff. During shutdown, the solenoids are deenergized, opening the vent ports. The spring loaded actuators close the shutoff valves and residual actuating fuel is vented overboard into space.

After flowing through the shut-off valve assembly the fuel and oxidizer enter manifolds that are integral with the engine injector assembly. From here the propellants enter the variable area injector and are injected into the combustion chamber.

An external line, the barrier cooling supply ring, is tapped off the fuel manifold, and enters the injector at two separate points, diametrically opposed. From here this fuel flows through internal passages and then is injected into the combustion chamber through orifices that are drilled around the rim of the injector assembly, and so angled that the fuel is sprayed against the combustion chamber wall. This fuel does not enter directly into the combustion process, but is used for barrier cooling. (See Figure 26.)



## Design and Performance Characteristics

Thrust	10,500 pounds
Throttling range	10:1
Propellants	Nitrogen tetroxide (oxidizer) and 50% hydrazine/50% UDMH (Fuel)
Oxidizer/Fuel ratio	1.6:1
Engine life	960 seconds
Restart capability	20 times
Specific impulse	300 seconds (approx.)
Chamber pressure	110 psi
Flow rate - oxidizer	21 lbs/sec (approx.)
" " - fuel	13 " " "
Expansion area ratio	49:1
Overall length	85 inches
Nozzle diameter (exit)	59 inches
Weight	360 lbs

## Major Components

### Thrust Chamber

(See Figure 27.) The thrust chamber consists of a composite ablative cooled nozzle extension to an area ratio of 16:1, a crushable radiation cooled nozzle extension to an area ratio of 49:1, and a gimbal ring assembly. The ablative components are encased in a continuous titanium shell and jacketed in a stainless steel foil/glass wool composite thermal blanket. The radiation cooled nozzle extension is made from stainless steel. The nozzle extension is flanged to the titanium chamber shell. The gimbal assembly is located at the chamber throat plane and provides for a  $\pm 6$  degree gimbal of the thrust vector during flight. The assembly is manufactured from aluminum alloy, except for the bearings, which are made of high strength steel.



The cylindrical combustion chamber incorporates a turbulence ring for improved propellant mixing and combustion.

### Variable Area Injector

Fuel and oxidizer manifolding are integral with the engine injector assembly. The oxidizer manifold is centrally located on the longitudinal engine axis, and contains screens for flow straightening purposes. Injection is effected through a double row of contoured slots - a large set and a secondary small set for proper distribution. Fuel is manifolded in the head assembly, flowing through a set of distribution baffles, over a contoured injection control shoulder, and through an extended sleeve guide to enter the combustion chamber longitudinally. The cylindrical fuel sheet is pierced by the radial oxidizer streams to form the main flame front. A metering sleeve incorporates an external, contoured shoulder for fuel sheet thickness control; and a set of teeth to cover oxidizer injection slots for stream shape control. The sleeve is sealed from the thrust chamber exterior by a double set of bellows, and is driven through a trunnion arrangement by the throttle valve actuator. The metering sleeve is the only moving part of the injector and its full travel over the 10:1 thrust range is  $3/16$  inch.

### Flow Control Valves

(See Figure 28.) Flow control valves are non-redundant venturis with movable pintle sleeves. Engine throttling is initiated by an electrical signal to the throttle actuator commanding an increase or decrease in engine thrust. Operation of the throttle actuator drives the linkage cross beam to a new position, thus repositioning the pintles in the flow control valves. This axial movement of the pintles results in decreasing or increasing the pintle flow areas the precise amounts to control propellant weight flow rate and thrust. The pintle contours are precision ground to  $\pm$  two ten-thousandths on the diameter with a surface finish of 8.

Below an approximate 70% thrust setting, flow through the valves will cavitate to hydraulically uncouple the propellant transfer system (and thereby, flow rate) from variations in thrust chamber pressure. The movable pintle sleeve is shaft driven through the valve case, and is sealed by two flexible bellows. All valve bearings are designed to operate in redundant modes - rolling or sliding - to improve reliability. Both pintle sleeve shafts are attached to a yoke which is driven by the throttle actuator.



## Throttle Actuator

(See Figures 29 and 30.) The throttle actuator is an electro-mechanical linear servoactuator powered by redundant DC motors. It is located between the fuel and oxidizer flow control valves on the engine head end. Its base is rigidly attached to the engine head end. The output shaft of the actuator is attached to the throttle linkage. In response to the command electrical input, it moves the throttle linkage, which positions the flow control valves and the injector element. Changing the position of the flow control valves changes the amount of fuel and oxidizer metered into the engine and thus changes the magnitude of engine thrust.

Three torque motors drive the jack screw. The actuator is designed to operate within specification using two motors, or at a reduced rate using only one. The actuator case is hermetically sealed to prevent cold welding in a vacuum environment. Although the actuator could operate without lubrication, a compound with known off gassing rate is included to maintain a small positive pressure if the actuator case leaks.

All mechanical elements of the actuator (motors, potentiometers, bearings, jackscrew, etc.) are within the hermetically sealed portion of the unit. The amplifiers are mounted in a separate housing which is mechanically fastened to the main actuator housing with screws and dowels. The area which contains the amplifiers is protectively sealed from the ambient environment but not hermetically sealed.

The actuator utilizes a five-gang potentiometer driven by the jack-shaft through a single stage planetary gear reduction. The potentiometer supplies position feedback information to each of three amplifiers.

Performance redundancy is provided by designing each of the three separate servo channels to have equal output performance. For a null-type or inoperative failure, two separate servo channels failing can be tolerated. The two malfunctioning motors will be driven along with the load by the one operating motor. In the case of a saturated or hardover-type failure of one servo channel, the load is effectively increased but the two operating motors have the capability of over-riding the malfunction and providing the required output performance.

## Propellant Shut-off Valves

(See Figures 25 and 26.) The shutoff valve assembly basically consists of a combined fuel and actuator housing, oxidizer housing, and the mechanical linkages connecting the fuel and oxidizer valves.



The primary function of the propellant shutoff valve is to initiate propellant flow to the engine during the start-up sequence, and to terminate the flow during engine shutdown. This component is located downstream of the flow control valve, and is exposed to the full pressure of the propellant feed system prior to engine firing.

The propellant shut-off valves are mechanically linked, pilot operated, fuel actuated ball valves. Each valve contains a series-parallel arrangement of balls. Fuel and oxidizer are completely isolated in separate valve bodies, with actuation of the oxidizer valve accomplished by a mechanical linkage driven from the fuel valve.

Valve housings are made of aluminum alloy. The ball element operates against a spring loaded teflon seat to assure positive sealing when the valve is closed. The purpose of the series-parallel, or quad, arrangement is to insure continued operation of the engine and/or to prevent loss of propellant in the event of malfunction. The parallel arrangement provides redundancy for valve opening (engine firing). The series arrangement provides redundancy for valve closing (engine shutdown). All ball valves are supported by ball bearings. Rotation of each individual valve is caused by a rack and pinion gear arrangement which translates the linear displacement of the actuator pistons in the fuel housing.

The fuel and actuator housing contains actuator pistons and springs, solenoids, solenoid connector, two-position three-way pilot valves, and the associated actuation and vent ports.

The solenoid-operated pilot valves controlling the actuation fluid (fuel) and the main ball valves are normally closed. In the closed position, all solenoids are deenergized and the actuation fuel is shut off by action of the spring-loaded solenoid plungers on the ball poppets seated in the lower pilot valve seats. The back side of the actuator pistons are vented to preclude air lock. In the open position, all solenoids are energized, and fuel actuation forces act against the spring-loaded plunger thus permitting fuel to flow to the actuator pistons to initiate oxidizer and fuel valve opening. At this point, the pilot valves are forced against the upper valve seats, thus sealing off the vent port. When the electrical signal is removed, the pilot valves are returned to their lower seat position to seal off the actuation pressure. Closing of the main propellant ball valves is accomplished by the return spring action of the actuator piston springs which expel the entrapped fuel in the cylinders and pilot passages out through the pilot vent port.



All shut-off valves are opened simultaneously at engine start; all are closed simultaneously at engine shut-down. The time from signal initiation to full open or from signal cutoff to full closed is 150 milliseconds. Switches are installed in the oxidizer housing to provide an indication of valve position.

Checkout features of the shutoff valve assembly include the capability to open the valves without disconnecting the actuation line, and without applying electrical signal to the solenoids. This can be accomplished by applying 200 psi GN<sub>2</sub> pressure to the pilot vent port. In cases where valve opening is required for engine system leak checks, this operation is necessary.

Test experience also indicates that with all valves closed, main ball seal integrity can be checked by applying 60 psi GN<sub>2</sub> pressure upstream of the valve and monitoring pressure decay rate.

#### Graphs:

1. Descent Engine Pressures. (See Figure 31.) Propellant tank pressure "A" is constant and is determined by the helium pressure regulators. Pressure "B" taken at the flow control valve inlet is lower because of the line drag. Injector manifold pressure "C" and chamber pressure "D" will vary with the flow control valve settings, being highest when the engine is operating at 100%, and lowest when the engine is throttled to 10%. (At this time only transient engine operation is permitted in the 60-99% range.)
2. Char Depth vs. Time. (See Figure 32.) The initial thickness of the ablative wall averages over .8 inches. Immediately upon engine start the wall starts to char and rapidly chars to a depth of about .25 inches. There follows a period of about 900 seconds during which the char depth increases only slowly to about .5 inches and during this time the surface of the ablative wall is gradually eroded away by the abrasive action of the hot gasses. At about 900 seconds there occurs a rapid increase in char depth and if the engine is not shut down the chamber wall will burn through.
3. Descent Engine Wall Temperature. (See Figure 33.) From the injector face to the 16:1 area ratio the engine structural wall is protected from the hot gasses by the ablative wall and a layer of insulating material containing asbestos. Consequently it is comparatively cool.



From the 16:1 area ratio to the exit area the nozzle is radiation cooled. This explains the very rapid increase in wall temperature, which drops off gradually with increasing distance from the flame front.

### Ascent Propulsion Subsystem Components

Because of their functional similarity ascent and descent propulsion subsystem components have been described together in one grouping. See the beginning of this chapter under Propulsion Subsystem Components.

### Functional Description of the Ascent Helium Pressurization and Propellant System Operation (See Figures 34 and 35.)

Note: The ascent helium pressurization and propellant system operation is, in many respects, functionally similar to that of the descent system. For that reason this description will be brief, concerning itself mainly with the differences in the two systems. For a more complete understanding of components it is suggested that the functional description of the descent helium pressurization and propellant system, in an earlier section of this chapter, be read first.

Gaseous helium is stored at 3500 psi in two storage tanks. The outflow of each tank proceeds to a separate closed isolation valve. Each valve is equipped with two squibs, either of which is capable of opening the valve. They are actuated by an electrical signal from the control panel. When opened, the isolation valves permit pressurization of ascent stage propellants.

For normal ascent propulsion mode of operation, both helium isolation valves are opened simultaneously. Should a leak or a rupture develop in one of the helium storage tanks, prior to ascent, the isolation valve in the affected flow path can be left closed and helium flow from the remaining tank can be initiated separately. The loss of helium through the affected storage tank via the downstream interconnecting manifold line can thus be prevented.

Each parallel helium flow path contains a filter to trap any debris resulting from squib valve actuation thereby preventing contamination of downstream components. After the filter, each helium flow path contains a normally open, latching, solenoid valve and two pressure regulators.

The upstream regulators in each flow path are set to a slightly higher pressure than the downstream regulators and the two series



regulators in the primary flow path are set to a slightly higher pressure than their corresponding regulators in the redundant flow path.

In normal operation the downstream regulator in the primary flow path is the controlling element; the upstream regulator senses a demand and remains open, as the sensed demand is below the setting. The downstream regulator in the redundant flow path is locked closed as its demand is satisfied. This blocks the helium flow through the redundant path.

Series-parallel redundancy is achieved without crew action: if either primary flow path regulator fails closed, control is obtained through the redundant flow path regulator with the lower setting. If a downstream regulator fails open, control is obtained through the upstream regulator of the same flow path. An open failure in an upstream regulator is of no consequence, as the downstream regulator is already in control.

It is only for a double open failure in the same flow path that crew action is required. Should this occur, and the pressure in the downstream manifold increases beyond the acceptable limit, a caution light on the cockpit display panel will come on and the solenoid shut-off valve in the malfunctioning flow path must be closed, so that normal pressure reduction can be obtained through the parallel flow path.

The pressure settings of the four regulators will vary from 176 psi to 190 psi with the primary path controlling regulator set at 184 psi.

During coast periods of ascent both shut-off valves may be closed to prevent possible helium loss due to regulator leakage.

Downstream of the pressure reducer legs, the helium flow paths are manifolded together and then divided into two separate propellant tank pressurization paths, with a quadruple check valve in each. The check valves function to prevent propellant vapors from the propellant tanks from backing up to the common helium manifold after system pressurization. A burst disk and relief valve is located in the helium pressure line to each tank for the purpose of preventing catastrophic tank overpressurization. The burst disk prevents possible leakage through the relief valve during normal operation. The helium is then piped directly into the propellant tanks, where it acts directly on the surface of the fluid.

Downstream of the quad check valves, in each flow path, are two, normally closed, explosive operated valves, arranged in parallel. These valves are a positive seal against propellant vapor mixing; they will be opened simultaneously with the helium isolation valves, just prior to the initial engine start. The parallel valve arrangement in each flow path is used for purposes of redundancy.



Ascent propulsion subsystem propellant tanks do not have a quantity gaging system, but do contain low level sensors that are used to monitor propellant quantities and will provide a 10 second warning of propellant depletion.

There is one oxidizer tank and one fuel tank. The outflow from each tank divides into two paths. The main path leads through a trim orifice and a filter to the engine shutoff valves; the other path leads to normally closed solenoid valves interconnecting the ascent and the RCS propellant systems.

Opening these valves permits the use of ascent system propellants in the RCS to conserve RCS propellants. Operation of this system will be more completely described in the next chapter.

In addition there is a third flow path branching off at the fuel tank outlet. It leads to two solenoid valves, arranged in parallel for the purpose of redundancy, and from there to the four engine shut-off valve actuators. The purpose of these valves is to prevent possible fuel loss through leaking shut-off valve actuators prior to initial engine operation and during periods of engine shut-down. These solenoid valves will be opened and closed simultaneously with the actuation of the engine shut-off valves.

## Ascent Engine

### General Description

The ascent engine consists primarily of an ablative lined thrust chamber, including the fully ablative lined nozzle; an injector; two trim orifices; four electromechanical flow control actuators; and eight propellant shut-off valves. (See Figure 36.)

It is a constant thrust, restartable engine and develops 3,500 lbs. of thrust in a vacuum. This engine is rigidly mounted along the center line of the ascent stage midsection.

Instrumentation includes sensors for measuring fuel and oxidizer inlet temperatures and pressures, thrust chamber pressure, propellant shut off valve positions, vibration and exterior surface temperatures.

Propellant flow to the engine is controlled through the valve package, trim orifices, and injector. (See Figure 37.) An expansion bellows is used in the feed lines between the valve package and the injector to accommodate the line expansion that results from the injector temperature rise during engine fixing. The valve



package assembly consists of similar propellant and isolation valves, mounted back to back, with oxidizer flow on one side and fuel flow on the other. This valve package contains a series-parallel arrangement of ball valves in fuel-oxidizer pairs. Each pair is simultaneously opened or closed on a common crankshaft by an actuator that uses fuel as the actuating medium. The fuel flow is controlled through solenoid valves.

At engine start all solenoids are simultaneously energized and all eight ball valves rotate 90° to the open position allowing propellant flow. At engine shut-down the solenoids are deenergized, blocking off the actuating fuel. Vent ports are opened and residual fuel in the actuators is vented overboard. The actuators can now close under spring pressure pulling the ball valves to the closed position and shutting off the flow of propellant from the engine.

#### Design and Performance Characteristics

Thrust	3500 pounds
Propellants	Nitrogen tetroxide (oxidizer) and 50% hydrazine/50% UDMH (fuel)
Oxidizer/fuel ratio	1.6:1
Engine life	460 seconds
Restart capability	35 times
Specific impulse	300 seconds (approx)
Chamber pressure	120 psi
Flow rate-oxidizer	7 lbs/sec (approx)
Flow rate-fuel	4.5 lbs/sec (approx)
Expansion area ratio	45.6:1
Overall length	47 inches
Nozzle diameter (exit)	31 inches
Weight	214 pounds



## Major Components

### Thrust Chamber (See Figure 38.)

The thrust chamber assembly consists of two major components: the engine case and mount and the plastic assembly which also includes the nozzle extension. The engine case and mount are bonded and locked to the plastic assembly to form an integral unit. The plastic assembly provides ablative cooling to the thrust chamber while the case and mount transfer the thrust force to the ascent vehicle. The plastic assembly consists of chamber ablator, chamber insulator, nozzle extension ablator, and a structural filament winding. The chamber ablator extends from the injector to an expansion ratio of 4.6 and provides the ablative cooling in this region. The chamber insulator is placed between the chamber ablator and case, and controls outer chamber skin temperatures to design requirements. The nozzle extension ablator extends from an expansion ratio of 4.6 to 45.6 (exit plane) and provides ablative cooling in this region. The structural filament winding provides the structural support to the plastic assembly and ties the chamber and nozzle extension sections together. The plastic assembly is subsequently bonded to the engine case.

### Injector

The injector assembly consists of propellant inlet lines, a fuel torus manifold, an oxidizer manifold, and an injector orifice plate assembly. The injector assembly is a fixed orifice type which employs a baffle for damping any induced combustion disturbances. The baffle geometry is Y shaped with an included angle of 120 degrees between the blades. The blade thickness and height are 0.43 and 1.25 inches, respectively. Cooling of the baffle is accomplished with the propellants which are subsequently dumped into the combustion chamber through orifices on the baffle blade tips. The injector assembly face is divided into three combustion zones: the primary, the barrier, and the baffle. The primary zone employs impinging triplets (two fuel on one oxidizer) which are spaced in concentric radial rings on the injector assembly face. The barrier zone utilizes fuel-on-oxidizer impinging doublets which operate off-ratio (fuel rich) to provide a barrier of low temperature gases near the ablative chamber wall. The baffle zone (1.25 inches downstream from the injector face) utilizes impinging doublets (fuel-on-oxidizer) placed in radial position relative to the injector face.



### Trim Orifices

One oxidizer trim orifice and one fuel trim orifice are located between the shut-off valve package and the injector assembly. These trim orifices are used to determine the thrust level of the engine and the mixture ratio of the propellant by trimming the pressure drop of the propellant feed system.

### Propellant Shut-off Valves

The operation of the ascent engine propellant shut-off valve package is functionally similar to that of the descent propellant shut-off valves.

At the propellant feed system/engine interface the oxidizer and fuel lines are connected to the valve package, consisting of two propellant valves and two isolation valves and their electromechanical actuators.

The propellant valve and the isolation valve each contain two fuel and two oxidizer balls sealing on teflon seats. One fuel and one oxidizer ball are operated by a common shaft. Shaft seals and vented cavities are used to preclude the possibility of the propellants coming into contact with each other. Engine fuel feed pressure is controlled through the three-way solenoid valve to open the normally closed ball-valve pair on the common shaft. Two such ball-valve pairs and solenoid valve combinations are found in each propellant and isolation valve assembly. Three overboard vents are included in each propellant and isolation valve assembly to carry away propellants that leak past the valve seals and propellants used for actuation of the valves, upon valve closing. The valve is designed to provide redundant sealing by having two valve seats in each flow path and redundant flow paths. This series-parallel redundancy is designed into the propellant and isolation valve assembly to achieve a high level of reliability.

A stainless steel housing is used for the oxidizer side of the valve package; the fuel side is made of aluminum alloy.

### Summary

The LM uses separate descent and ascent propulsion subsystems, each complete and independent of the other and each with its own job to perform. The descent subsystem provides the thrust to control the descent to the lunar surface and the ascent subsystem provides the thrust to control the ascent from the lunar surface.

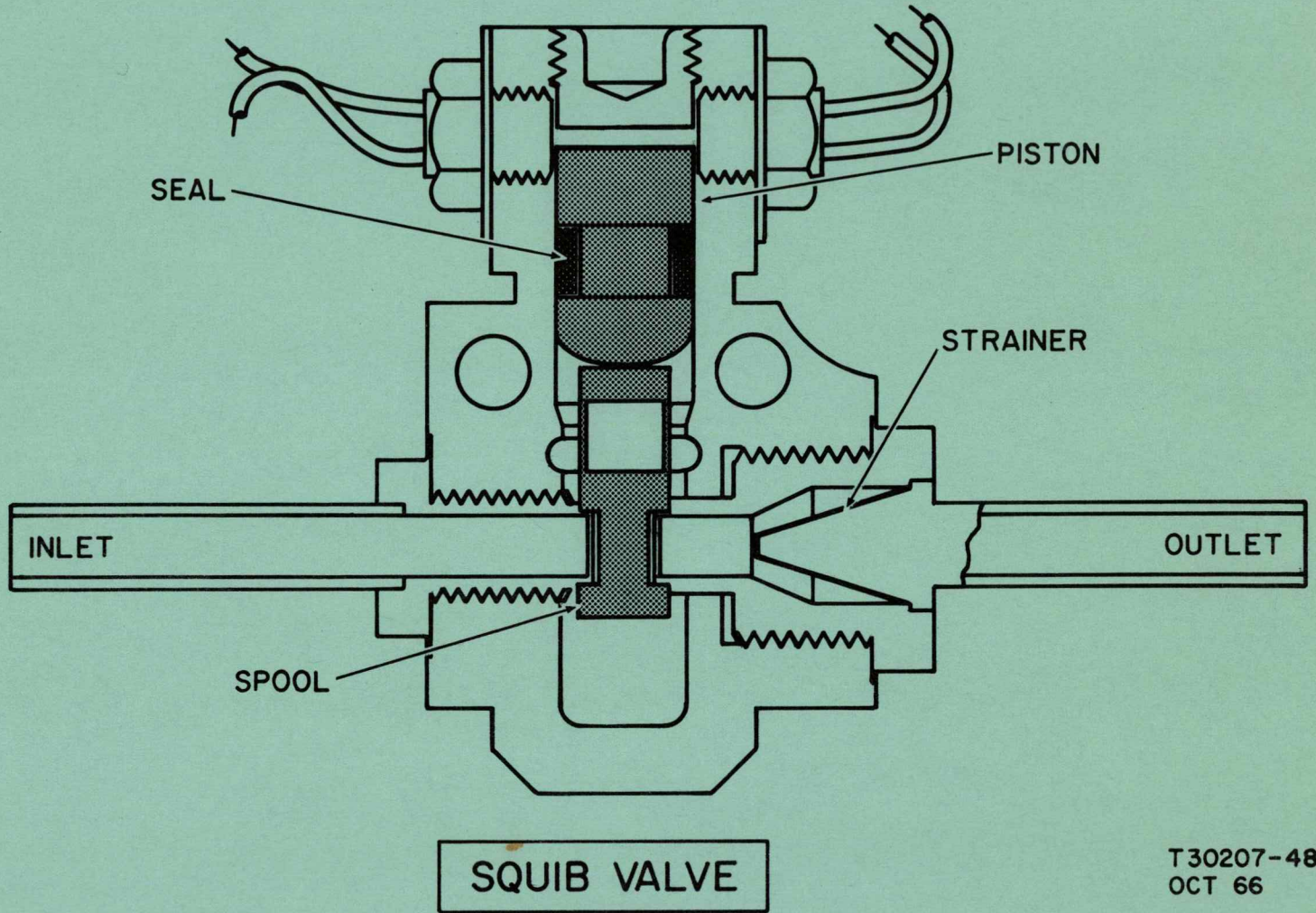


Basic components and operation of the two propulsion subsystems are functionally similar; the descent propulsion subsystem utilized a supercritical helium pressurization system, while the ascent propulsion subsystem uses ambient gaseous helium for propellant pressurization. The primary reason for the difference is the weight saving involved in the use of the cryogenic fluid due to its greater density. In each system, the propellants, under controlled pressure, are forced from their tanks, through control valves, to the engine injectors.

The descent and ascent engines are structurally and functionally similar; the primary difference being that the descent engine is larger, produces more thrust, is throttleable for thrust control, and is gimballed for vector control. Both these engines consist primarily of a thrust chamber where the propellants are burned and the resulting gases are accelerated to supersonic velocity; an injector that determines the spray pattern of the propellants into the combustion chamber and thereby largely determines combustion characteristics; and propellant control valves and orifices used to start and stop propellant flow, and to control the volume of flow.

A failure in the descent propulsion subsystem, of any of the vital components, or the engine, will result in a mission abort. A similar failure in the ascent propulsion subsystem will result in the loss of the crew. It is for this reason that the ascent subsystem is designed to have a higher reliability factor than the descent subsystem. This is achieved through the application of the principle of redundancy, in helium tankage, pressure regulation, and valving, throughout the subsystem.





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Figure 5

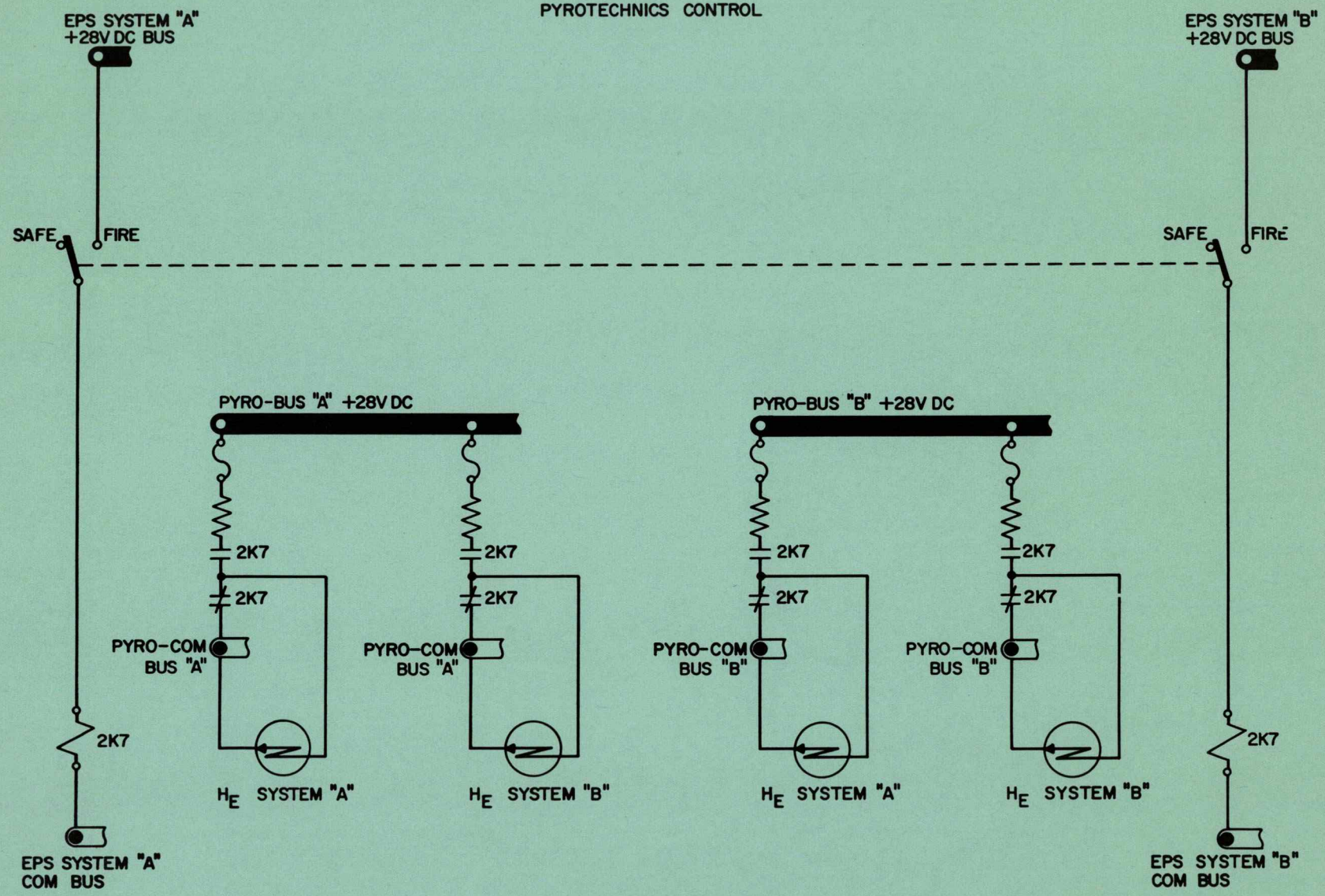


OBSOLETE

FOR TRAINING PURPOSES ONLY

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### PYROTECHNICS CONTROL

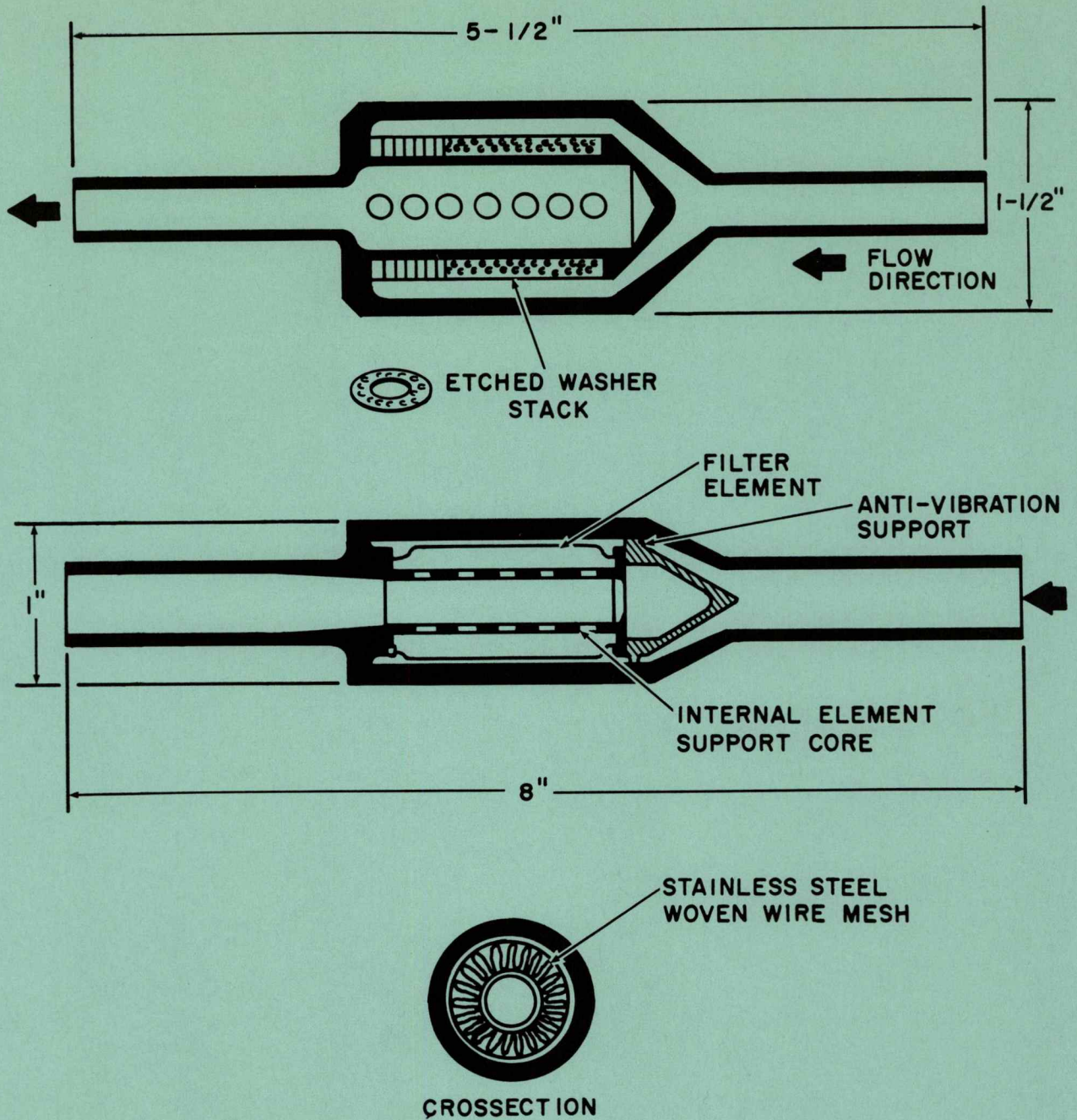


**LM PYROTECHNICS  
REACTION CONTROL SUBSYSTEM (RCS) RELAY CONTROL CIRCUIT**

Figure 6

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**HELIUM FILTER -  
ASCENT-DESCENT SUBSYSTEM**

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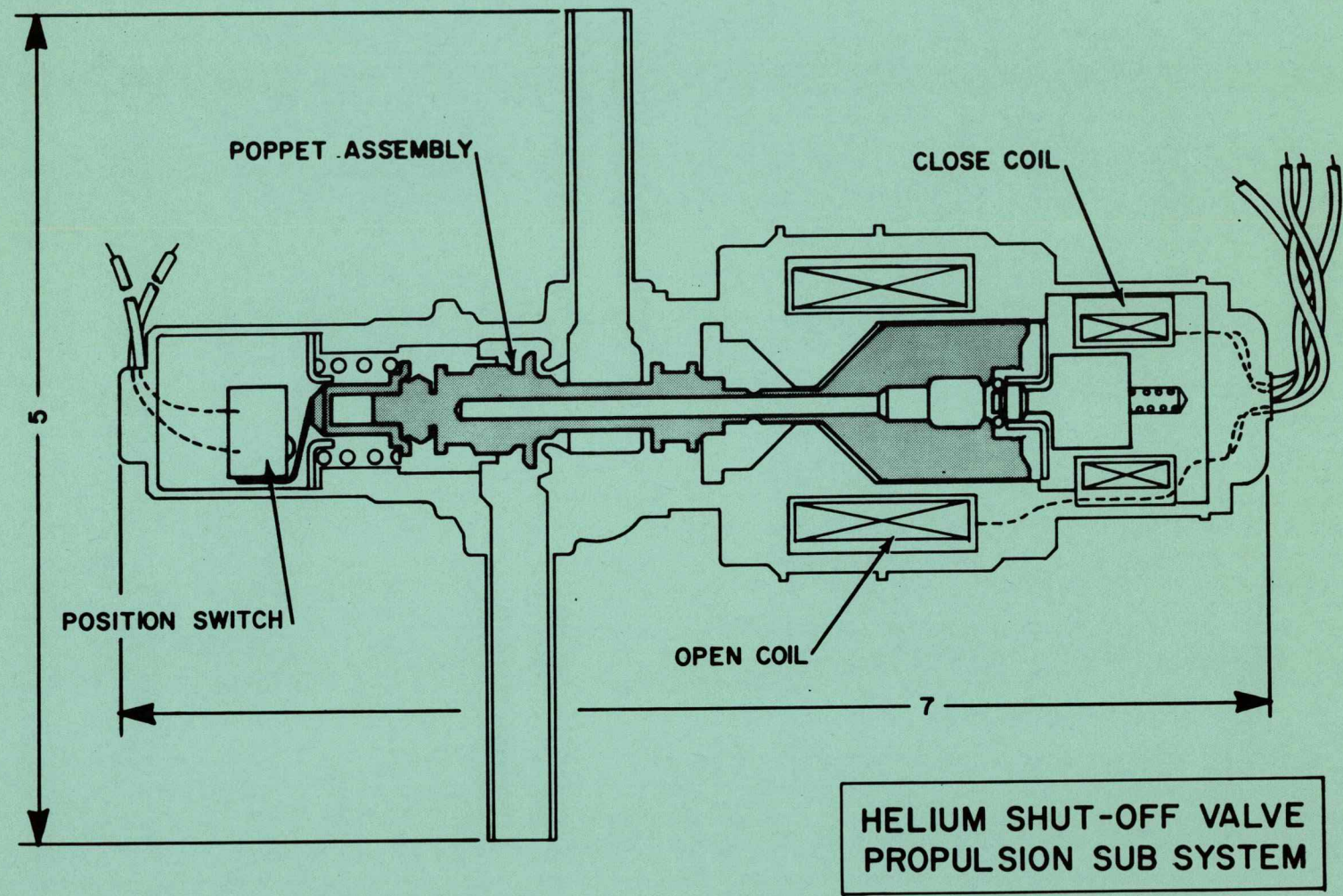
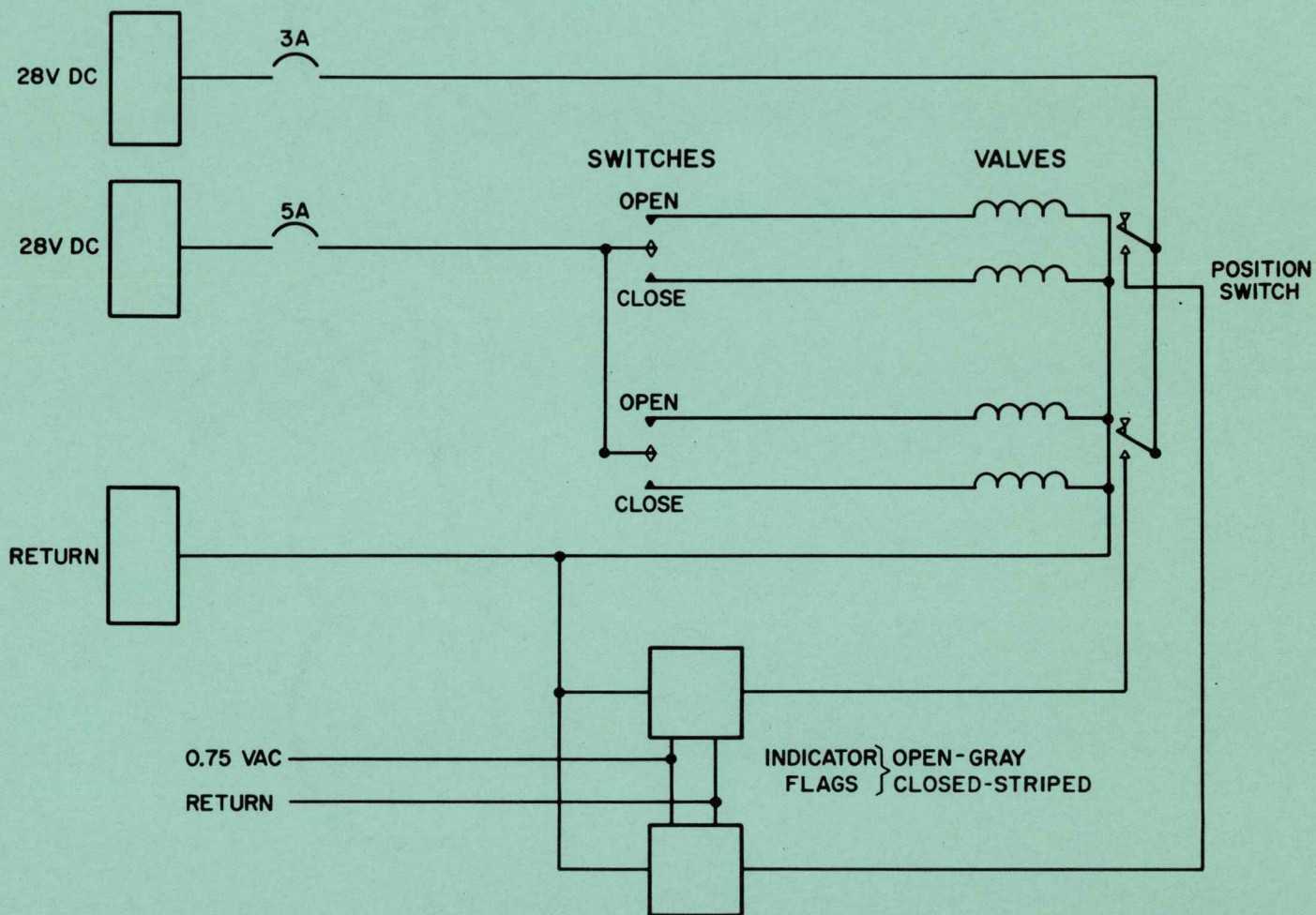


Figure 8



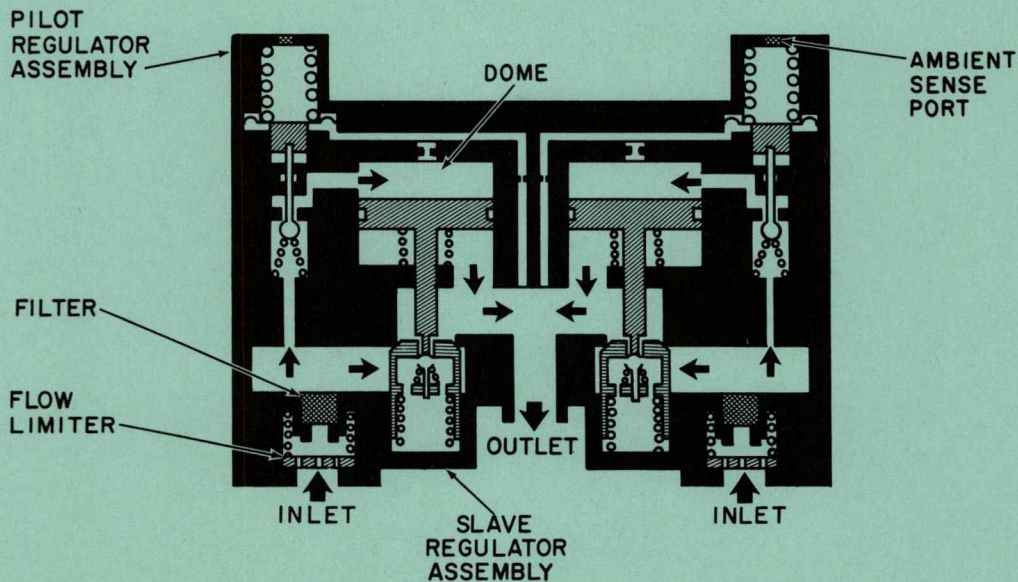
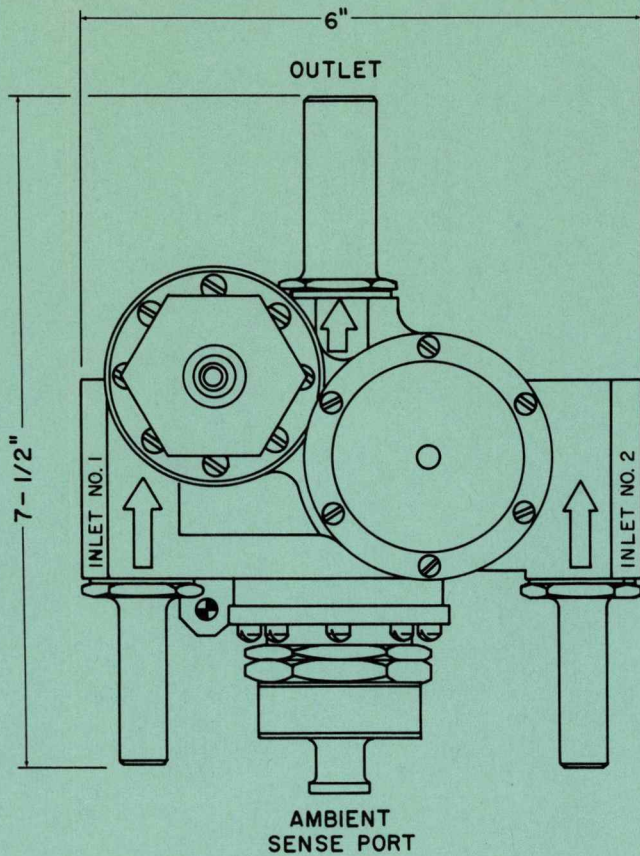


HELIUM-SHUT-OFF VALVE  
ELECTRICAL SCHEMATIC

T30207-129  
MAY 66

Figure 9

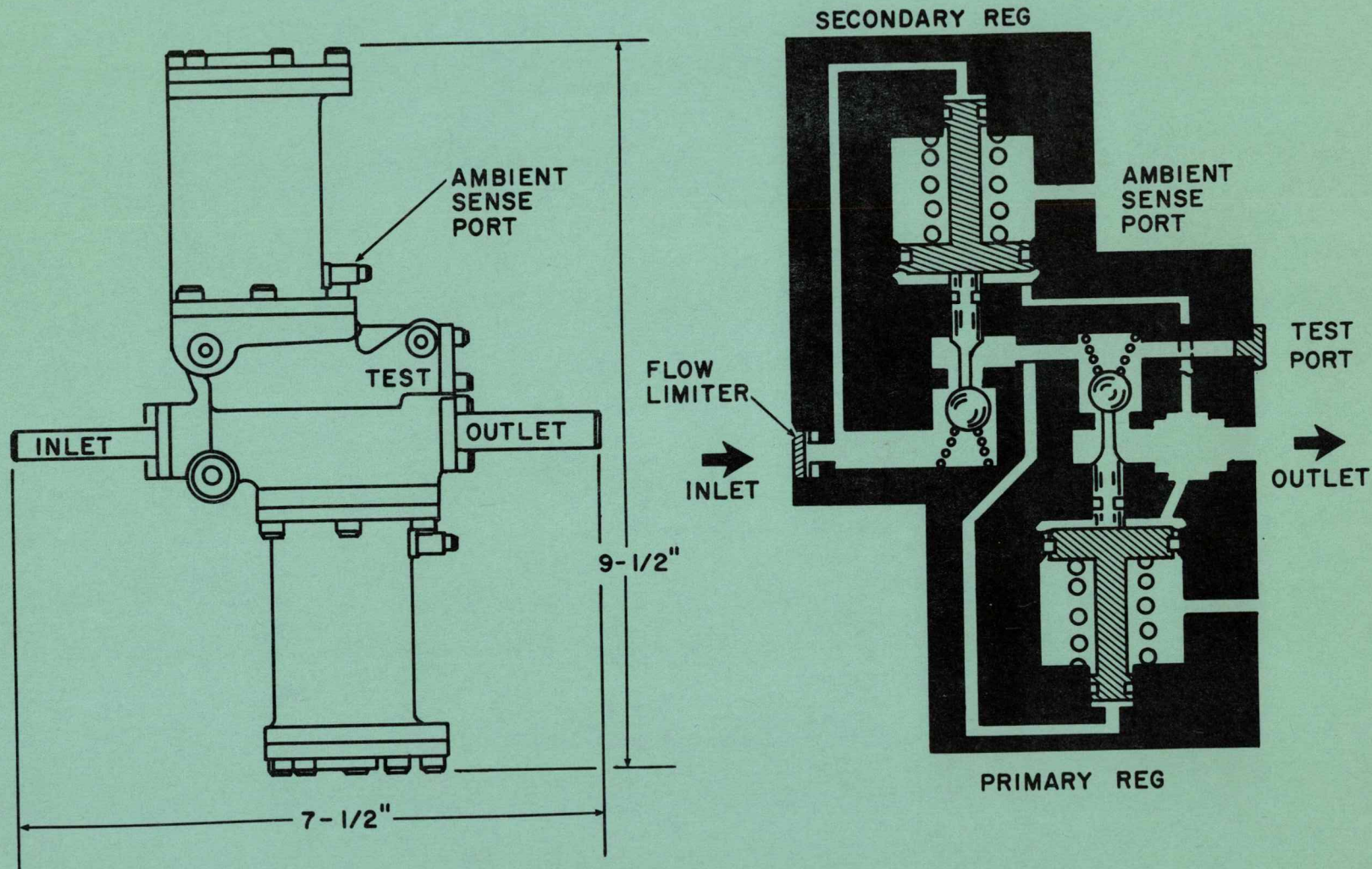




**HELIUM PRESSURE REDUCING  
 VALVE-DESCENT SUBSYSTEM**

T30207-143  
 OCT 66

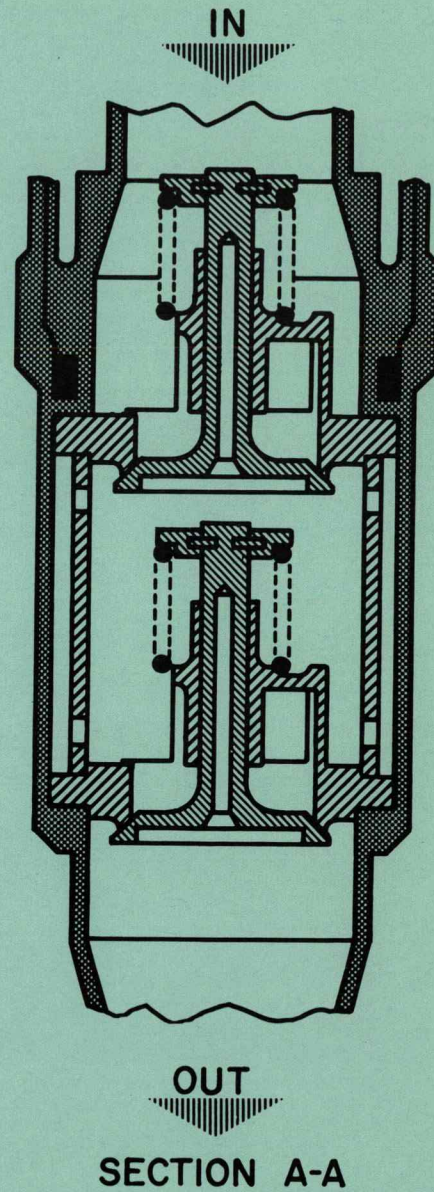
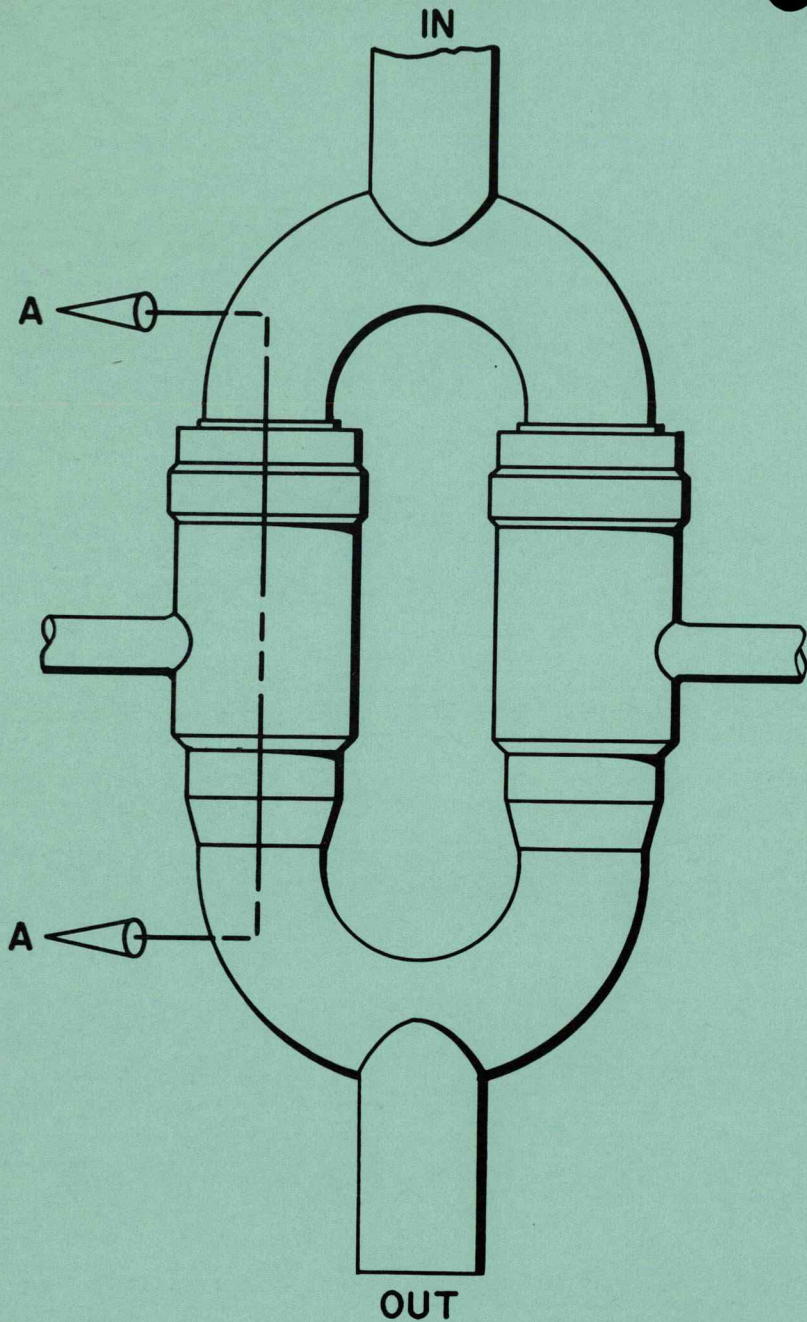




HELIUM PRESSURE REDUCING VALVE-ASCENT SUBSYSTEM

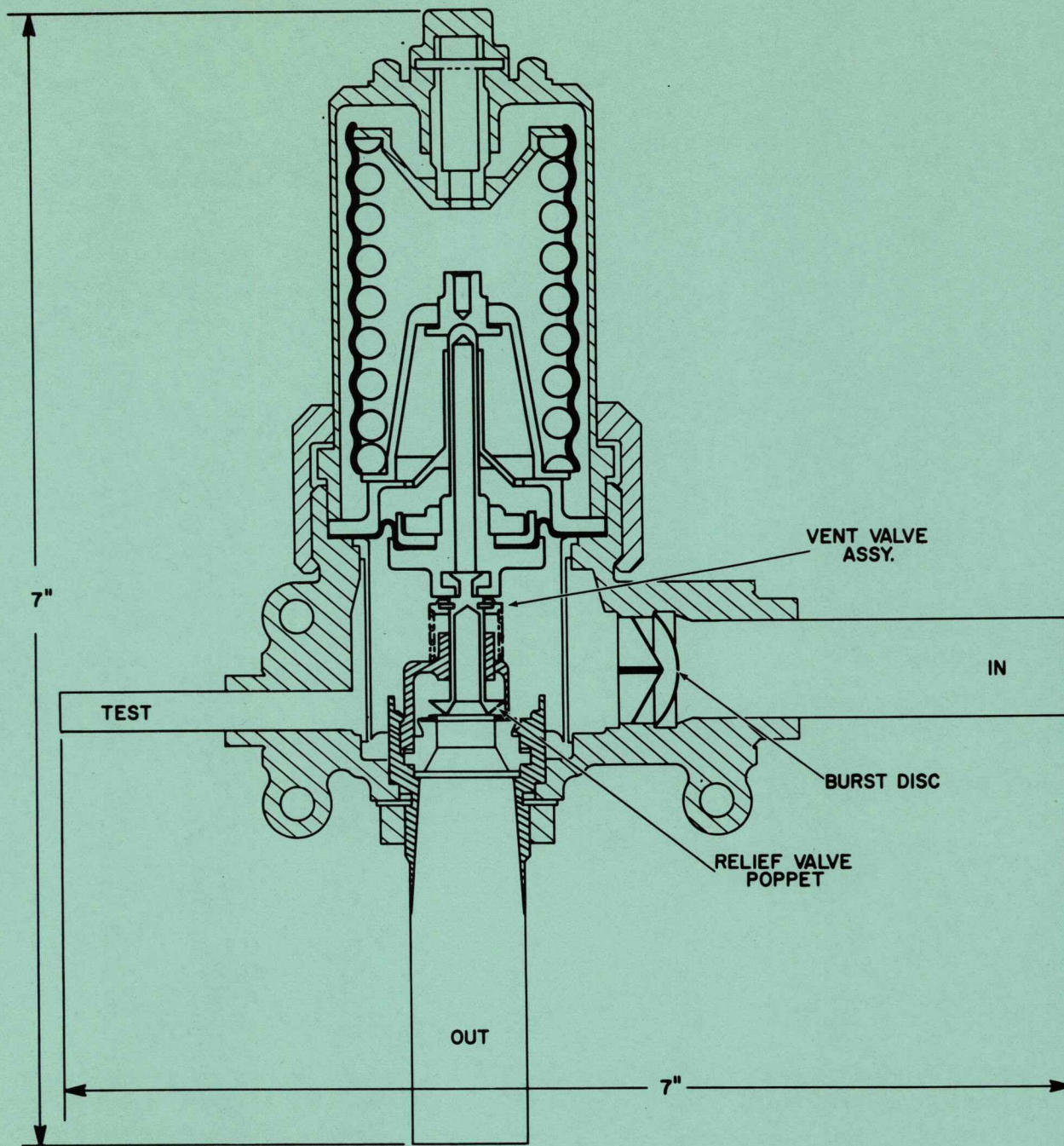
Figure 11





CHECK VALVE





**RELIEF VALVE ASSY.  
DESCENT SUB SYSTEM**

T30207-140  
OCT 66

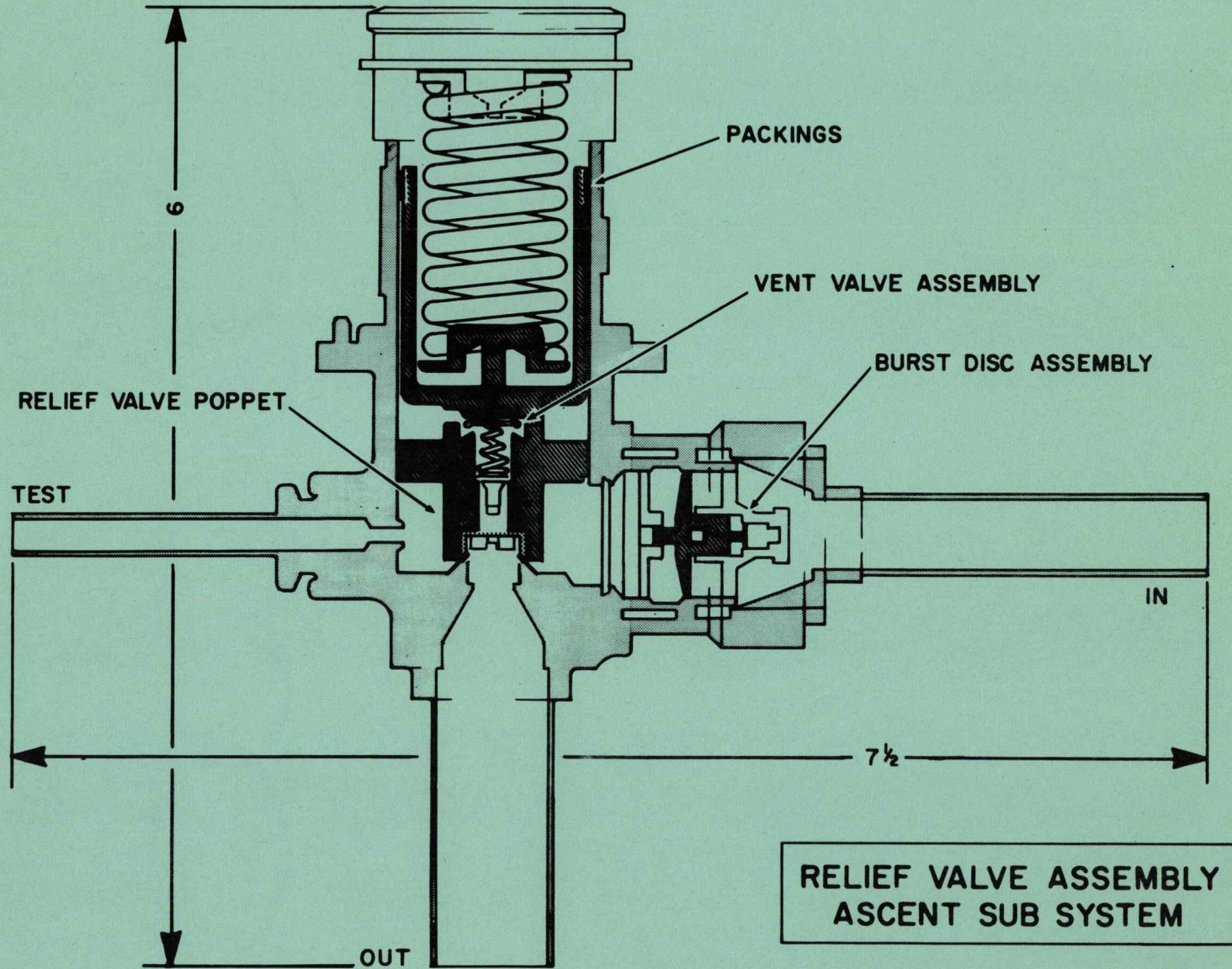


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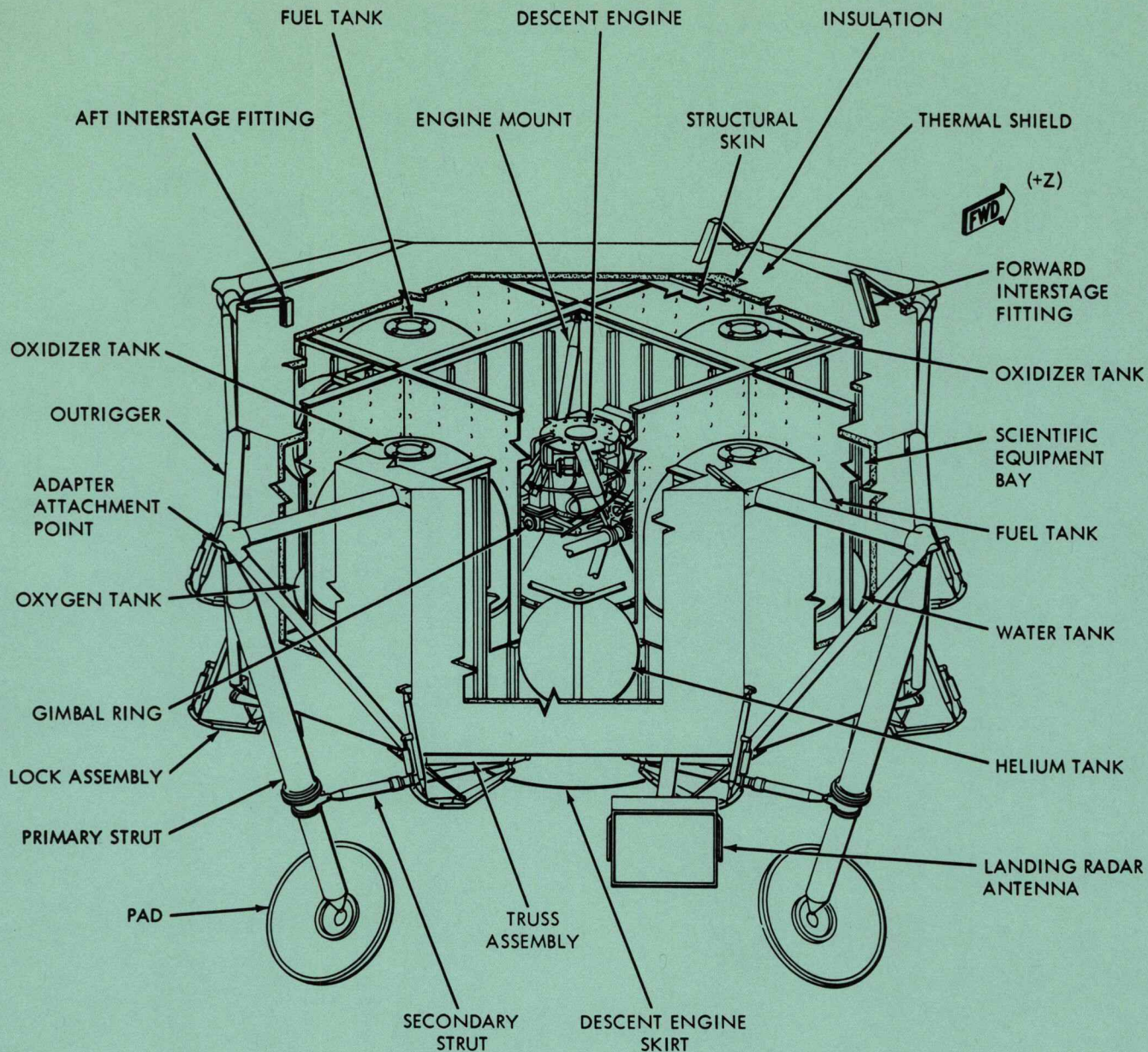
41

Figure 14



T30207-139  
SEPT 66



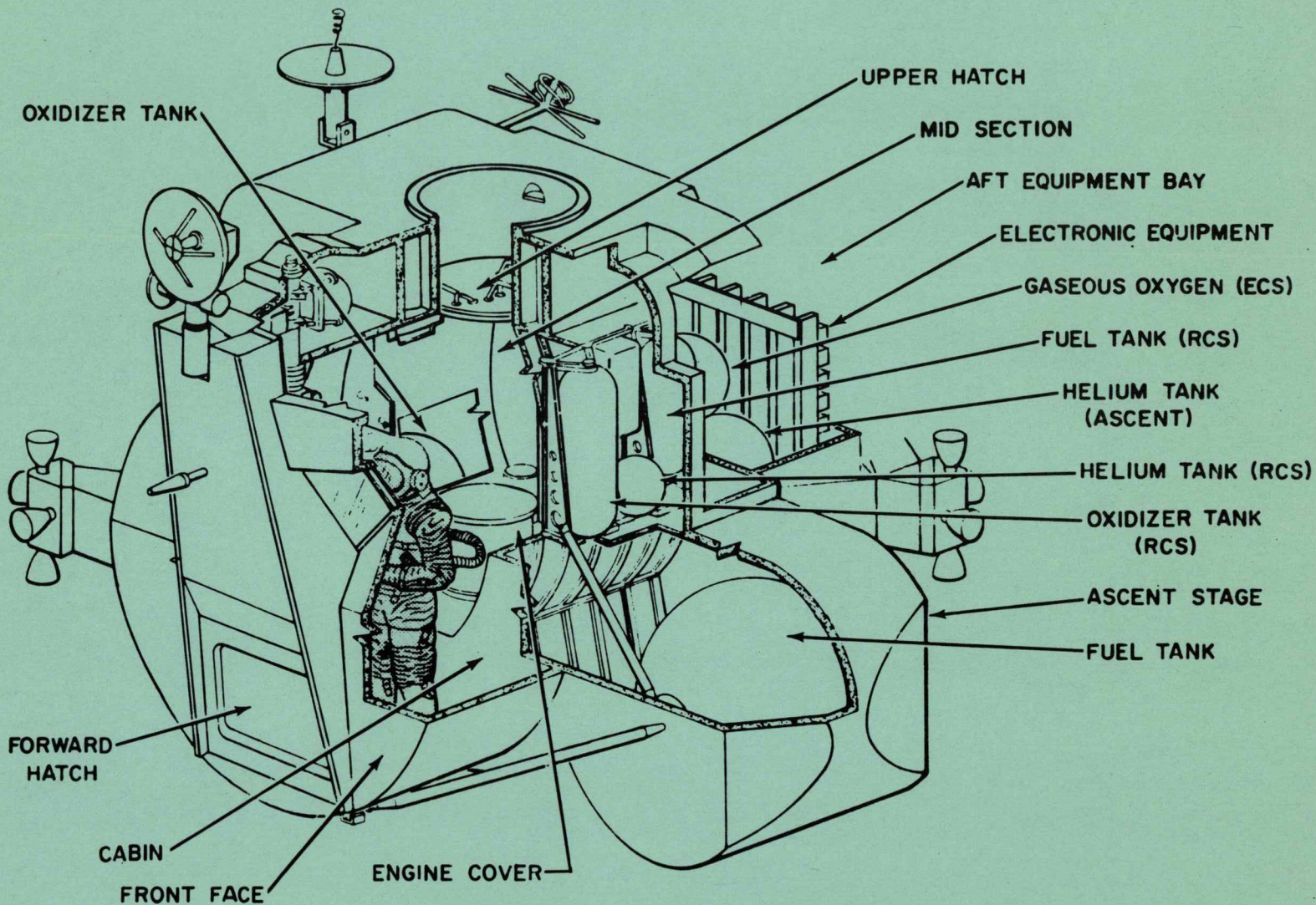


NOTE:  
LANDING GEAR SHOWN IN  
RETRACTED POSITION.

**DESCENT STAGE TANKS**

T30207-21  
FEB 67





ASCENT STAGE TANKS

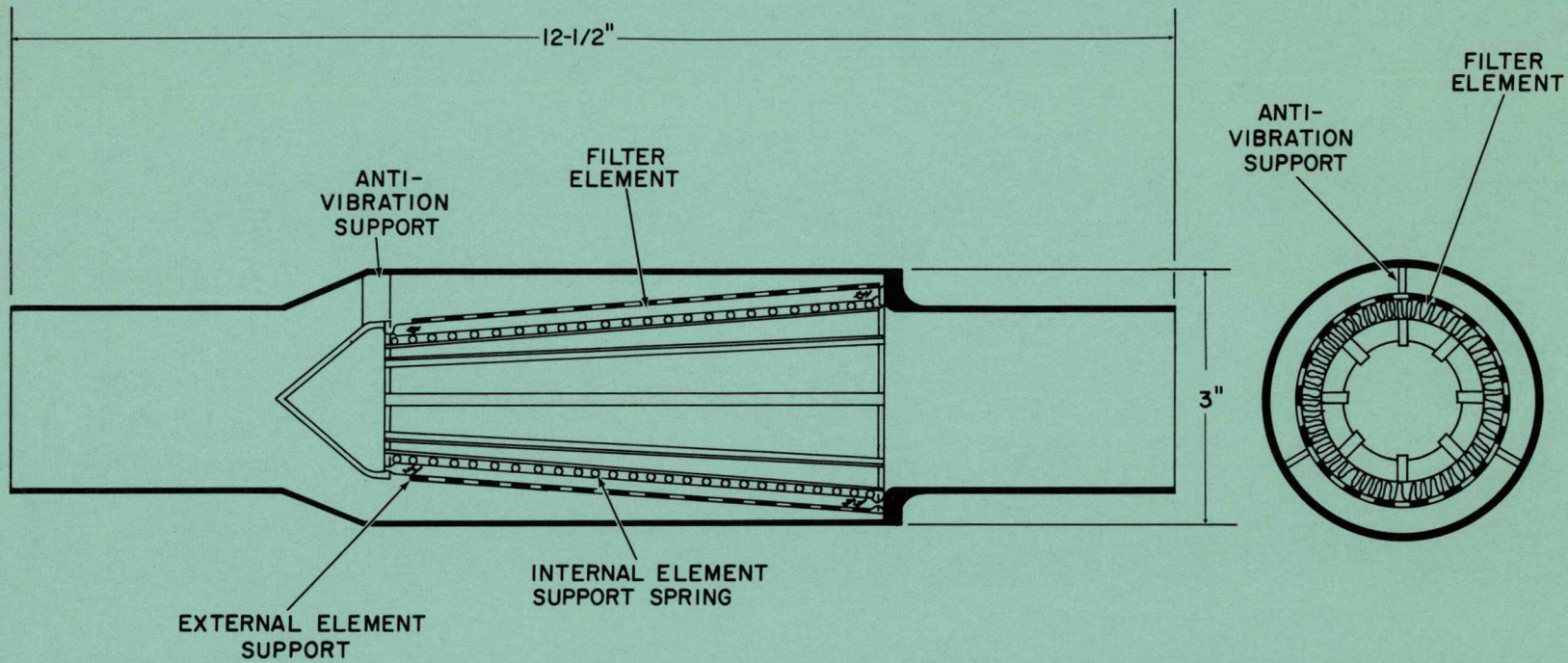
T30207-45  
JUNE 66



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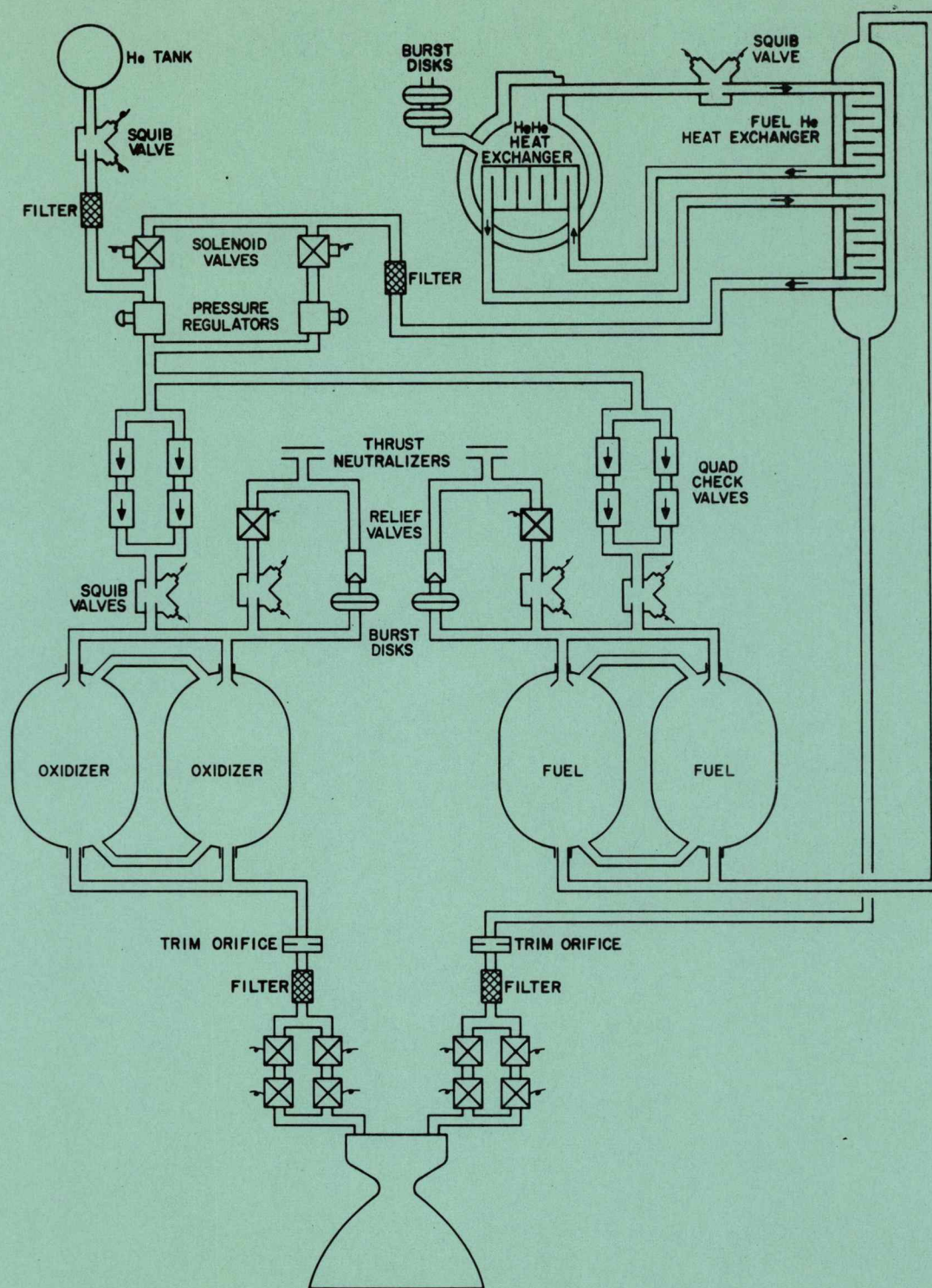


PROPELLANT FILTER, DESCENT SUBSYSTEM

Figure 17

T30207-141  
OCT 66

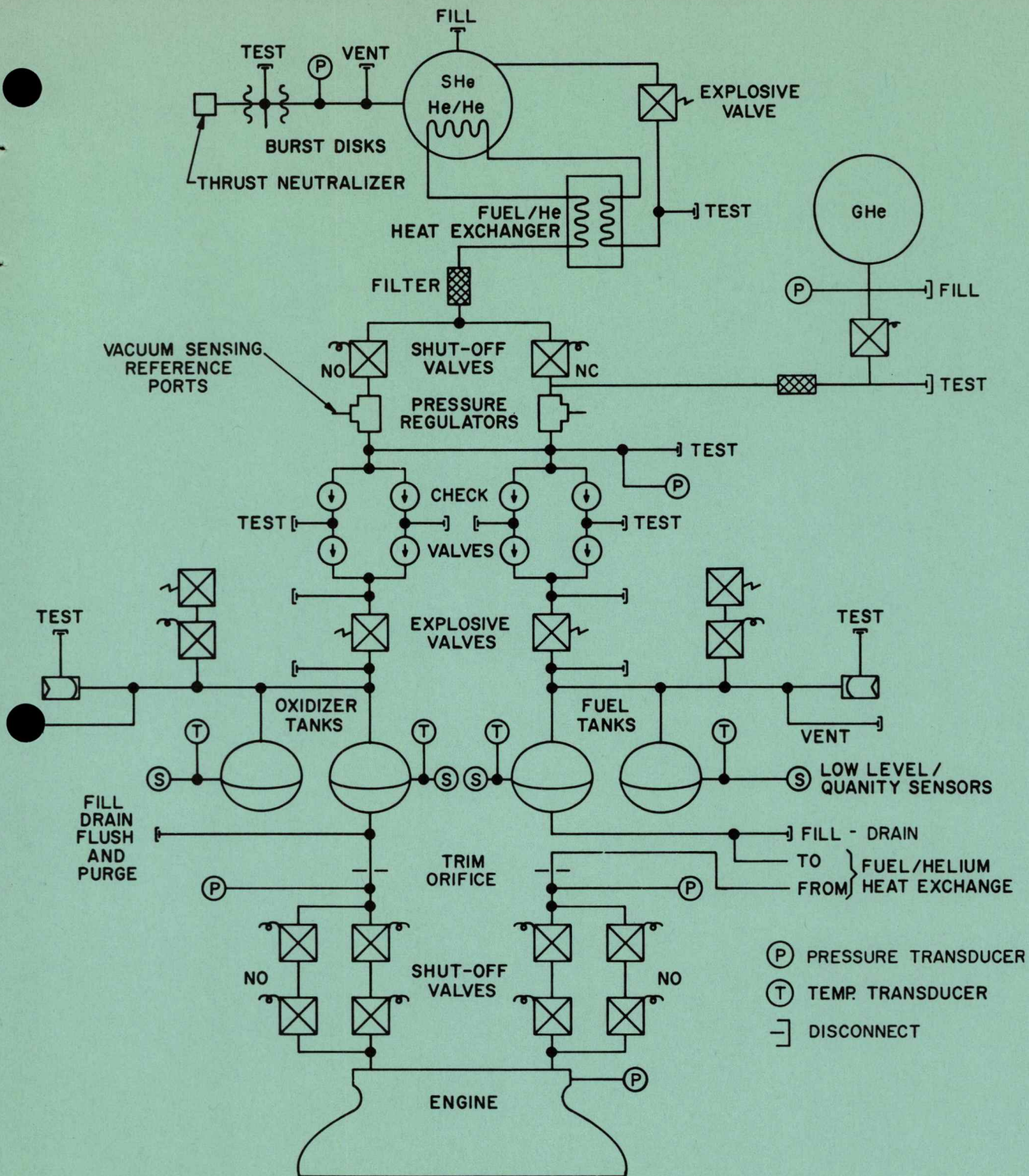




**SUPER CRITICAL HELIUM  
PRESSURE SYSTEM SCHEMATIC**

T30207-108  
JUNE 66

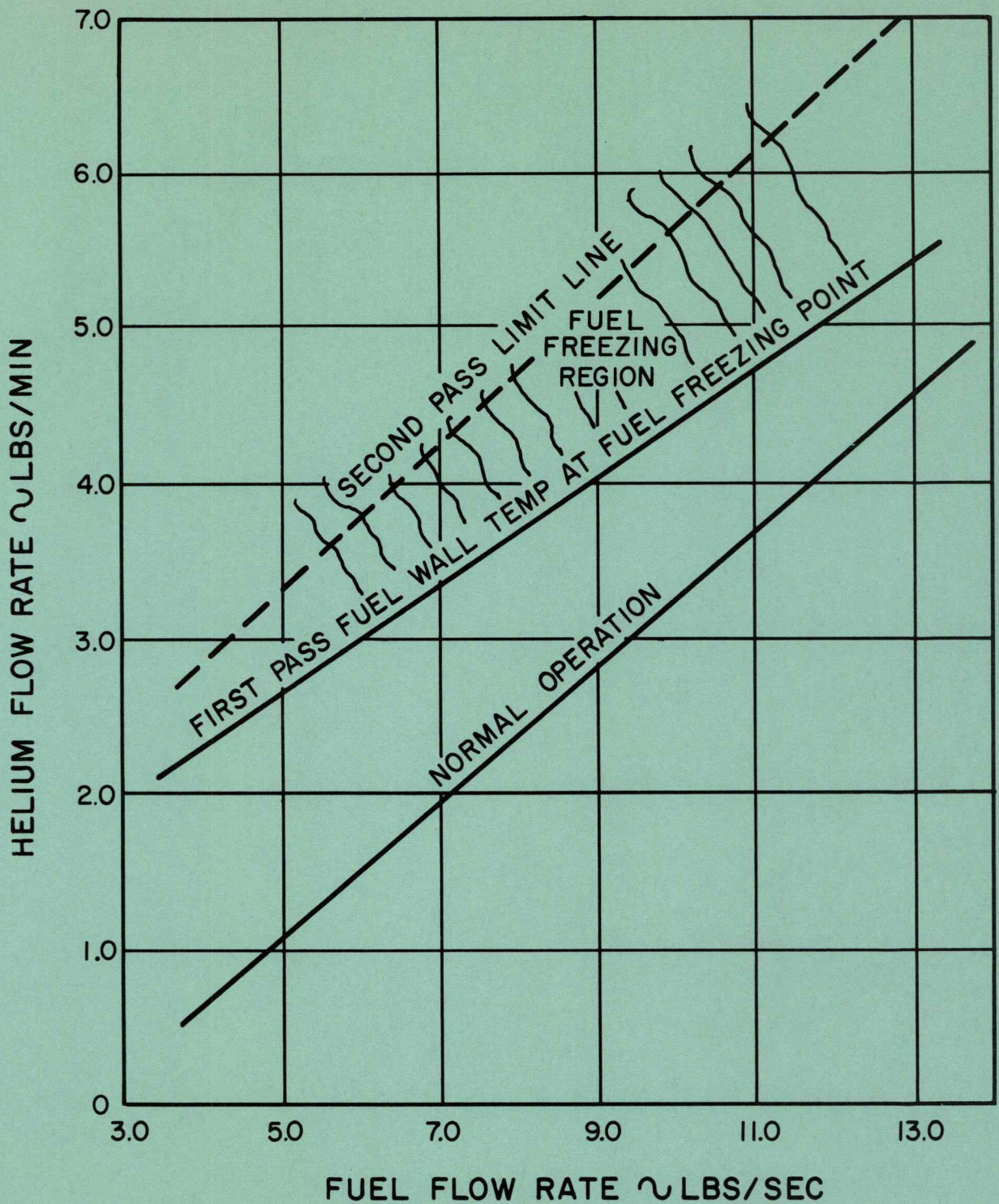




**PROPULSION SUBSYSTEM INSTRUMENTATION AND DISCONNECTS (DESCENT STAGE)**

T 30207-103  
FEB 67

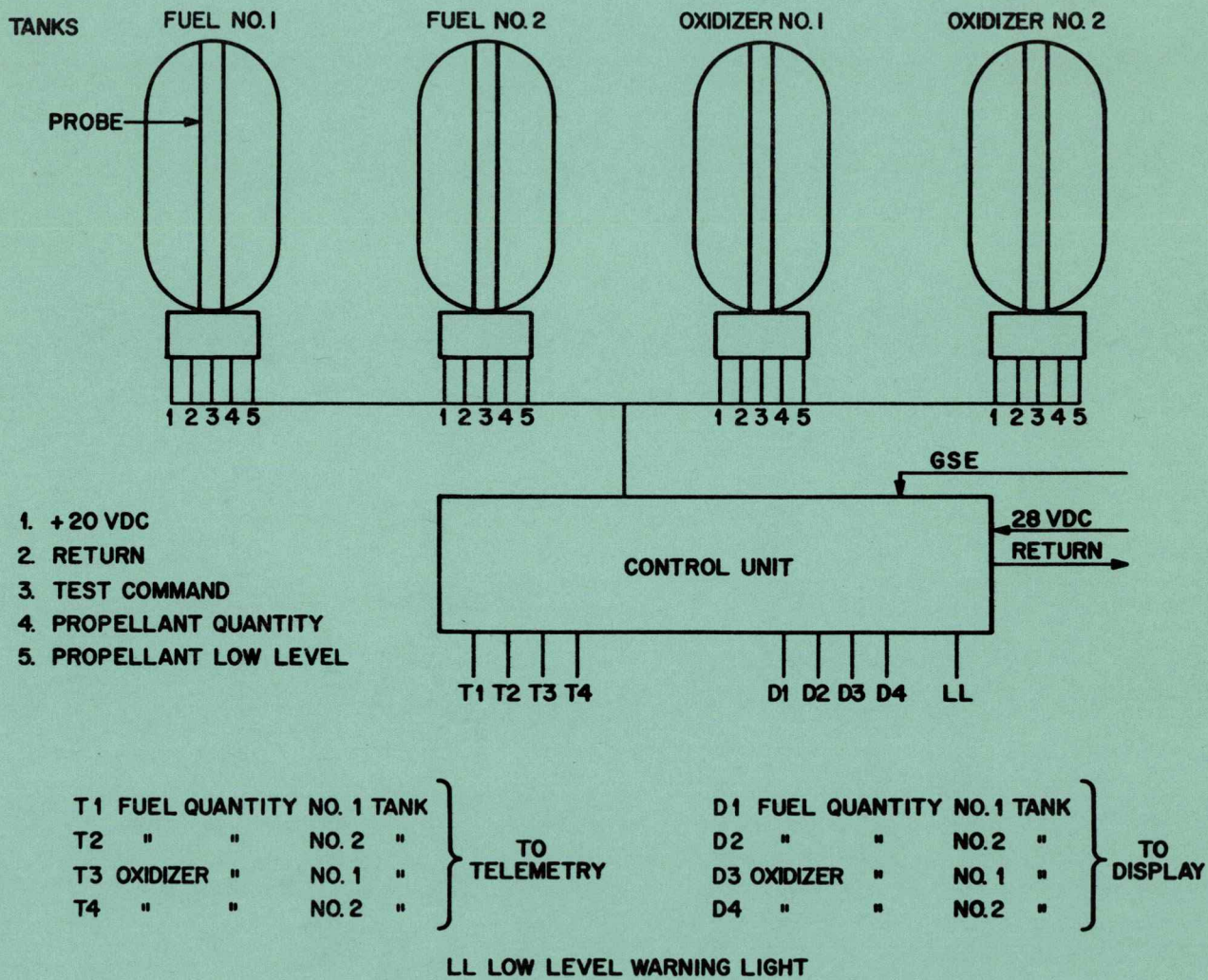




**DESCENT STAGE FUEL TO HELIUM  
HEAT EXCHANGER CHARACTERISTICS**

T30207-146  
OCT 66

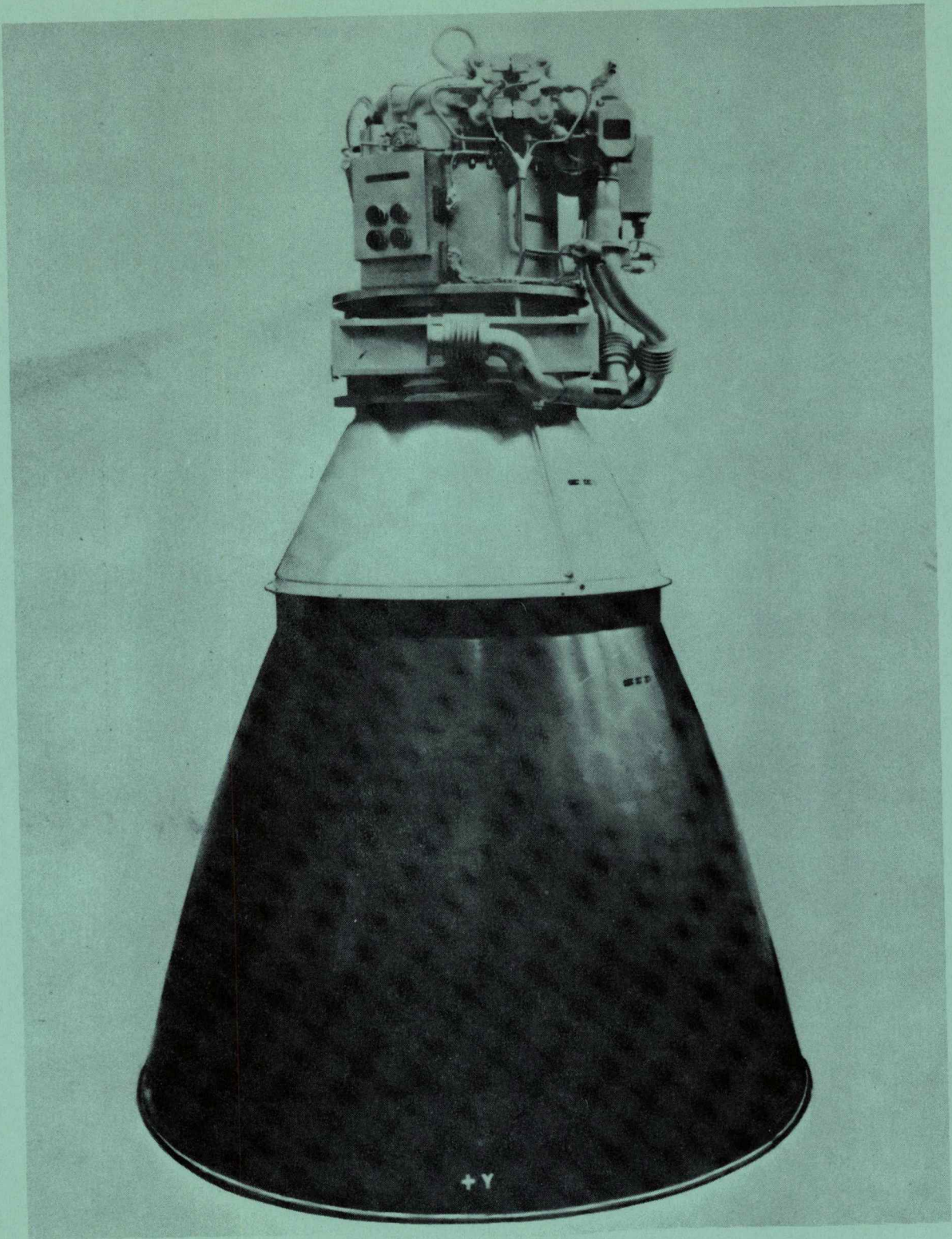




**DESCENT PROPELLANT QUANTITY GAGING SYSTEM-SIMPLIFIED DIAGRAM**

Figure 21

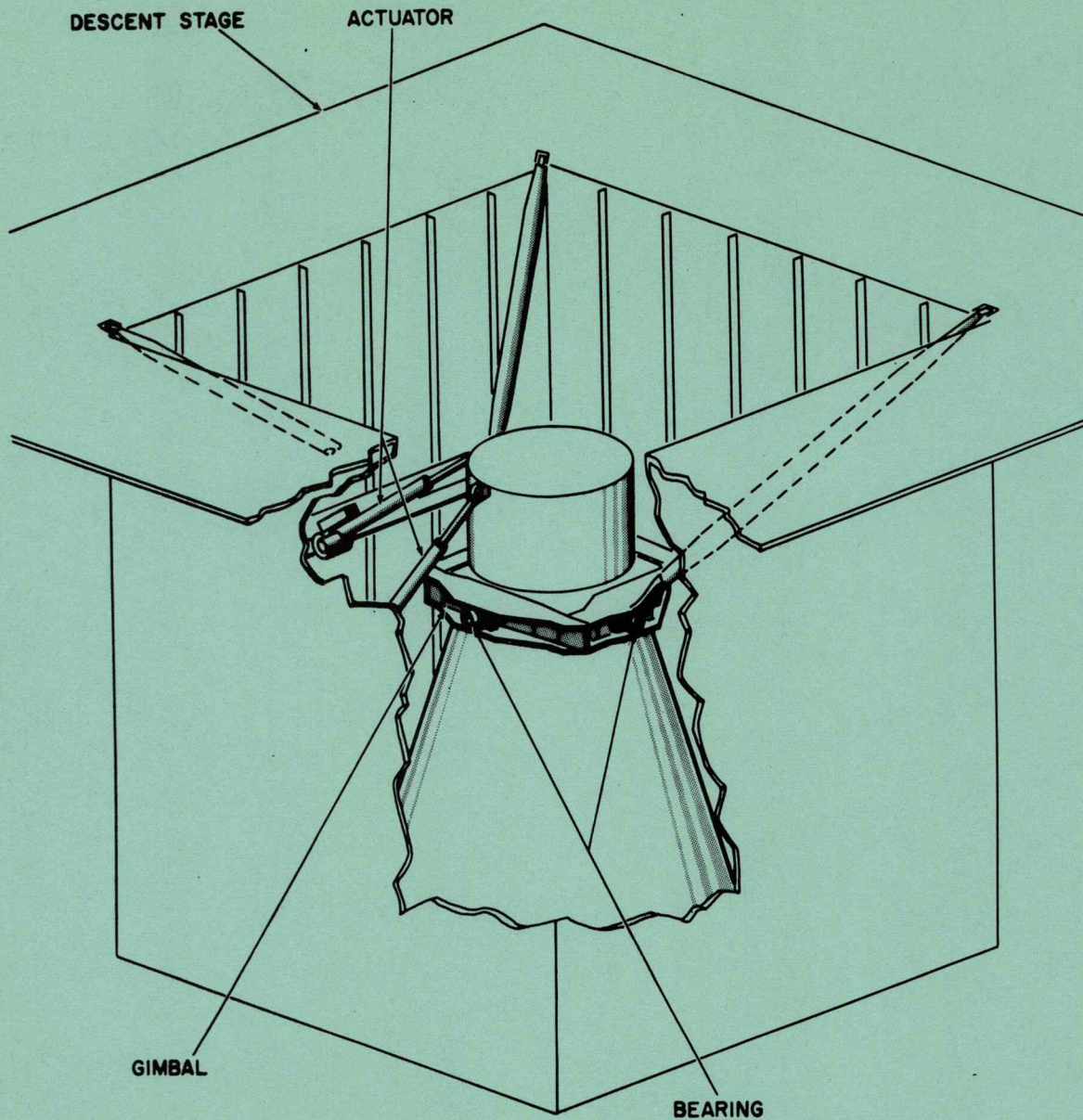




DESCENT ENGINE

T 30207-34  
FEB 66

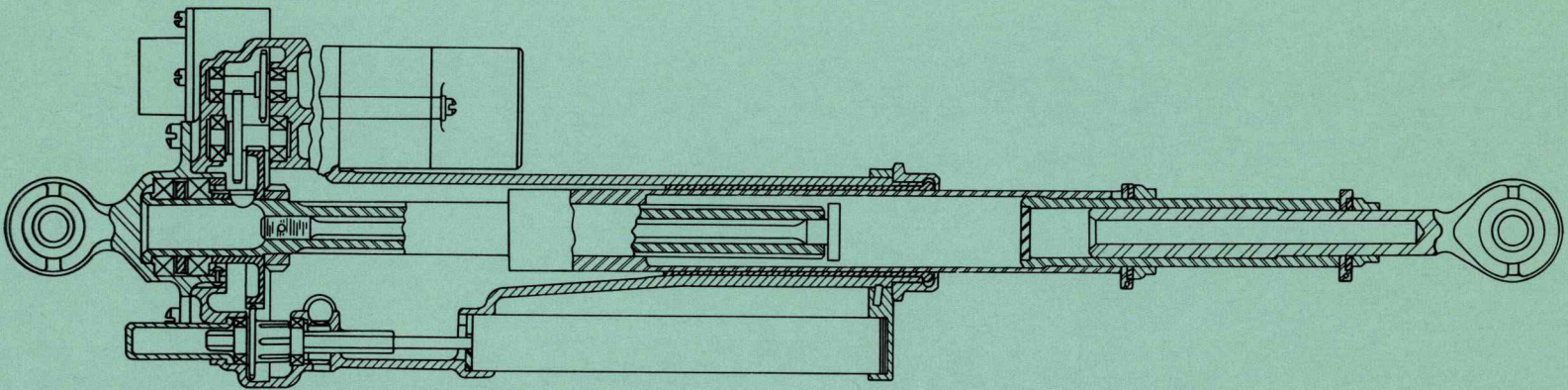




**DESCENT ENGINE INSTALLATION**

T30207-121  
FEB 66





DESCENT ENGINE GIMBAL DRIVE ACTUATOR

OBSOLETE

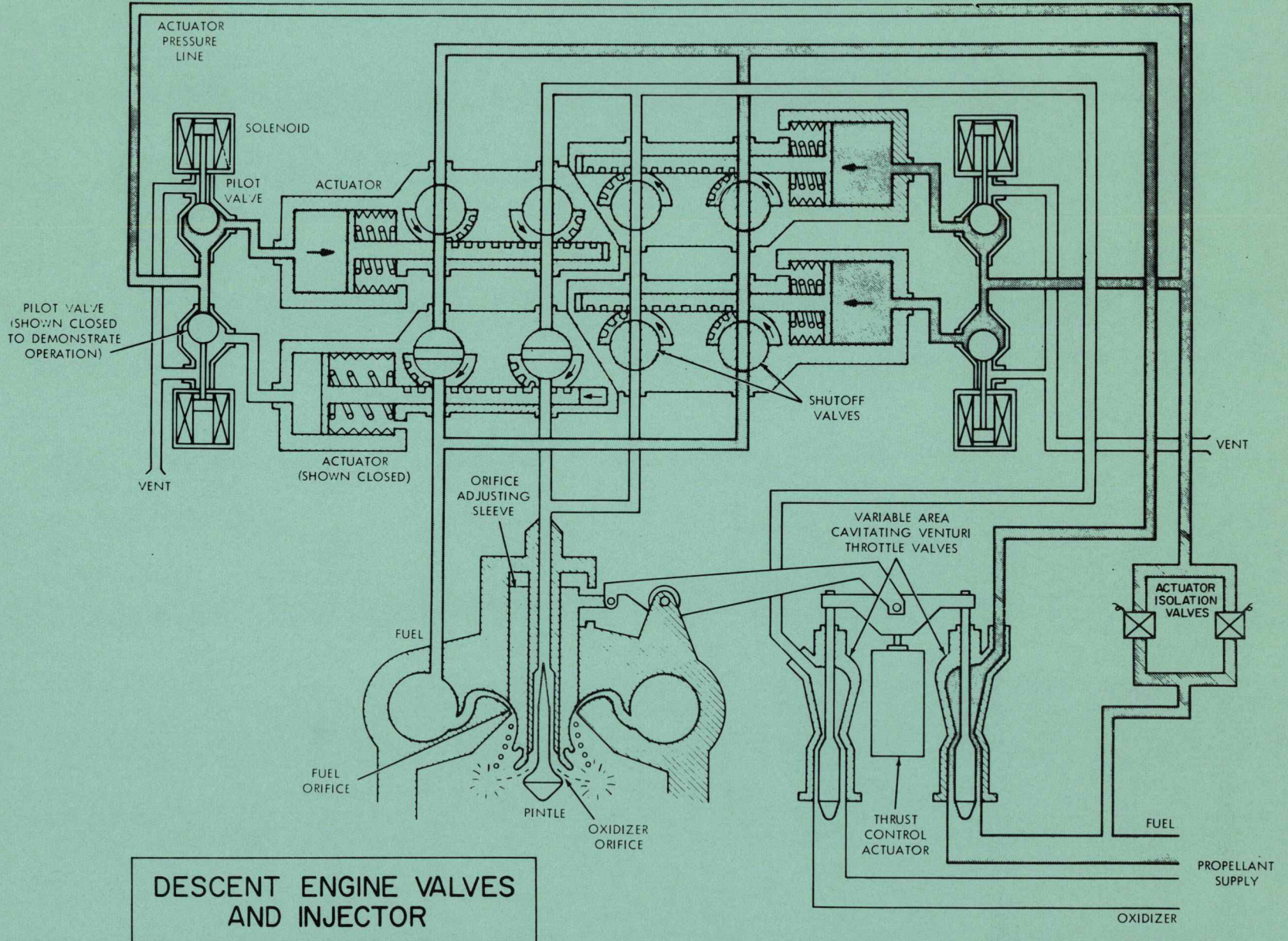
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51

Figure 24

T30405-82  
MAY 66

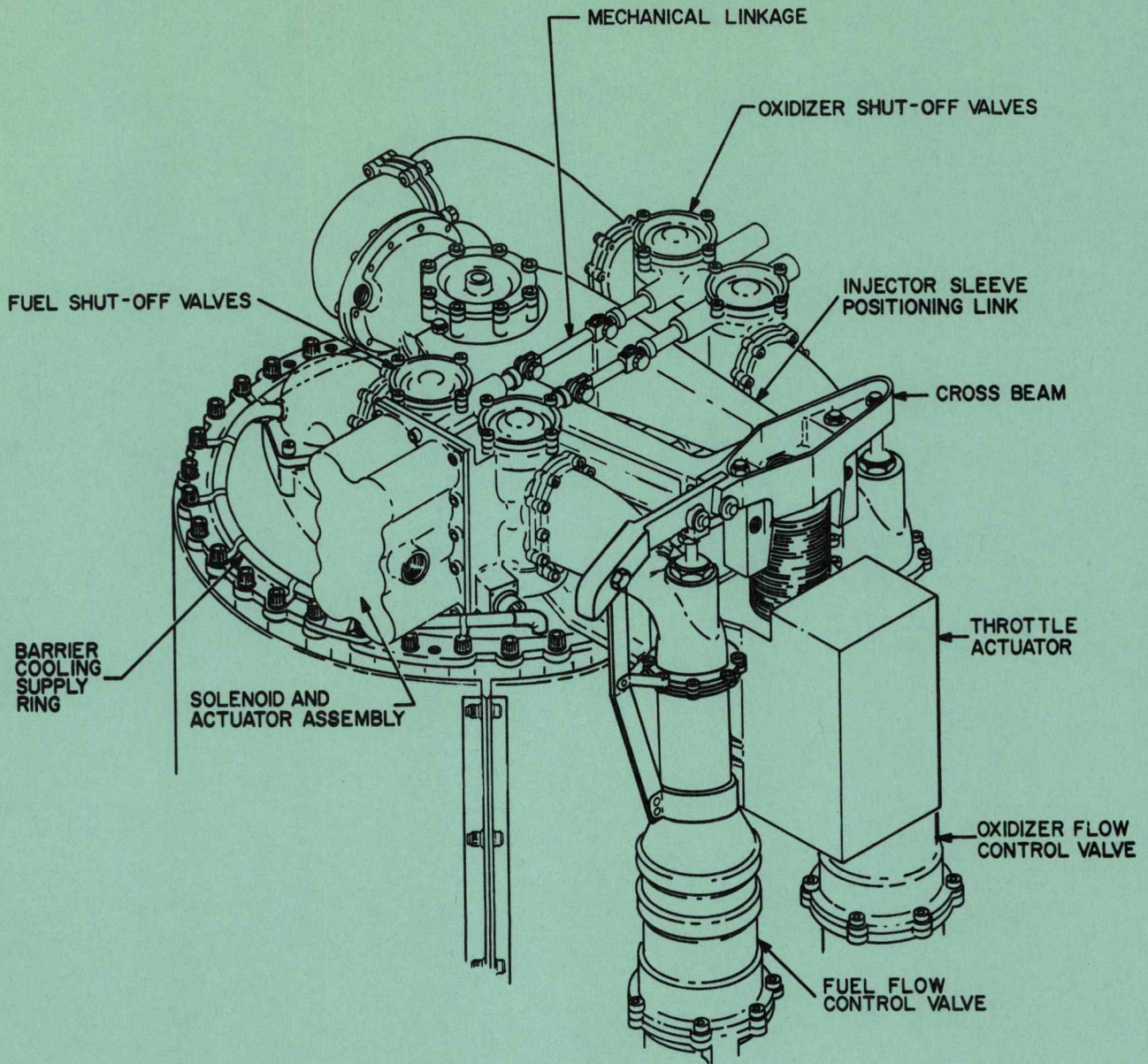




DESCENT ENGINE VALVES AND INJECTOR

Figure 25

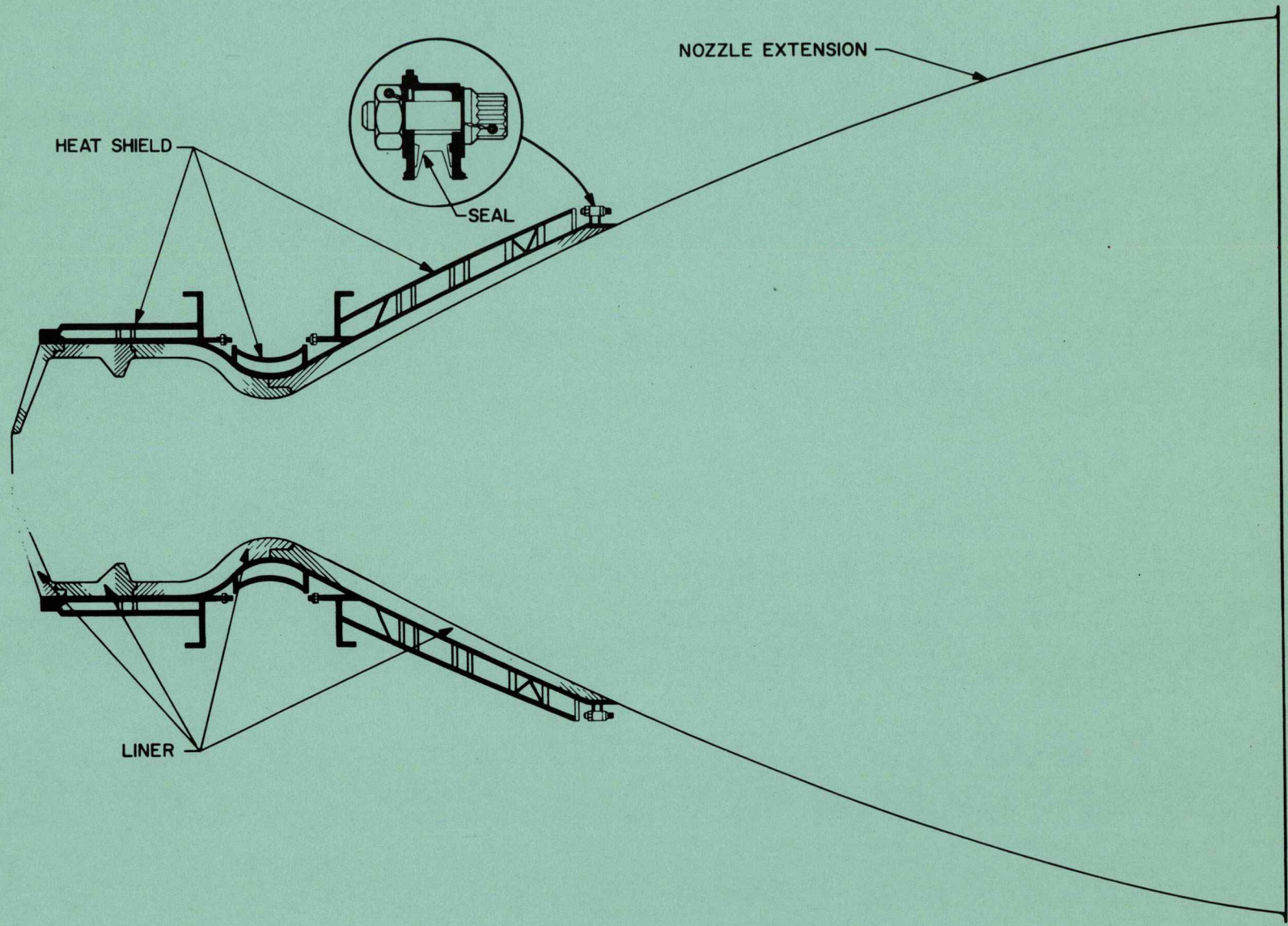




DESCENT ENGINE HEAD  
END ASSEMBLY

T30207-32  
MAR 66





HEAT SHIELD

SEAL

NOZZLE EXTENSION

LINER

THRUST CHAMBER  
CROSS-SECTION

T30207-38  
OCT 65

OBSOLETE

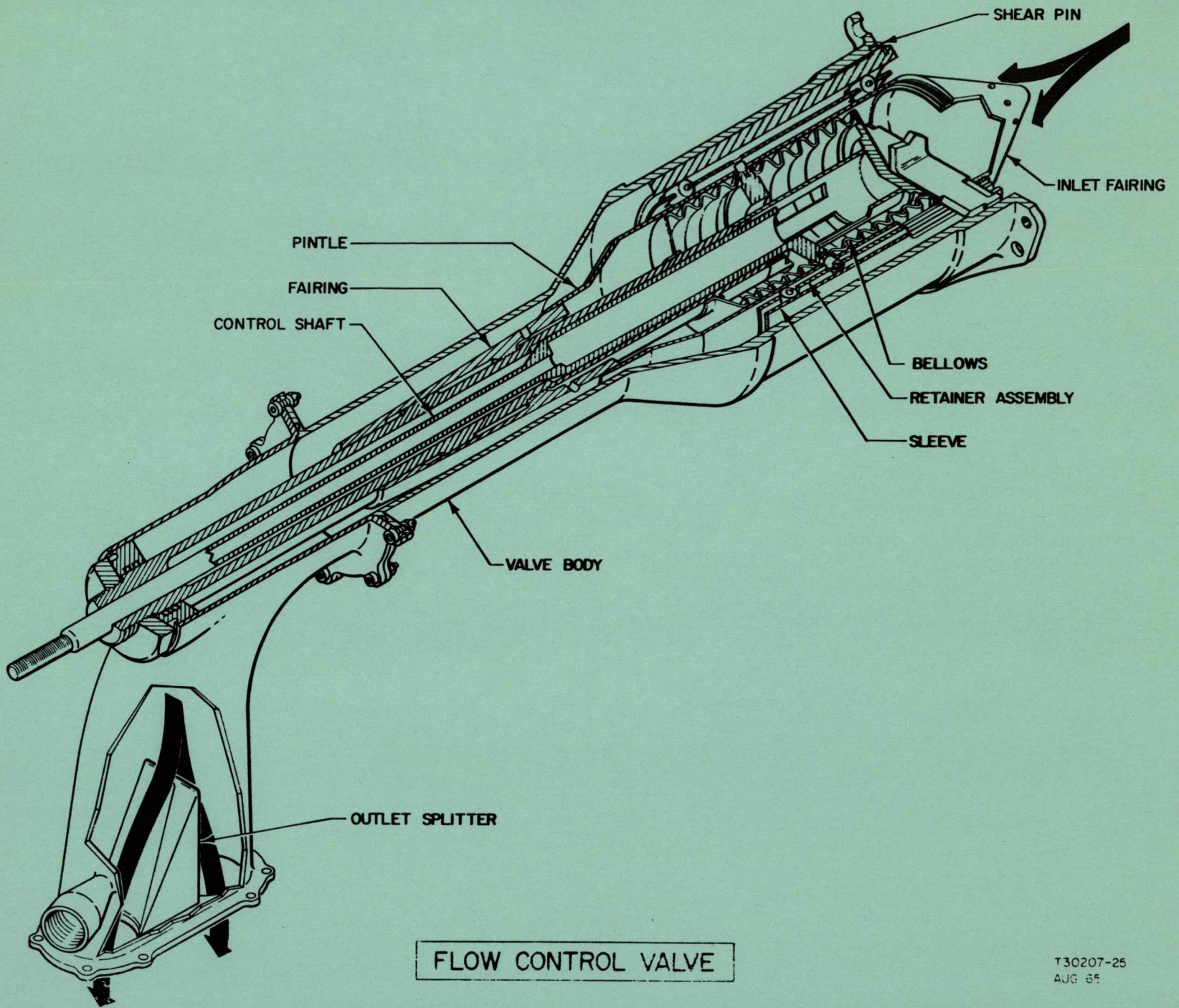
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54

Figure 27

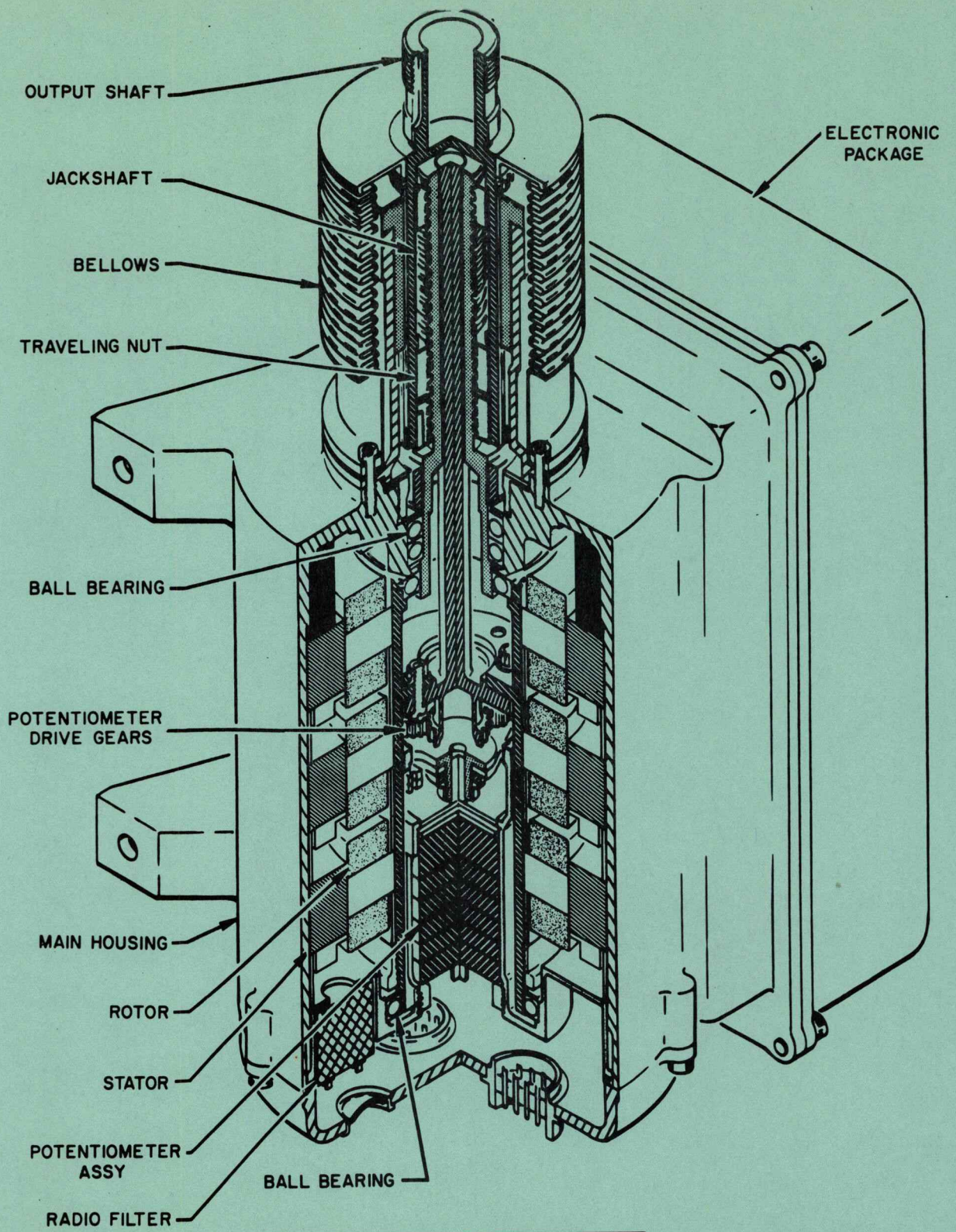


Figure 28



FLOW CONTROL VALVE

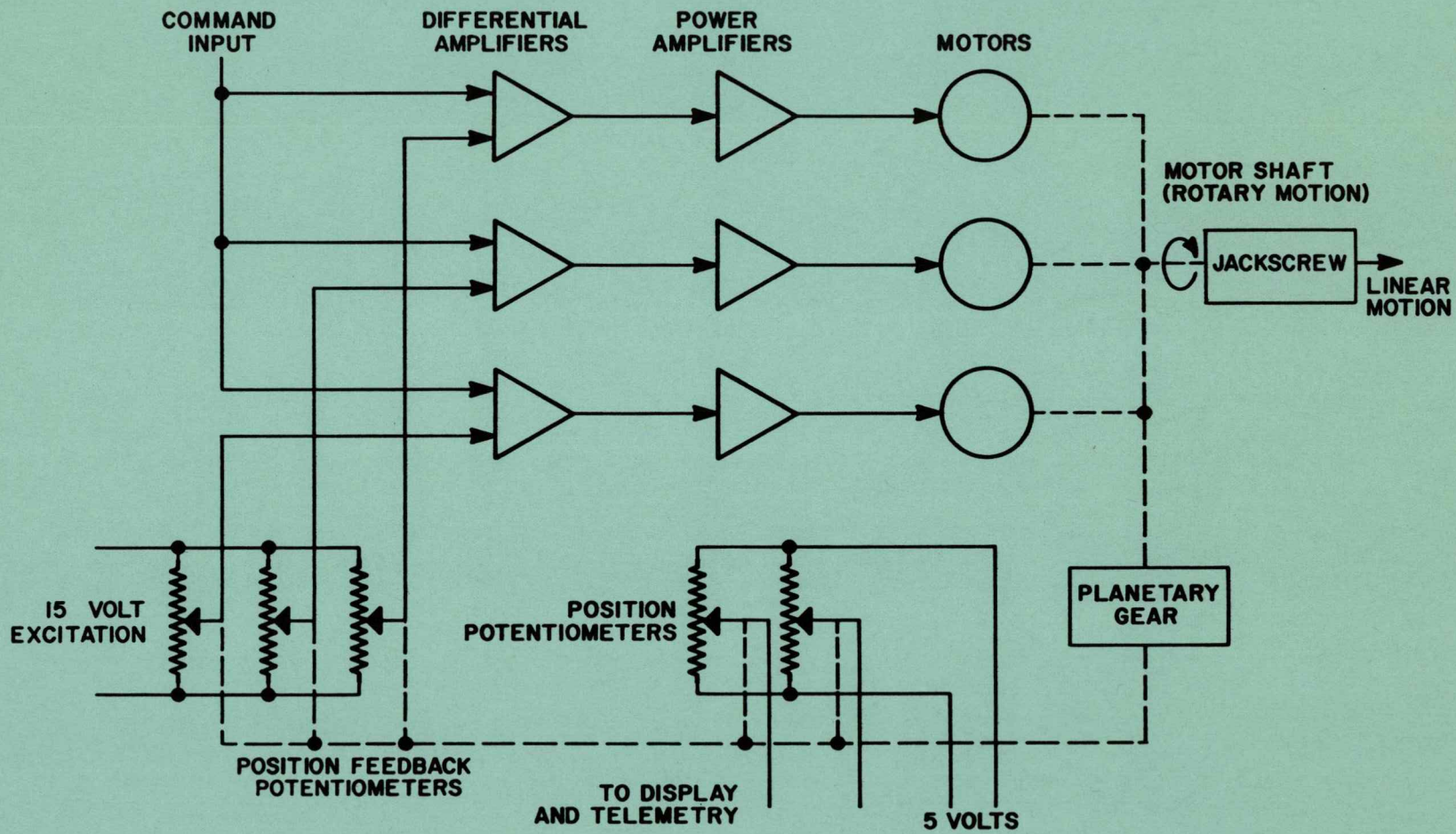




**THROTTLE ACTUATOR**

T 30207-26  
JAN 67





**DESCENT ENGINE THROTTLE ACTUATOR BLOCK DIAGRAM**

OBSOLETE

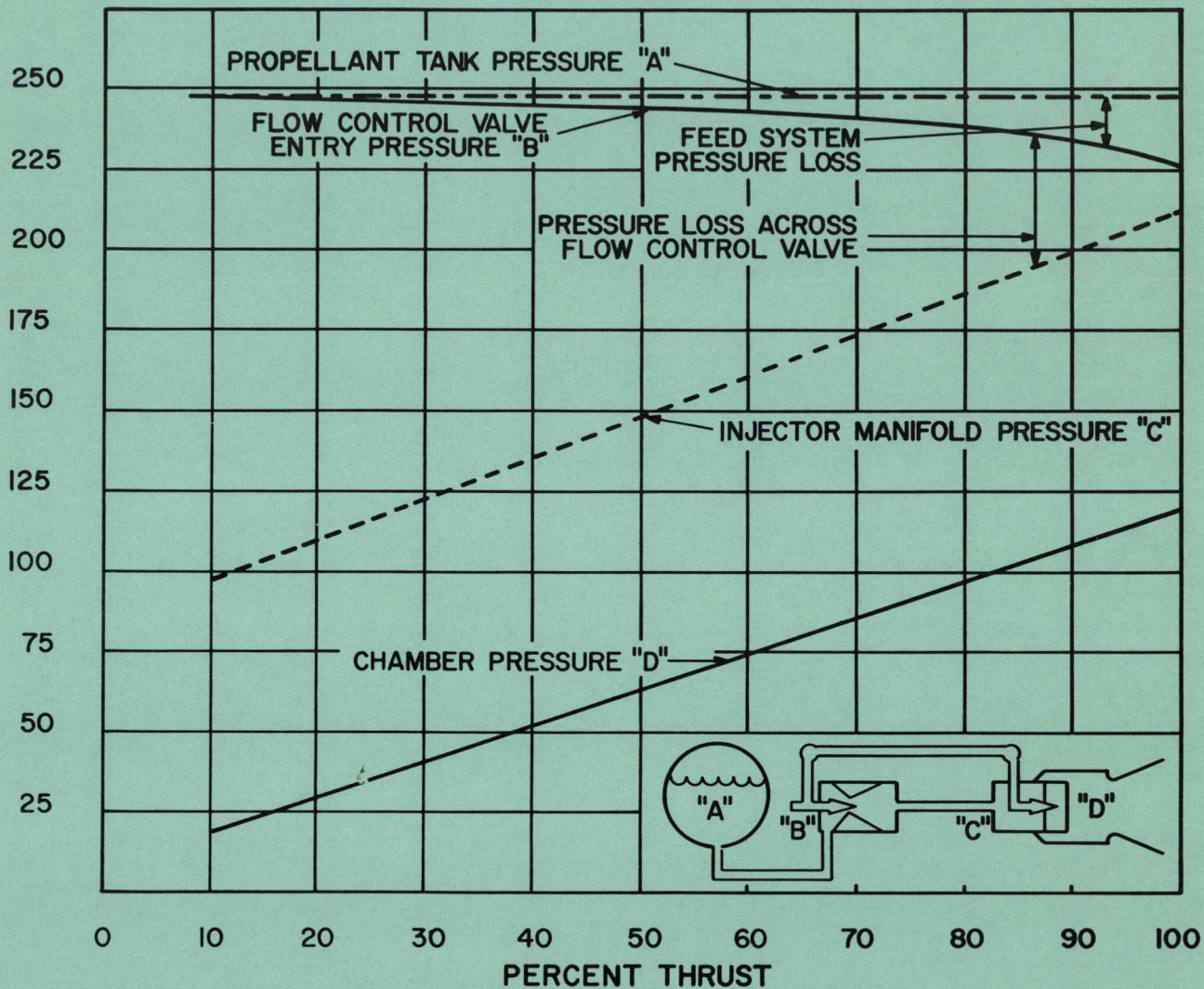
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Figure 30

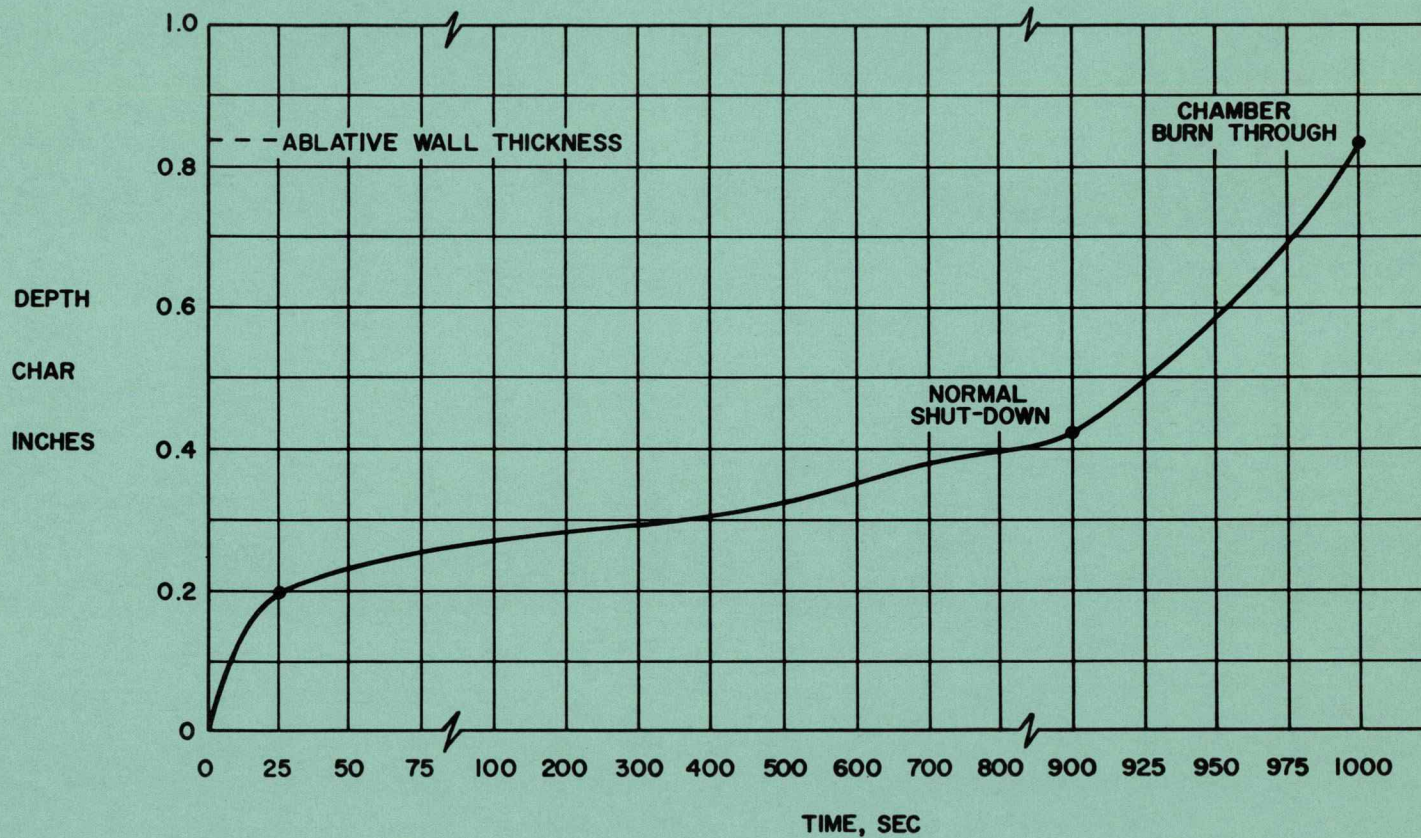


PSIA



DESCENT ENGINE PRESSURE





CHAR DEPTH VS TIME



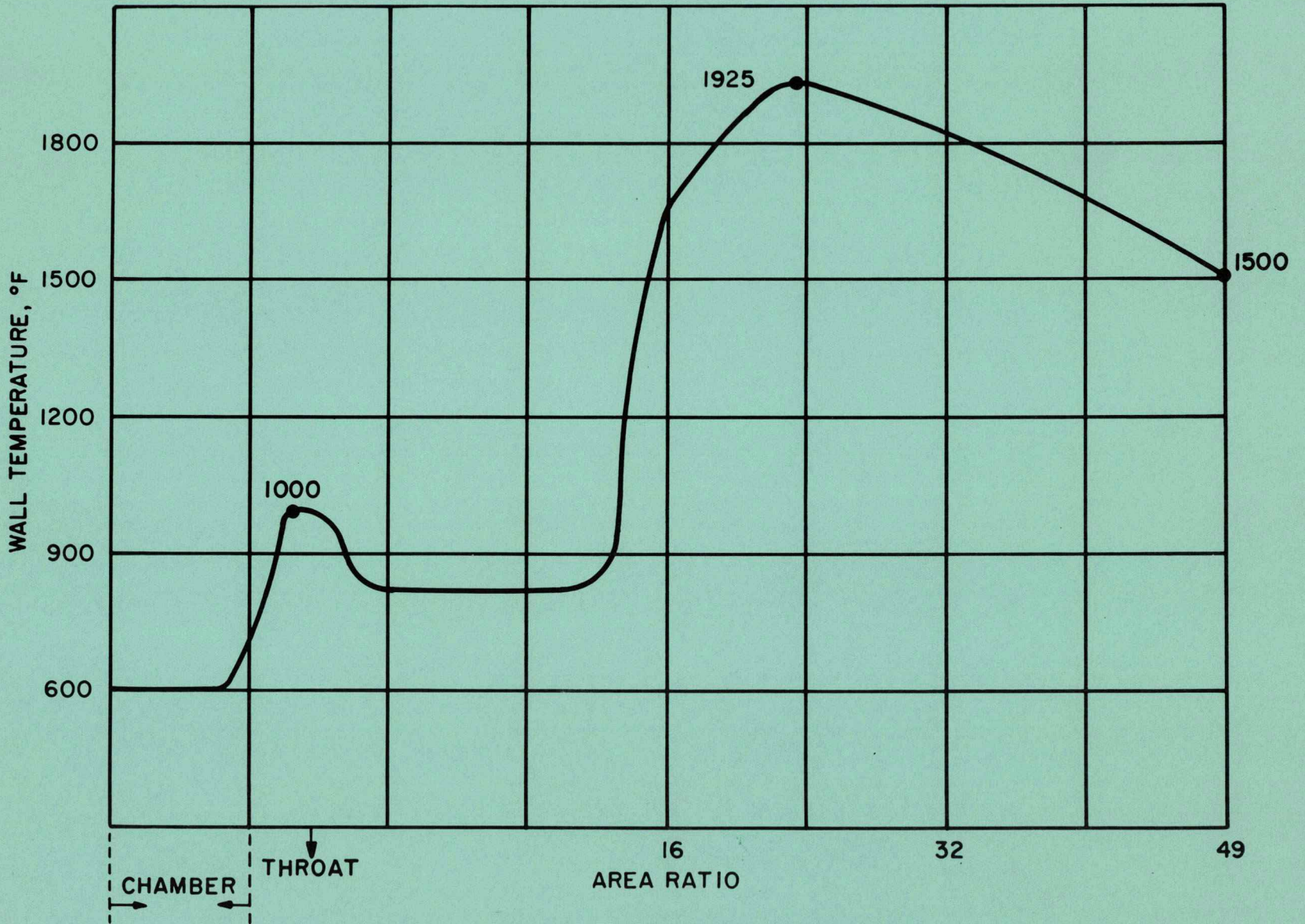
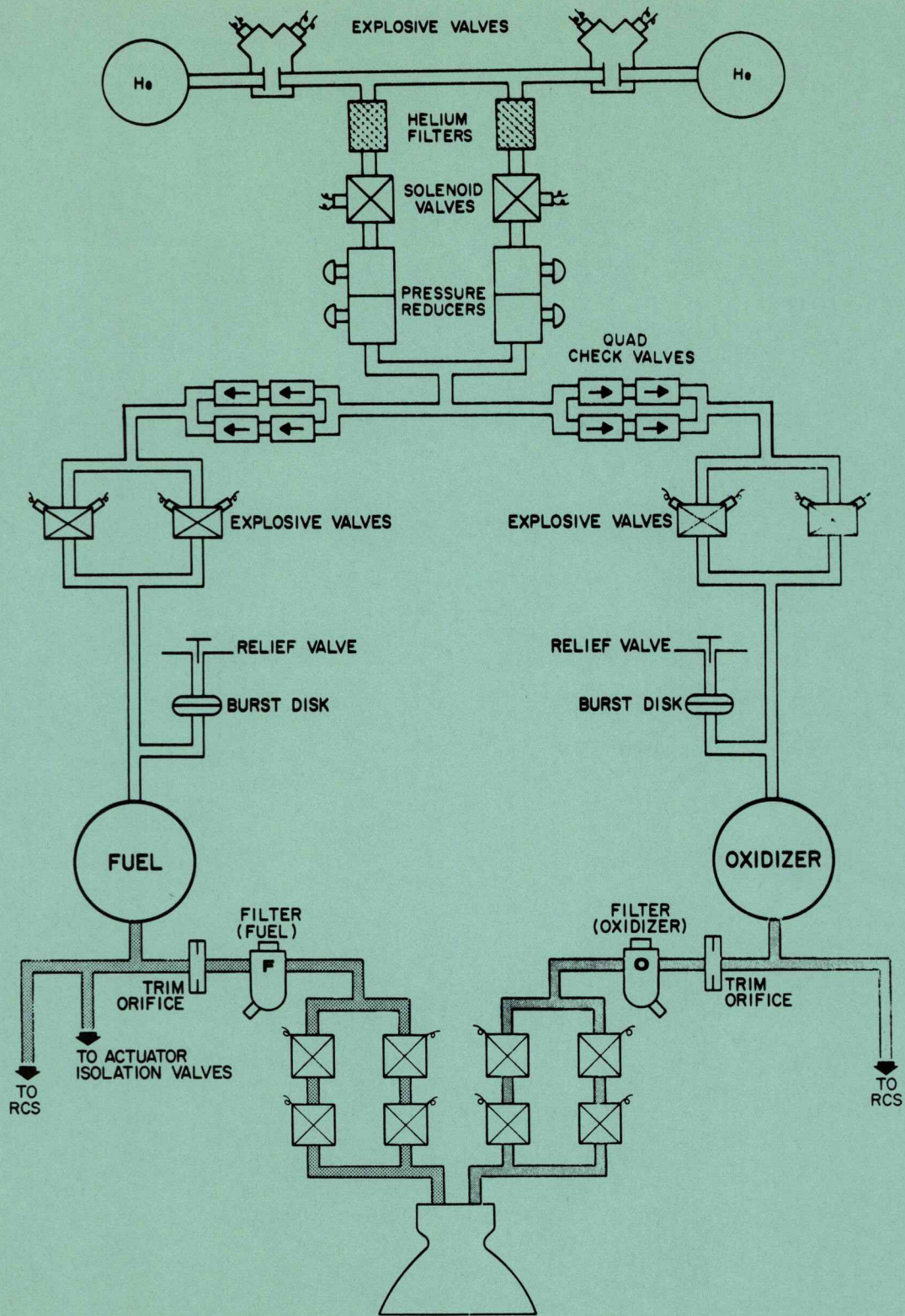


Figure 33

DESCENT ENGINE WALL TEMPERATURES

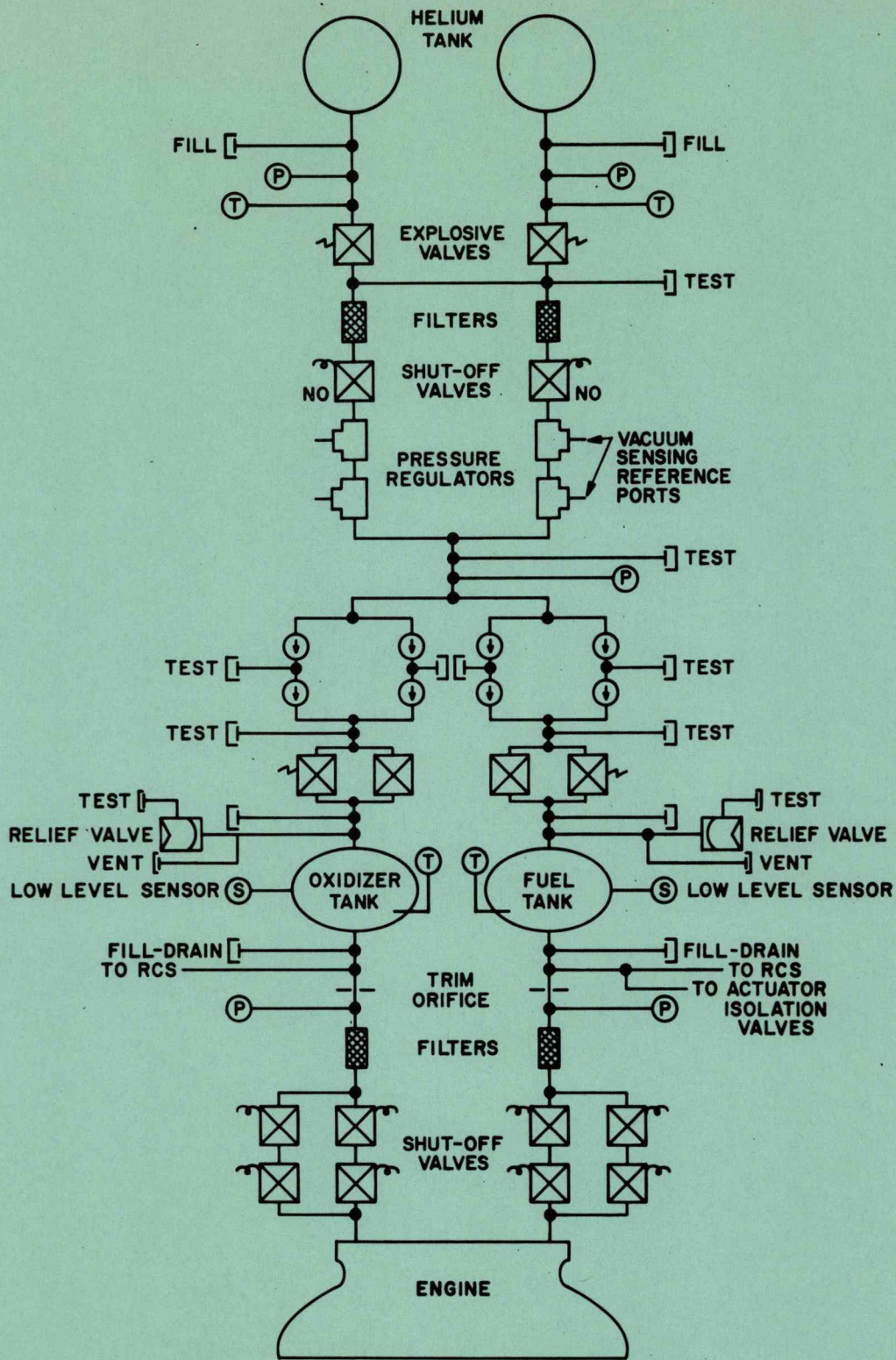




**ASCENT PROPELLANT SYSTEM**

T30207-46  
JUNE 66

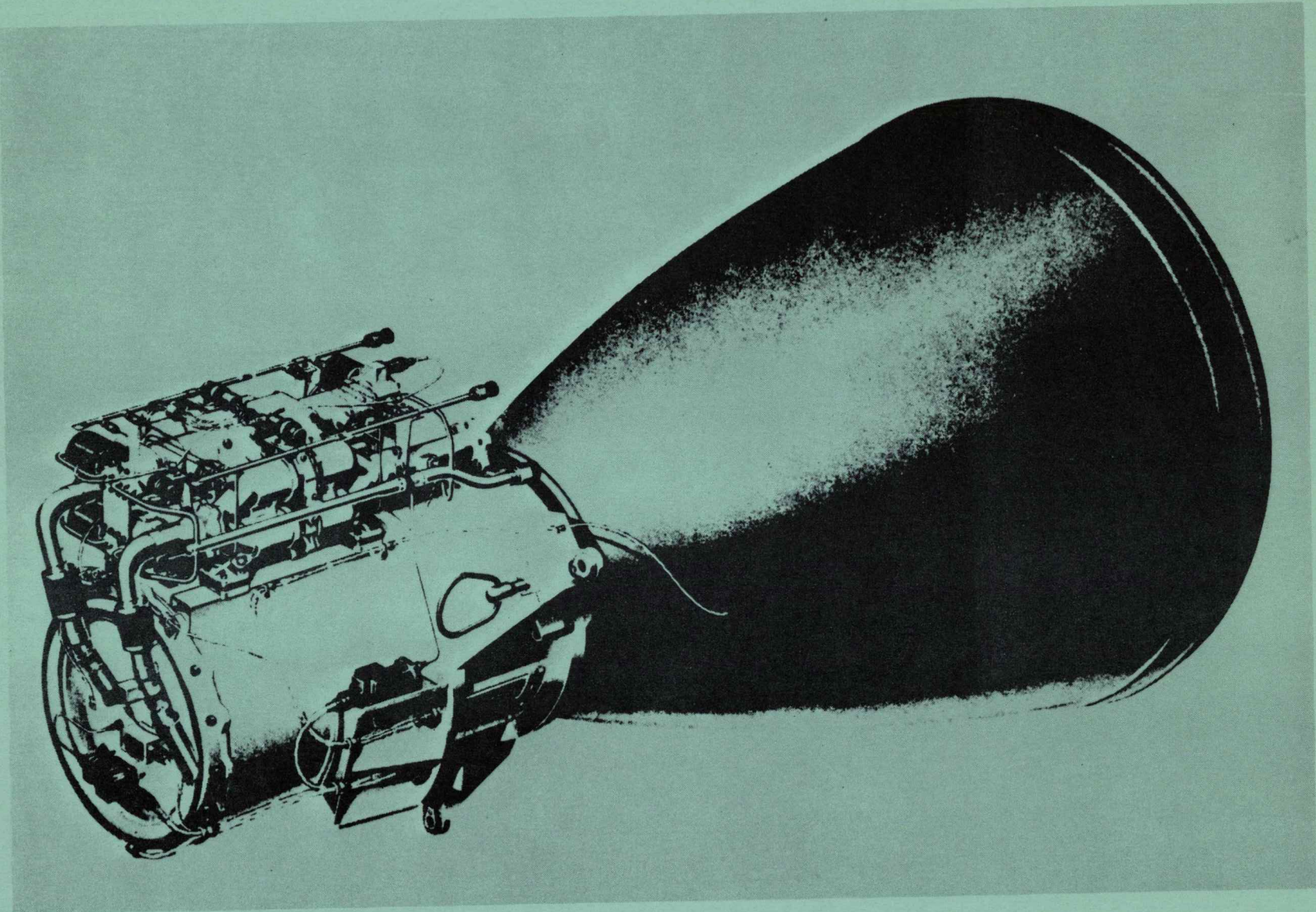




**PROPULSION SUBSYSTEM INSTRUMENTATION AND DISCONNECTS (ASCENT STAGE)**

T 30207-54  
FEB 66





ASCENT ENGINE for LM

T30207-57  
AUG 65

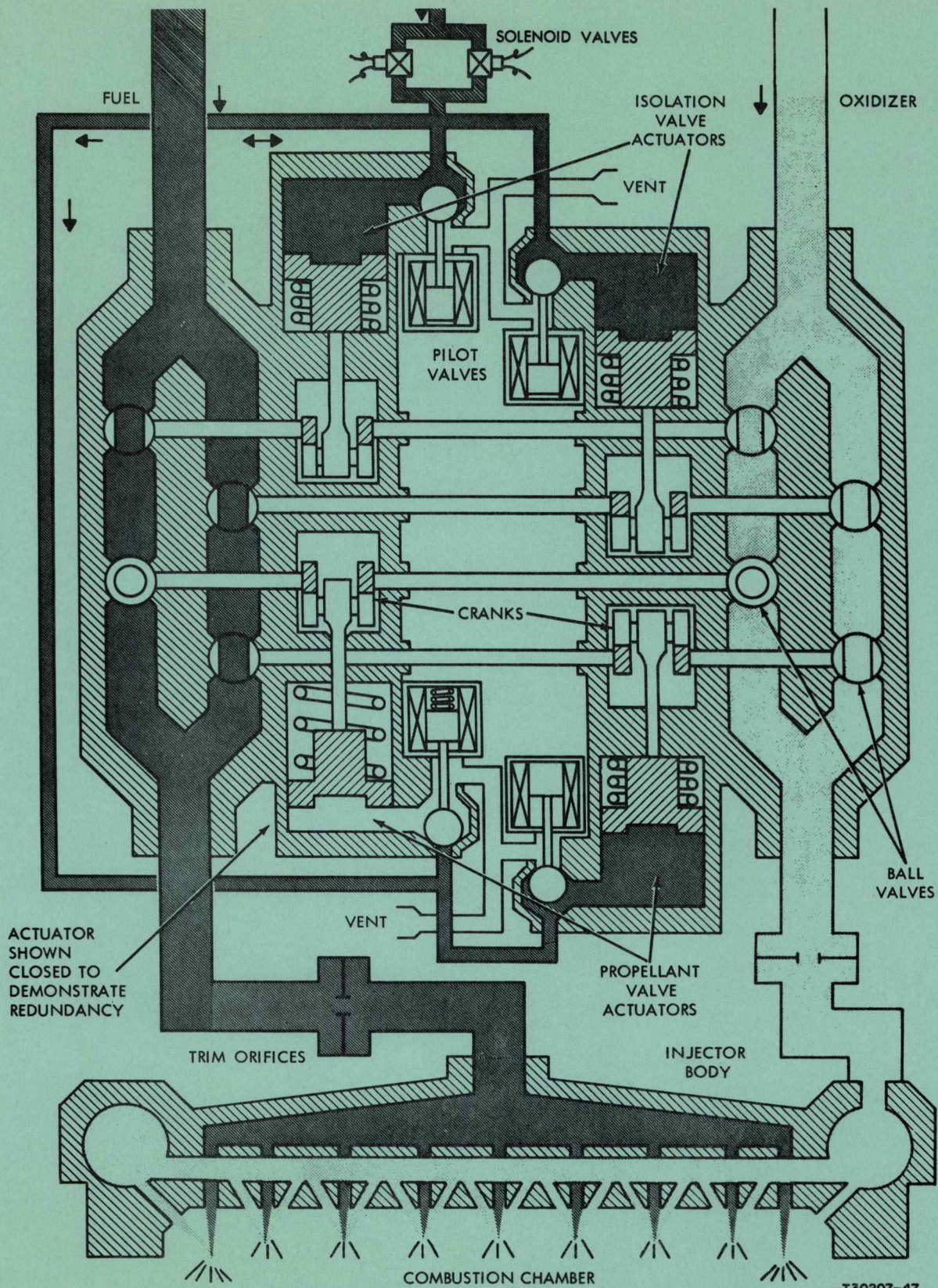
Figure 36

63

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OBSOLETE



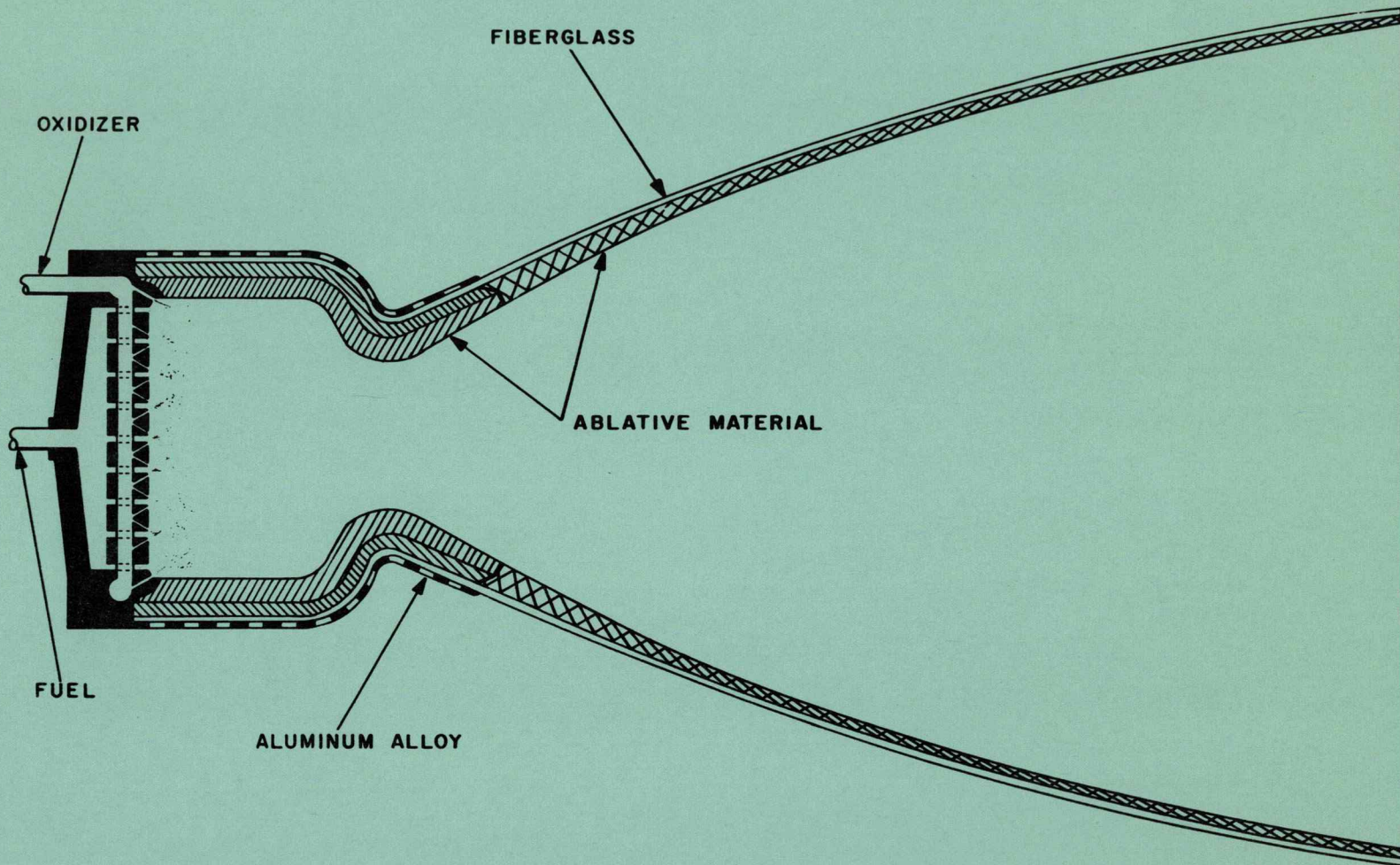


**ASCENT ENGINE INJECTOR & VALVES**

T30207-47  
DEC 65

Figure 37





OBSOLETE

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65

Figure 38

ASCENT ENGINE CROSS-SECTION

T 30207-126  
MAR 66



## CHAPTER III

### Reaction Control Subsystem

#### Introduction

The Reaction Control Subsystem (RCS) is composed of two parallel, independent systems ("A" system and "B" system). (See Figure 39.) Each system contains identical helium pressurization components and propellant feed components, together with the associated valves and piping necessary to deliver the propellants to the thrust chamber assemblies.

Sixteen identical thrust chamber assemblies (engines) are arranged in clusters of four and are mounted on four outriggers that are equally spaced around the LM ascent stage. In each cluster two engines are mounted parallel to the vehicle "X" axis, but facing in opposite directions. (One engine faces up, the other down.) The other two engines are mounted in a plane normal to the "X" axis (facing horizontal) and spaced 90° apart. The center line of one engine parallels the vehicle "Y" axis; the center line of the other parallels the "Z" axis. (See Figure 40.) Two of the engines are supplied propellants by system "A"; the other two by system "B". Normally, both systems are operated together, but the arrangement of the engines is such that complete control in all axes is still possible despite a failure in either system.

The RCS performs the following functions:

1. Provides small thrust impulses to stabilize the LM during descent and ascent.
2. Provides necessary thrust impulses to control the vehicle attitude (movement around an axis) and vehicle translation (movement along an axis) during hover, landing, rendezvous, and docking maneuvers.
3. Provides necessary thrust impulses to accomplish the LM/Service-Command Module separation maneuver.
4. Provides necessary thrust impulses to accomplish accelerations for ullage, settling for the descent or ascent propellant storage tanks, when required.



## Reaction Control Subsystem Components

1. Helium Storage Tanks. Gaseous helium is contained at a nominal pressure of 3050 psi, at 70°F in two spherical, titanium storage tanks. This helium is used as a pressurant for expelling propellants from the propellant tanks.
2. Helium Isolation Valves. These are normally closed valves that isolate the helium in the supply tanks until propellant tank pressurization is required. An electric signal from the control panel ignites a squib and expanding gases force the valve open. It cannot be closed again. (See Figures 5 and 6.)
3. Helium Filter. Contaminants from the helium storage tanks or debris generated by the actuation of the isolation valves are trapped by a filter in order to prevent contamination of downstream components. (See Figure 7.)
4. Pressure Reducing Regulators. There is one pressure regulating leg in each system, each containing two pressure regulators, arranged in series. Each regulator has the ability to reduce the helium pressure from that of the helium storage tank to that required to provide correct propellant tank pressure. Each regulator contains a pilot valve and seat assembly which modulates inlet pressure to control the opening of the main poppet valve and seat assembly. (See Figure 41.)
5. Quad Check Valves. This assembly is composed of four single poppet type check valves working in a series-parallel arrangement to prevent the mixing of propellant or propellant fumes in the upstream helium pressurization manifold. (See Figure 12.)
6. Relief Valve Assy. This assembly is installed to prevent propellant tank damage in case of an open failure of the pressure reducing regulators, with resulting system overpressurization. A burst disc isolates the relief valve from the helium pressurization system during normal operation and so prevents helium loss through a possibly leaking relief valve. If overpressurization occurs the burst disc will rupture and excess helium will be dumped overboard. When the pressure drops below the nominal setting the relief valve closes preventing further helium loss and permitting



a resumption of normal operation. A normally open vent valve, located between the burst disc and the relief valve, will prevent any pressure build up in this area, should the burst disc leak. Following any system overpressurization and burst disc rupture this vent valve will close. A filter is included between the burst disc and relief valve to prevent possible contamination of the valve by fragments from the ruptured disc. (See Figure 42.)

7. Propellant Storage Tanks. There are two propellant storage tanks in each system, one for oxidizer and one for fuel. These tanks are cylindrical with hemispherical ends and are fabricated of titanium. The propellants are contained within a one ply teflon bladder with a thickness of six mils (.006 inch), supported by a standpipe running lengthwise in the tanks. (See Figure 43.) Helium entering the tank under pressure squeezes the bladder and expels the propellant through holes in the standpipe into the propellant feed system piping. This arrangement provides positive propellant feed to the engines during zero "G" operation.
8. Propellant Quantity Gaging System. This system determines the amount of propellants contained in the RCS tanks under zero "G" conditions. It provides a separate measurements of "A" system and "B" system propellants. Primarily, it consists of a sensing probe in each system helium tank and two signal conditioning units which convert the input information into a form suitable for control panel display and telemetry. (See Figure 51.)
9. Propellant Shut-off Valves. A latching type solenoid valve is located downstream of each propellant tank. These valves are normally open for system operation, but can be closed in pairs (both system "A" valves, or both system "B" valves) to isolate the propellant tanks in case of an upstream malfunction or if ascent subsystem propellants are being used in the RCS. (See Figures 44 and 45.)
10. Ascent Interconnect Valves. Four, normally closed, latching solenoid valves isolate the ascent propellant system from the RCS propellant system. They can be open during periods of ascent engine thrusting to allow the use of ascent subsystem propellants in the RCS for the purpose of conserving RCS propellants. These valves can be opened in pairs, selectively, interconnecting the ascent propellant system to RCS "A", or "B", or both "A" and "B" simultaneously.



11. Crossfeed Valves. Two, normally closed, latching solenoid valves (one for oxidizer and one for fuel) are used to isolate the system "A" propellant manifolds from the system "B" propellant manifolds. In case of an upstream failure or propellant depletion in either system, these valves may be opened to connect the "A" and "B" system propellant manifolds and so allow propellants of one system to be used in the other system.
12. Isolation Valves. Sixteen, normally open, latching type solenoid valves allow propellant flow from the propellant manifolds to the engine clusters. They can be closed selectively, in pairs, in event of engine malfunction. (Two isolation valves - one pair - is controlled by one switch at the control panel and controls oxidizer and fuel flow to two engines of the same system in one cluster.)
13. Plumbing. All helium supply lines and propellant feed lines are made of stainless steel. Brazed connectors are used throughout.

#### Functional Description of the RCS Helium Pressurization and Propellant System Operation

(See Figures 46 and 47.) Gaseous helium is stored at a nominal pressure of 3050 psi at 70°F in two spherical storage tanks. Each independent system ("A" and "B") contains one helium tank and a set of pressurization components. The out flow from each tank separates into parallel paths. Each flow path contains one normally closed, squib actuated isolation valve. The two valves in each system are redundant and isolate the helium tank from downstream components prior to RCS pressurization. All valves are simultaneously opened by an electrical RCS pressurization command from the control panel just prior to LM/Service-Command Module separation, permitting pressurization of the RCS propellants.

Downstream of the squib isolation valves the two flow paths are manifolded, and routed through a filter. The filter is provided to trap any debris, generated by activation of the squib valves thereby preventing contamination of downstream components.

Downstream of the filter the flow path contains two pressure regulators, in series. The upstream regulator is set to regulate the pressure to approximately 180 psi, the downstream regulator is set to a slightly higher pressure, about 185 psi.

In normal operation the upstream regulator reduces the helium supply pressure to the required level for proper propellant tank pressurization, while the downstream regulator senses a demand and remains open as the sensed demand is below the setting. If the



upstream regulator fails open, control is obtained through the downstream regulator at a higher pressure setting. An open failure of the downstream regulator is of no consequence as the upstream regulator is already in control.

If either regulator fails closed, or if both regulators fail open, the pressure at the downstream manifold will either increase or decrease beyond acceptable limits and a warning light on the cockpit display panel will come on. As there is no alternate helium flow path, there is no crew action required or possible. In the first case, a regulator closed failure, engine operation in blow down mode will continue briefly until the helium pressure drops below the point where propellants can be injected into the engine combustion chamber. In the second case, a double open failure, the burst discs will rupture and the relief valves will vent helium overboard, preventing a propellant tank rupture. Engine operation will continue, as above, in blow down mode, until near depletion of the helium.

In both cases of malfunction, following pressurization failure, the use of the eight RCS engines of that particular system is lost. However, the eight engines of the other system remain in operation, and can, at reduced efficiency, provide the attitude and translational control necessary to complete the mission.

Downstream of the regulators the pressurization manifold divides into two flow paths, one leading to the oxidizer tank, the other leading to the fuel tank.

Each flow path incorporates quad check valves, arranged in a series parallel configuration to provide protection against the backflow of propellant vapors. This is necessary to prevent hypergolic vapors from meeting in the helium pressurization manifold.

Just prior to the propellant tanks each flow path contains provisions for a pressure relief valve assembly. This valve is composed of a burst disc, a filter and a relief valve. The burst disc isolates the relief valve from helium supply during normal operation to insure against pressurant leakage through the valve. Should the pressure in the helium flow path exceed specified limits the disc ruptures and permits helium to be vented overboard by the relief valve. The filter prevents contamination of the relief valve by burst disc fragments. When pressure attains a safe level the relief valve closes, thereby permitting normal system operation.

Each independent system contains one oxidizer and one fuel storage tank. The propellants are contained within a teflon bladder



supported by a standpipe running lengthwise in the tank. The helium pressurant flows between the bladder and the tank wall and acts upon the propellant filled bladder for positive expulsion. The propellant is introduced into the tank through the feed port from a fill point accessible from the exterior of the LM vehicle. A bleed line runs up through the standpipe to draw off trapped gases in the bladder. This allows the bladder to be completely filled with propellants without excessive flexing. The propellant will be fed into the tank under a back pressure.

After being forced from the tank bladder, the propellants from each system flow through a shut-off valve and into separate manifolds. Therefore, there are four manifolds: one for system "A" fuel; one for system "A" oxidizer; and two similar manifolds for system "B".

The propellant shut-off valves, located just downstream of the propellant tanks are normally open, latch type solenoid valves. They can be closed in pairs from the control panel to isolate the propellant tanks of one system if an upstream malfunction occurs, or propellants become depleted.

If the propellant supply from one system must be shut down in this manner, then normally closed latch type solenoid valves in a crossfeed piping arrangement between the "A" and "B" system manifolds can be opened to provide propellant flow from the operative system manifolds to the non-operative system manifolds.

In addition there are similar normally closed valves in the piping that connects the ascent propellant system feed lines with the RCS propellant manifolds. These valves may be opened in pairs to supply ascent subsystem propellants to the non-operative RCS manifolds. However, the utilization of ascent subsystem propellants in the RCS will be possible only during positive "X" axis acceleration.

"A" system manifolds feed propellants to eight RCS engines, two in each cluster. Likewise "B" system manifolds feed eight engines, two in each cluster. This ensures control in all axes despite a failure in any one system.

The lines feeding propellants to the engines contain normally open, latching solenoid valves. These valves can be closed in pairs from the control panel, preventing propellant flow to a pair of engines in one cluster. They are called isolation valves, as their function is to isolate malfunctioning or damaged RCS engines.



Downstream of the isolation valves, just before entering the cluster, the line contains a propellant filter to prevent any debris contained in the propellants from entering the engine.

### RCS Cluster

(See Figures 48 and 49.) The RCS cluster consists of a frame, four engines, 8 heating elements mounted directly on the engine injectors, and associated sensors and plumbing. The cluster is enclosed in a thermal heat shield in such a manner that only the engine nozzles protrude.

The frame is basically an aluminum alloy casting in the shape of a hollow cylinder. Provisions are made for attaching four engines to the cylindrical frame. The vertical firing engines are mounted to the top and the bottom of the cylinder and the horizontal firing engines are mounted at mid-point.

The cluster is attached to the LM structure by hollow aluminum alloy struts. The frame supporting the engines bolts to one end of the struts; the other end of the struts bolts to the ascent stage structure. It is therefore possible to replace individual engines in the cluster, or to replace the entire cluster as an assembly.

The entire cluster assembly (except the protruding engine nozzles) and the supporting struts is covered by a thermal shield which serves the function of maintaining a temperature controlled environment for the propellant lines running from the ascent stage to the engines. The thermal shield will have two sections, basically similar, and slightly overlapping each other. The inner section extends from the ascent stage structure to a point just short of the cluster, covering the attaching struts. It consists of an aluminum alloy skin to the inside of which is attached an aluminized mylar insulating blanket. The outer section covers the cluster and consists of a stainless steel skin with an inner insulating blanket of aluminized mylar and an outer shield of multi-layer nickel foil separated by fiberglass sheets.

Two resistance wire electric element type heaters are attached to each engine injector. Their purpose is to maintain the injector temperature at approx. 128°F as an aid to prevent pressure "spiking" during pulse mode engine operation and to keep propellant temperatures in the lines between the ascent stage and the cluster within a safe operating range. (See Figure 50.)

The sixteen RCS engines require a total of 32 heaters. These are divided into two separate systems, one heater from each system



being mounted on each engine. Although only one heater per engine would be adequate, two are used for the purpose of redundancy. There are eight circuit breakers, so each breaker supplies power for the four heaters of the same system in one cluster.

All the heaters are capable of an intermittent heating cycle, or of continuous duty. Each heating unit consists of the heating element and a central mechanism that will switch the heating element on and off, as required, to maintain the desired temperature. The heaters of one system are wired directly to their circuit breakers and will cycle on and off, as required, unless the breaker is pulled, which will, of course, turn the heater off. The heaters of the other system are wired to their circuit breakers through a 3 position switch. When the switch is in "automatic" the heaters will cycle on and off, as required, to maintain desired temperatures. When it is in the "off" position the circuit is interrupted and the heaters are off. When it is in the "manual" position the control mechanism is bypassed, and the heating element remains energized regardless of the temperature.

Should an out of limits temperature condition occur and the caution light comes on, the use of a monitor switch and temperature indicator will tell the crew which cluster is out of limits, and corrective action can be taken.

#### PROPELLANT QUANTITY GAGING SYSTEM (See Figure 51.)

The propellant quantity gaging system is used to determine the amount of propellants contained in the tanks of the Reaction Control Subsystem. It accurately reports the quantity of remaining propellant to the crew by panel indication and to earth by telemetry, and will accomplish this function under conditions of zero gravity and constantly changing attitudes characteristic of a spaceflight environment.

The system shall consist of two pressure/temperature sensing probes; two pressure/volume/temperature computers (which may be referred to as analog signal conditioning units); and a dual scale analog quantity display.

The P/T sensing probe and the P/V/T signal conditioner together constitute a single end-item called the Propellant Quantity Measuring Device (PQMD). This device will sense directly the pressure/temperature ratio of the pressurizing gas and compute the volume of propellant remaining in the propellant tanks.



In this system a high pressure tank contains the helium while low pressure tanks contain the propellants. The propellant tanks are pressurized with helium at a constant pressure set by a regulator between the helium and the propellant tanks. The pressurizing gas is separated from the propellant by means of a flexible bladder.

In order to measure the quantity remaining in the propellant tanks, it is assumed that the mass of the pressurizing gas in the entire system is constant, although the mass of gas in both helium and propellant tanks will vary as propellants are consumed. The pressure/temperature sensor measures the mass of gas remaining in the helium tanks and provides a continuous input into the signal conditioner. The gas mass in the propellant tanks is obtained by subtracting the gas mass remaining in the helium tank from the known total gas mass in the system. Then the propellant quantity is obtained by subtracting the gas volume in the propellant tank from the total tank volume.

#### Sensing Probes

The sensing probes or transducers are installed one in each of the RCS helium tanks, and shall be capable of sensing both the temperature and the pressure of the pressurization gas, and of supplying electrical signals representative of these parameters to the signal conditioning units.

The transducer will employ four active strain gage sensor elements arranged in a predetermined geometric pattern, all of which will be subjected to strains of approximately equal magnitude. When operated with a constant voltage source the sensitivity factor is such that the pressure indications will decrease with increasing temperature. As a result the output will always be directly proportional to the gas mass.

Each transducer is about 1 1/2 inches long and has a diameter of about 1/4 inch. It will be capable of operation over a gas temperature range of -20°F to +120°F and over a pressure range of 0 to 3500 psia. It is connected to its respective signal conditioning unit by a cable about 20 inches long.

#### Signal Conditioning Unit

The signal conditioning units are located one at each of the RCS tank modules adjacent to the P/T probe.



Each unit shall be capable of performing the following functions:

- a. Supplying the electrical excitation to the sensing probe.
- b. Accepting the temperature and pressure signals from the sensing probe.
- c. Computing the helium tank gas mass from the input signals.
- d. Computing the gas mass in the propellant tanks and the propellant volume remaining.
- e. Supplying an output voltage directly proportional to this propellant volume.

The entire PQMD (both signal conditions) is powered through one 28 vdc circuit breaker; the output of each signal conditioner is paralleled to one half of the dual analog display and to the Pulse Code Modulator for telemetry transmission to earth.

Each signal conditioner is about 4 x 2 x 1 1/2 inches and capable of operating over a temperature range of 0°F to 160°F and an environmental pressure range of 15 psia to a near vacuum. The acceptable error band shall not exceed  $\pm 2 \frac{1}{2}\%$ . Cold rail mounting is not required.

#### Analog Display

The dual analog display is mounted near the upper left hand corner of the right main display panel, easily visible to both flight crew members. It has two indicator hands, one showing the propellant quantity remaining in "A" system tanks, the other for "B" system tanks. The display is calibrated to indicate 100% for a 5 vdc signal conditioner output equivalent to full propellant tanks, down to 0% for a zero vdc signal conditioner output equivalent to empty tanks. Readout will be continuous; no switches are required in the system.

#### Thruster Control Failure Detection System (See Figures 52 and 53.)

The thruster control failure detection system has the capability of detecting either "on" failures or "off" failures, in either the Primary Guidance Control Mode or the Abort Guidance System Control Mode.



### "On" Failures

An "on" failure is defined as a jet thrusting condition without the presence of a guidance "on" command. It would be caused by a malfunction of the command signal sources upstream of the engine. Uncorrected, this condition would result in excessive RCS propellant consumption.

"On" failures will be identified by routing all engine commands through a logic scheme which will detect the presence of opposing command signals. Opposing colinear engines are never called upon to fire simultaneously unless it is necessary to compensate for the effect of a failed "on" engine. The detection logic will sense this condition and generate a failure signal which will be routed to the warning display and to the respective isolation valve status flag. (See Figure 53.)

### "Off" Failures

An "off" failure is defined as a non-thrusting jet condition in the presence of a guidance "on" command. It would be caused by open circuitry or a malfunction of the engine itself, and will result in a degrading of the altitude and translational control.

"Off" failures are detected by comparing the output of each engine (chamber pressure sensor) with its respective jet driver (guidance command). Should an "on" command fail to induce a response, an "off" failure signal will be initiated, and will be routed to the warning display and the respective isolation valve status flag.

It is recognized that under normal operating conditions, RCS engines may not respond to all individual "on" command signals, if these signals, or pulses, are of short duration. A "short" pulse is defined as having a duration of less than  $80 \pm 8$  milliseconds. This pulse skipping is not critical until a number of consecutive "short" pulses are skipped, and does not warrant detection until that point. Thus, it is not until six consecutive "short" pulses do not produce a thrust response, that a failure will be detected and a failure signal generated.

However, if just one "long" pulse is missed, that is, if a pulse with a duration in excess of  $80 \pm 8$  milliseconds does not produce a thrust response, then a failure will be detected and a failure signal generated.



## RCS Engine

### Design Criteria

The design of reaction control system engines is based on different criteria than those usually associated with larger rocket engines.

These include:

1. High thrust to a minimum impulse ratio. This is the ability of the same engine to produce a high thrust for its size and to also be capable of producing a very small thrust impulse. It is necessary in order to make either coarse or fine altitude corrections, as necessary, and reduces the number of engines required.
2. Long cycle life. This is the ability of the engine to be restarted many times. It is necessary when the mission involves repeated maneuvers during a prolonged flight requiring continuous "on-off" cycling of the engine.
3. Fast response time. This is the time required from the propellant valve "open command" for the engine to build up to stable operation at rated thrust and the time from the propellant valve "shut-down command" for the thrust to drop to an insignificant value. It is necessary to achieve rapid corrections of attitude errors during critical maneuvers.
4. High efficiency. This is important in any rocket engine; in RCS engine it is of particular importance as it reduces spacecraft upper stage weight and mission propellant requirements.

### General Description

The RCS engine consists primarily of a radiation cooled thrust chamber, including a radiation cooled nozzle extension; an injector; and two solenoid operated propellant shut-off valves.

The engine develops 100 pounds of thrust and is capable of either pulse mode or steady state operation. Pulse mode is defined as engine operation lasting less than 1 second - it may be as short as 10 milliseconds. Steady state is operation in excess of 1 second.



When the engine propellant valves receive an "open" command it takes them about 7 milliseconds to reach full opening. Propellants flow immediately through the valves into the injector and reach the chamber about 12 milliseconds after the "open" command. Propellant ignition occurs soon after the two liquids contact each other. Combustion build-up to stable burning is achieved at about 40 milliseconds after the "open" command. From this point on, engine steady state operation at the full 100 lbs. of thrust continues until the shut-down operation.

Operation of the engine at steady state conditions continuously subjects it to high combustion gas temperatures. This results in heat transfer to the combustion chamber walls which reach a nominal 2800°F after about 20 seconds of operation. Gas temperatures within the chamber stabilize at about 5200°F following ignition. The engine will continue to operate at this steady state level as long as required within the 500 second specification limit. To achieve this capability both a film cooling and a radiation cooling technique are employed. For proper operation the thrust chamber must be exposed to an environment that will readily accept radiant heat energy. Such an environment is provided in space.

Upon receipt of an engine "shutdown" command the propellant valves start to close, reaching the full closed position 5 milliseconds later. Propellant flow rate starts decreasing about 4 milliseconds following the shutdown command and is zero about 9 milliseconds later. Propellant flow continues to be injected for a short time, however, caused by the trapped propellant volume within the head. This "dribble" effect results in a total thrust tail off lasting about 50 milliseconds. Thrust drops from 100 lbs. to 20 lbs. in the first 10 milliseconds after the shutdown command. The remaining decay from 20 lbs. to 0 lbs. takes 40 milliseconds.

In pulse mode operation the total command "on" time may be as low as 10 milliseconds and propellant transients make up the whole run. Engine thrust is just beginning to rise when the shutdown command is given and only a very small amount of propellant will be injected into the combustion chamber. Under these conditions of "minimum impulse" the full 100 pounds of thrust will not be achieved and engine operation will be comparatively inefficient. (See Figure 54.)



## Design and Performance Characteristics

Thrust	100 pounds
Propellants	Nitrogen tetroxide (oxidizer) and 50% hydrazine/50% UDMH (fuel)
Oxidizer/fuel ratio	2.0 :1
Engine life (steady state)	500 seconds
Engine life (pulse mode)	500 seconds
Engine life (total)	1000 seconds
Restart capability	10,000 times
Specific impulse	275 seconds (approx)
Chamber pressure	95 psi.
Flow rate - oxidizer	.24 pounds/sec.
Flow rate - fuel	.12 pounds/sec.
Expansion area ratio	40 :1
Overall length	13 1/2 inches
Nozzle diameter	5 3/4 inches
Weight	6 lbs.

### Major Components

#### Thrust Chamber

(See Figure 55.) The RCS thrust chamber consists of two principal parts. The first is the combustion chamber and nozzle up to an expansion area ratio of about 5:1. This section is a machined molybdenum forging and is coated on all surfaces with silicon to prevent oxidization of the molybdenum at high temperatures. The other section is the nozzle extension and extends to the exhaust gas outlet. It is fabricated of stainless steel and has eight stiffening rings machined around its outer surface. The two sections are joined together by a large coupling nut which is safetied by a lockring.



There is no seal between the sections; a close fit of the surfaces being depended upon to prevent gas leakage.

The combustion chamber section is mounted to the injector by an attaching ring assembly and a ring of bolts. Between this section and the injector is a metallic seal used to prevent gas leakage in this area.

Combustion temperatures inside the combustion chamber reach 5200°F and the melting point of the molybdenum chamber walls is 3200°F. Obviously the extremely high combustion temperature must be kept away from the metal walls. This is done by spraying the walls with fuel, which vaporizes, and forms a relatively cool boundary film. Combustion heat is carried away by this moving boundary film and the actual wall temperature reaches about 2800°F, below the melting point of the metal. This remaining heat is dissipated by radiation, whereby the heat absorbed by the inner wall surface is conducted through the wall and radiated to the infinite heat sink of space.

#### Injector. (See Figure 56.)

The injector used with this engine has a fixed area, fixed orifice design. Materials used in its fabrication are aluminum alloy and stainless steel. The design incorporates a pre-igniter chamber where initial combustion occurs. The purpose of this chamber is to minimize overpressurization or "spiking", which is a transient condition, but, if sufficiently severe, can lead to destruction of the engine. (See Figure 57.) Spiking is caused primarily by ignition delay, and it has been determined that ignition delay can be held to a minimum by establishing a fuel lead, that is, by having fuel enter the combustion chamber a few milliseconds before the oxidizer; by pre-pressurizing the combustion chamber; and by preheating the combustion chamber. The first of these is a function of propellant shut-off valve opening; the last two are functions of injector design, in particular the pre-igniter chamber.

Inside of the pre-igniter chamber are two orifices, one oxidizer and one fuel. When the shut-off valves are opened propellants flow into the injector and fill the injector passages. Direct passages lead to the igniter chamber doublet and primary ignition occurs here. The resultant pre-pressurization and pre-heating minimizes spiking. Propellants then flow through other passages that lead to orifices that surround the outside of the pre-igniter cup. There are eight oxidizer orifices and eight fuel orifices in this area arranged in doublets, at angles to each other, so that the emerging



propellant streams impinge. Due to the hydraulic delay built into the injector, ignition at these eight doublets occurs four milliseconds later than ignition inside of the pre-igniter cup.

Additional fuel flow is provided from eight orifices that spray fuel on the inner wall of the combustion chamber and eight more orifices that spray fuel on the outer wall of the preigniter chamber. This additional fuel vaporizes and forms the cooling pre-igniter chamber.

The injector provides the attaching surface and holes for mounting the engine to the cluster and the support surfaces for attaching the propellant shut-off valves.

#### Propellant Shut-off Valves.

(See Figure 56.) The task of the propellant shut-off valve is two-fold. First, it must respond very rapidly to an electrical "open" or "close" command and, secondly, it must provide a positive propellant shut-off to prevent leakage during periods of engine non-operation.

The actuating mechanism utilized is essentially an electro-magnet. When the valve is not energized, a spring holds the armature against teflon seats at the injector inlet to shut off flow. Application of current to the valve coil will draw the armature away from the seat and fluid will travel through the valve, past the seat, and into the injector. Removal of the current permits the spring to reseal the armature.

The valves mount directly to the injector and are held in place by screws. Each valve incorporates a fluid orifice, located at the valve inlet. It is the function of these orifices to meter the propellant that can pass through the valve when it is open, thereby determining both the mixture ratio and the thrust level of the engine.

Each valve utilizes two coils: an automatic coil and a direct coil, either of which is capable of opening the valve. Each coil has its own electrical leads and operate independently of the other.

The automatic coil is designed to operate with 24 to 32 VDC, at a current flow of 2.0 Amps, and the valve will be fully open just 7 milliseconds after the electric "open" command is received.

The direct coil operates at 20 to 32 VDC, and at a current flow of 0.5 Amps the valve opens 15 milliseconds after the "open" command.



In addition it should be stated that an added resistance has been built into the oxidizer valve coils so that the opening time is about 2 milliseconds slower than that of the fuel valve. This 2 millisecond fuel lead is an aid in preventing spike pressures during pulse mode operation.

Closing time for both valves, from the time the electrical "off" command is received, to the fully closed position, is 5 milliseconds.

The minimum electrical pulse width, that is, the shortest time between an electrical "on" and "off" command, is 10 milliseconds.

### Summary

The primary purpose of the reaction control system is to provide the necessary thrust impulses to control the vehicle attitude during all periods of main engine thrusting and/or coasting.

Redundancy is achieved by the utilization of two parallel, independent helium pressurization and propellant feed systems, each supplying propellants to eight of a total of sixteen rocket engines. These engines are arranged in four clusters of four engines each, equally spaced around the ascent stage of the LM, and two engines in each cluster are supplied propellants by each of the parallel supply systems. Normally, both systems operate together, but should either system fail, the mission can still be completed.

Operation of the helium pressurization and propellant feed systems is quite similar to that of the main engine systems. Helium is stored in tanks and released prior to engine operation. The gas pressure is controlled by valves and pressure regulators and then pressurizes the propellant tanks.

The propellant storage tanks are equipped with bladders and the propellant is stored inside of these bladders. Gas pressure against the outside expels the propellant effectively, even under zero "G" conditions.

The propellants then pass through control valves to the engines.

Cross-feed valves between the two parallel propellant feed systems of the RCS, and interconnect valves between the ascent and RCS propellant feed systems are also utilized to provide the system with a considerable degree of flexibility to compensate for possible malfunction.



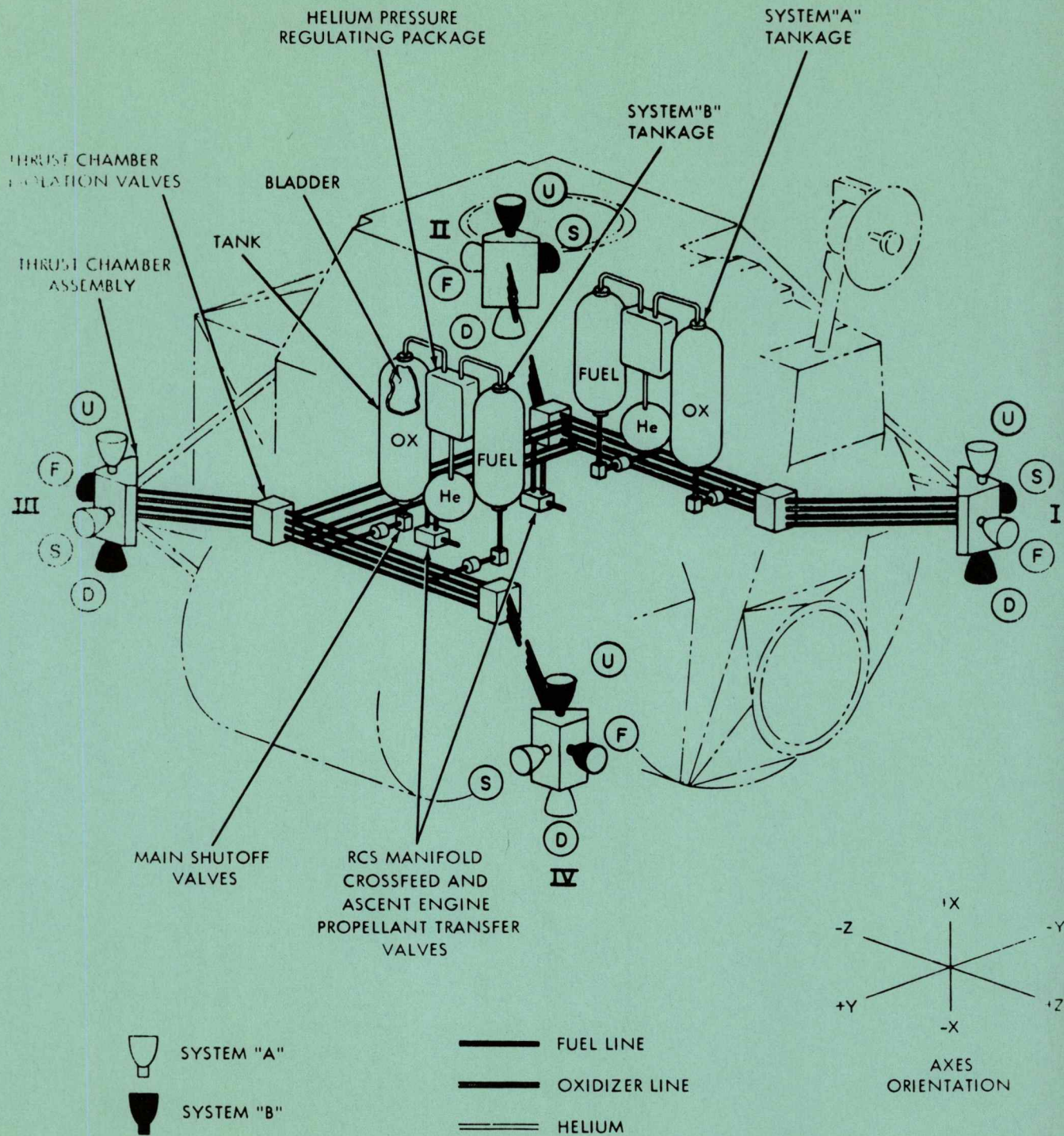
The cluster assemblies and their support struts are covered by a thermal shield so that the propellants can be maintained in a temperature controlled environment. In addition each engine is equipped with two electric heaters which will assist in maintaining temperatures within the required range.

The propellant quantity gaging section consists of sensing probes and analog signal conditioning units. It accurately reports the quantities of fuel and oxidizer remaining in the tanks under conditions of zero gravity. This information is made available in a form usable for panel display and telemetry transmission.

Functionally the RCS engines are quite similar to the main engines. Propellants are shut off from the engine or admitted to the engine by control valves. These propellants pass through an injector into a thrust chamber where they are burned and the gases accelerated to produce thrust. Boundary layer cooling and radiation cooling is used for heat control.

The engines can operate either steady state (1 second and longer) or pulse mode (under 1 second). The response time of the engine is very rapid and very narrow pulse widths are possible.





# RCS INSTALLATION

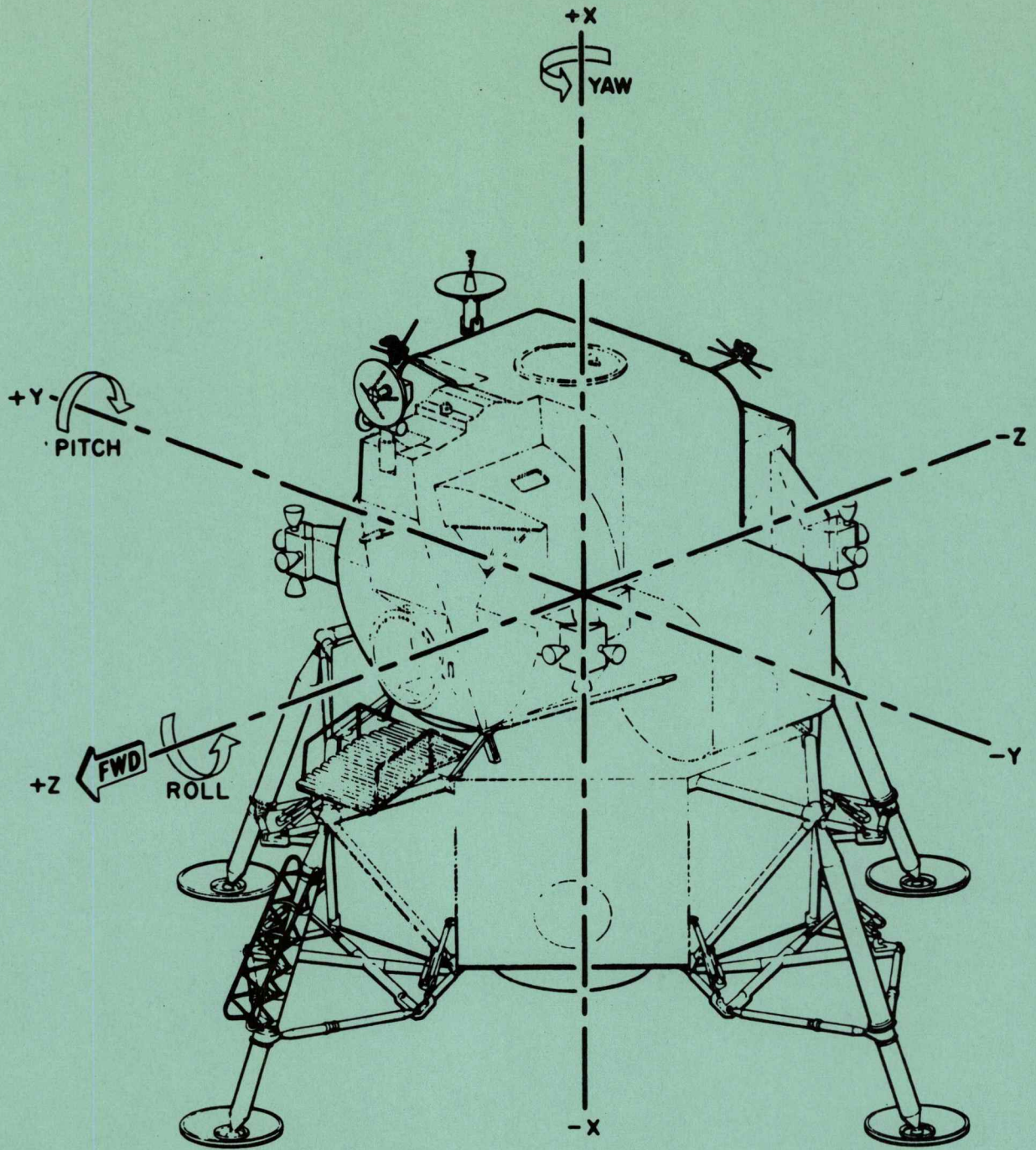
Figure 39

T30207-62  
AUG 65

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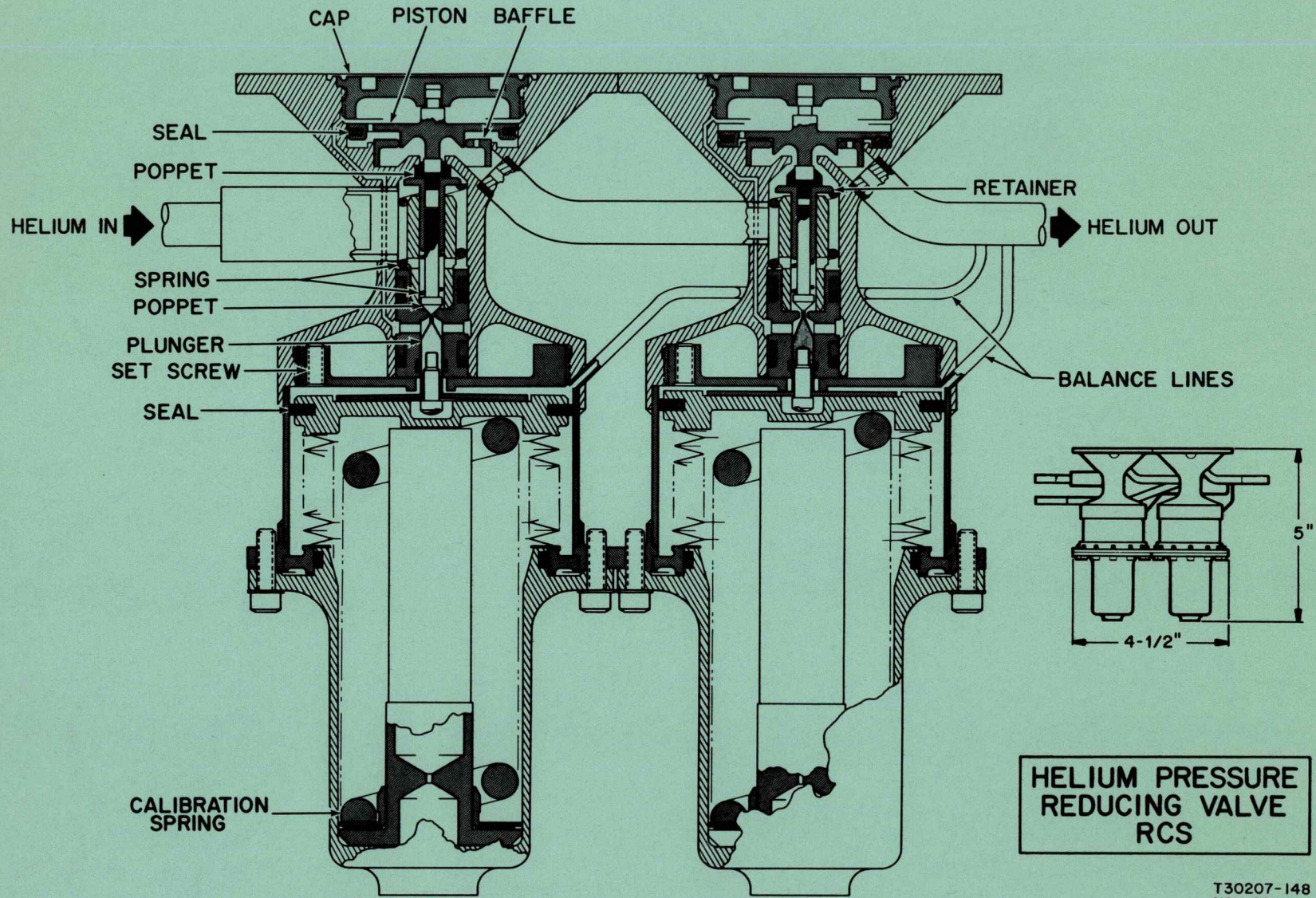




**LM AXES**

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MAR 66

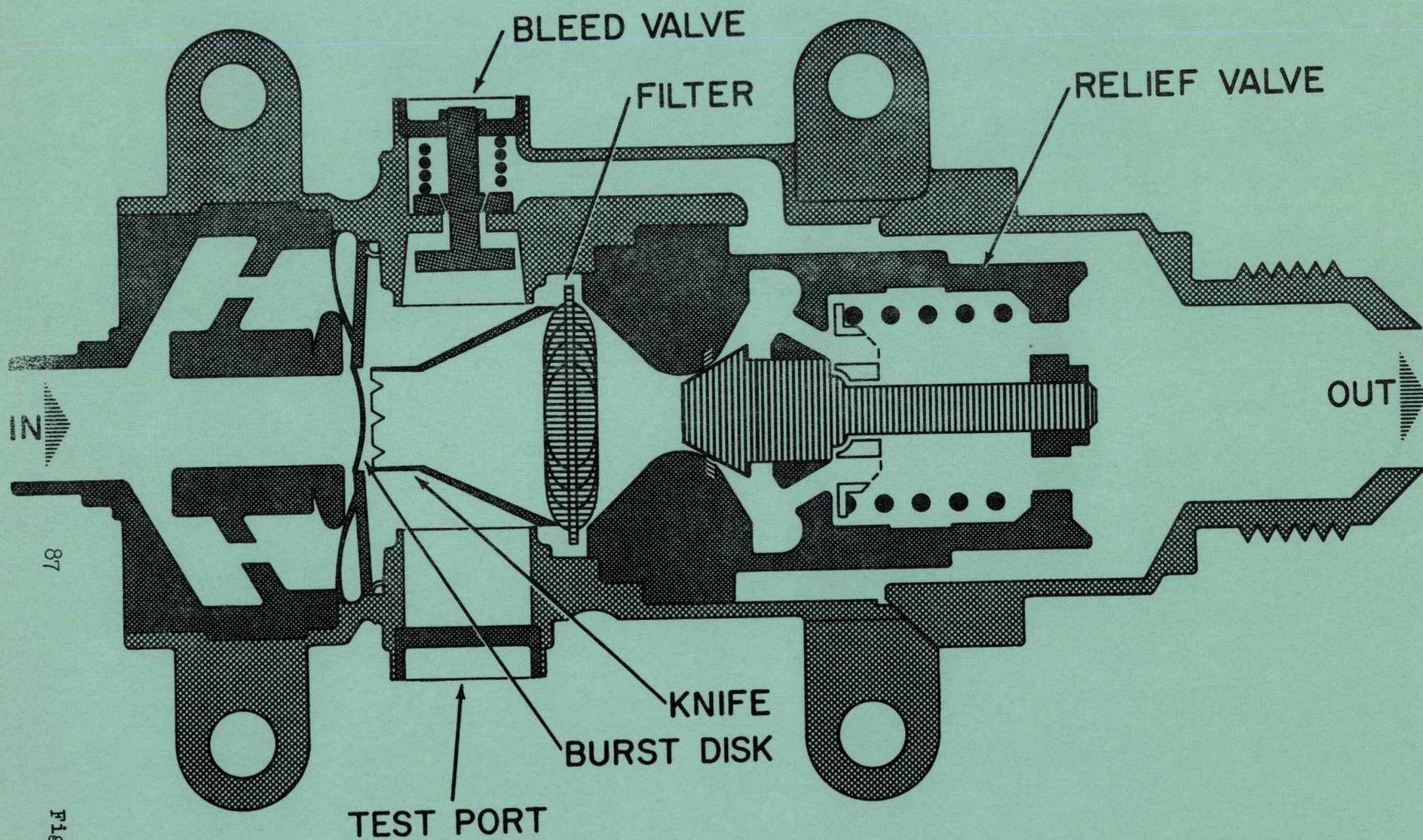




**HELIUM PRESSURE  
REDUCING VALVE  
RCS**

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NOV 66





**PRESSURE RELIEF VALVE**

T30207-53  
OCT 65

Figure 42

87

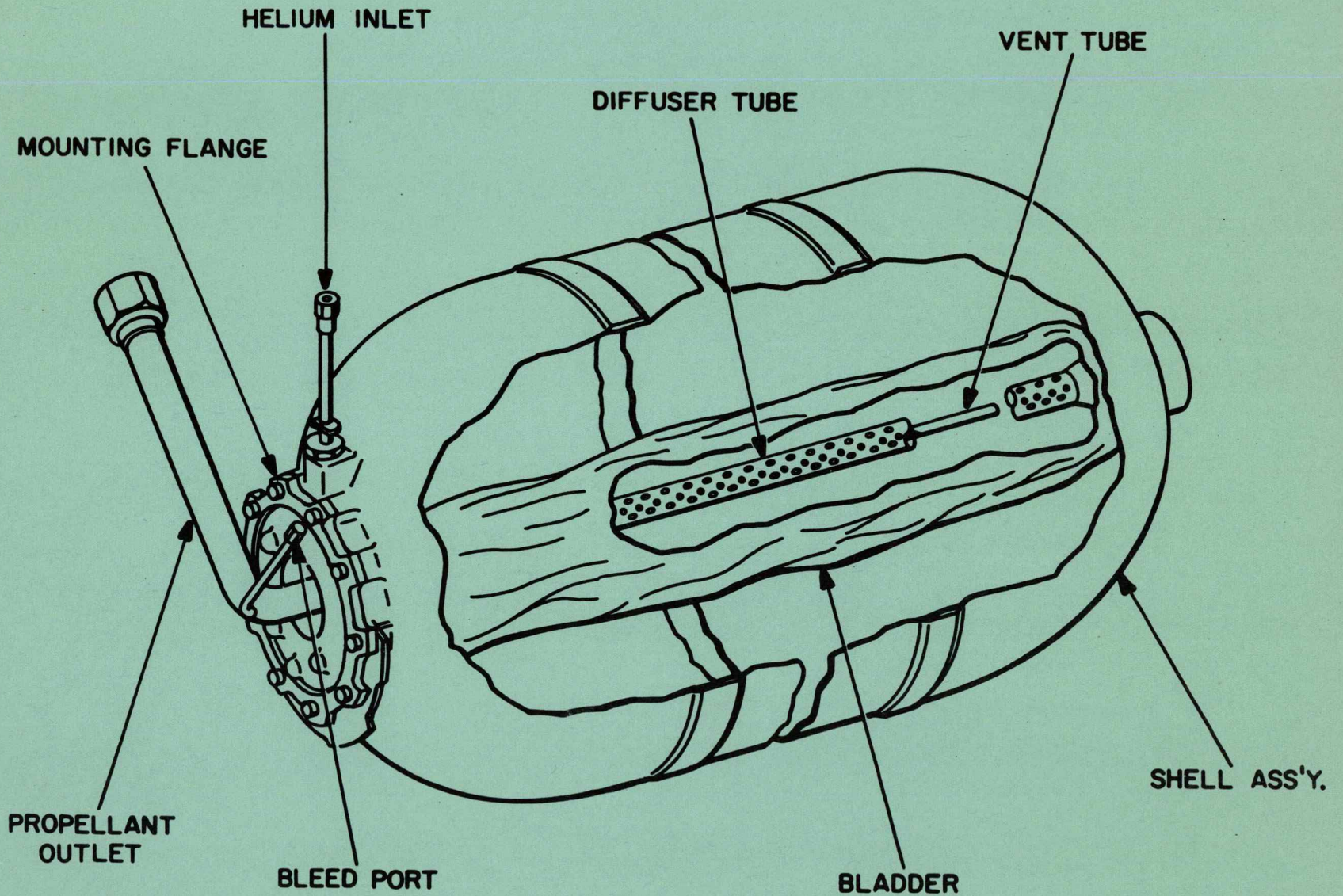
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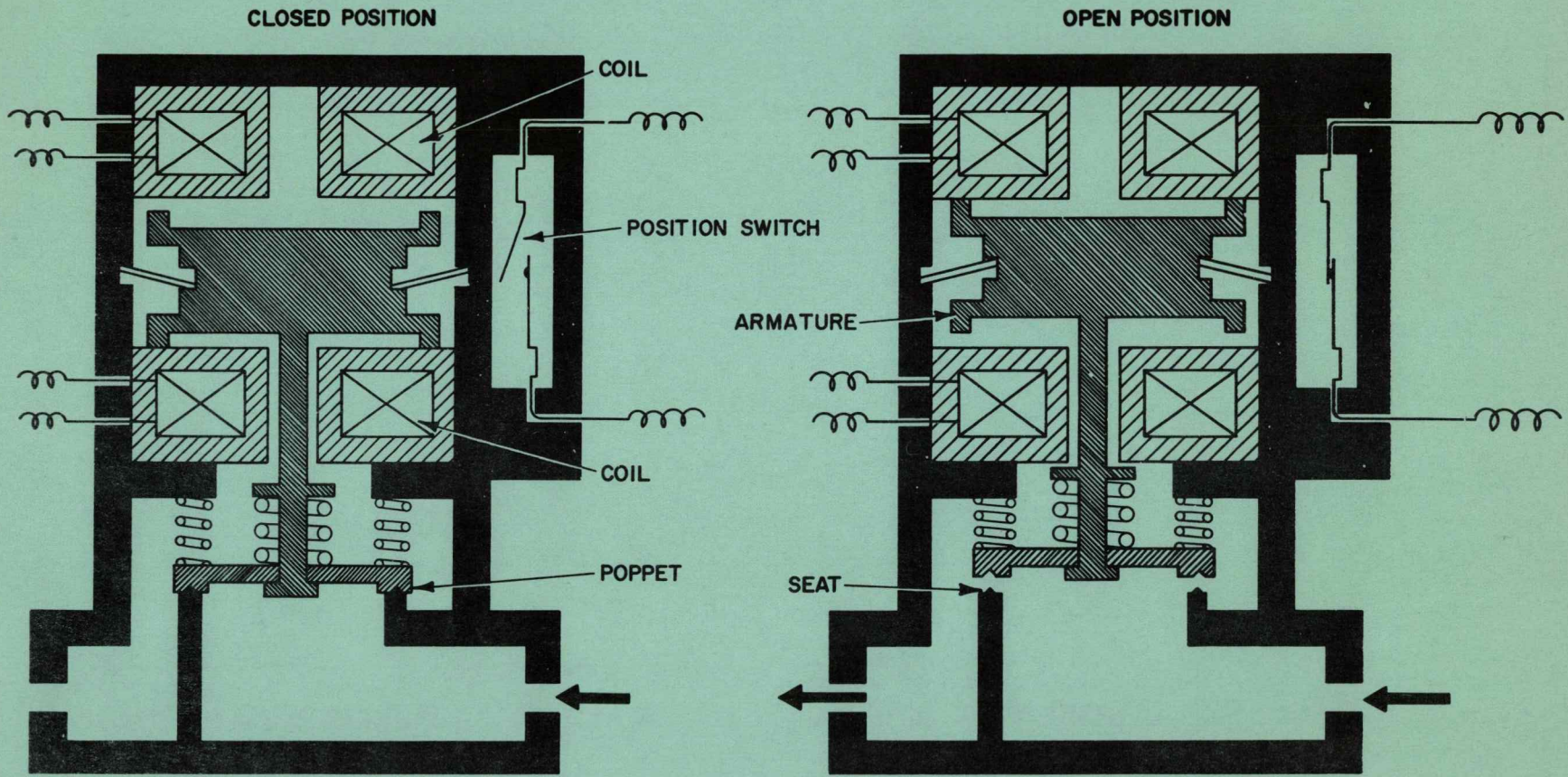
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Figure 43



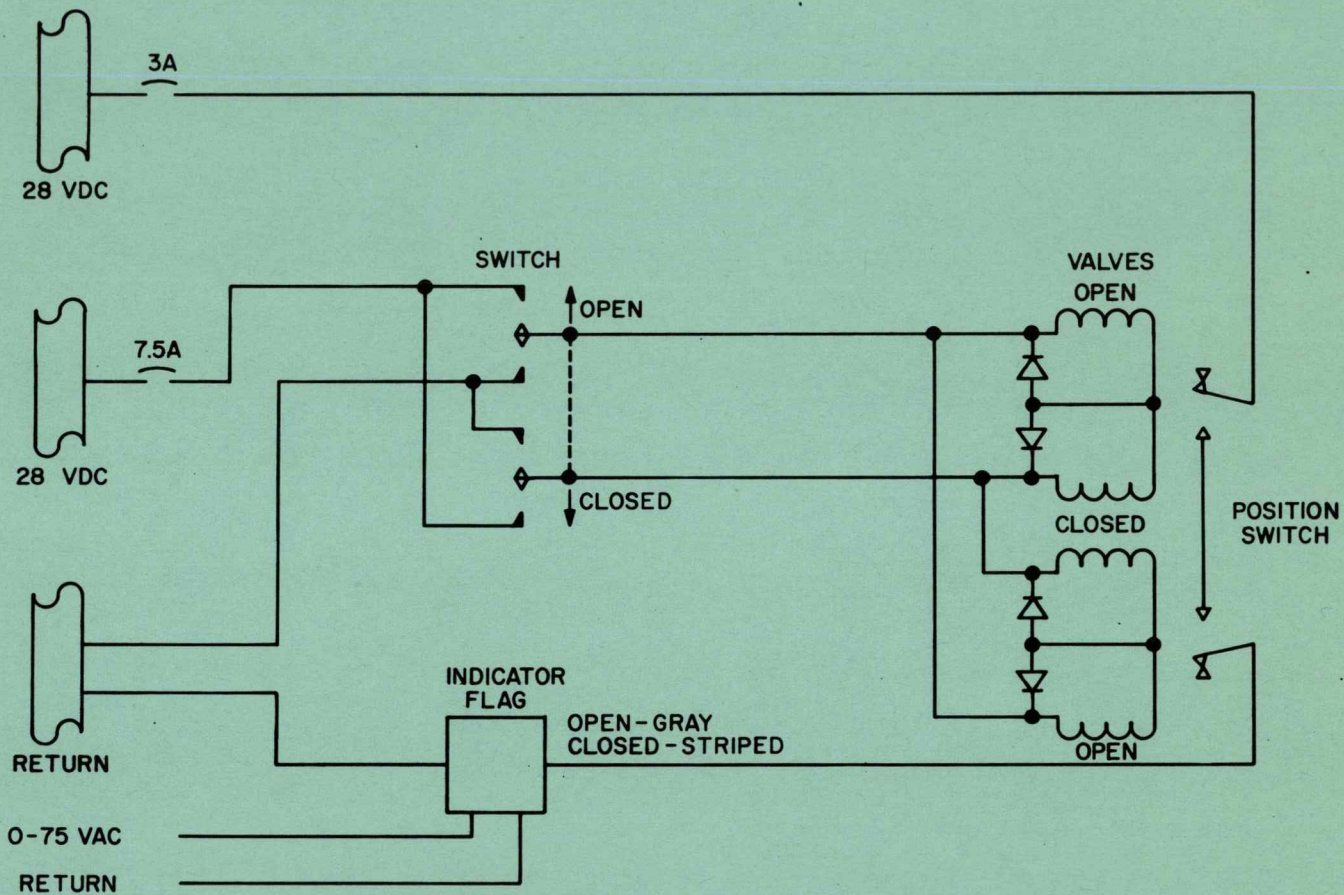
**TANK ASSEMBLY**





SHUT-OFF VALVE - PROPELLANT

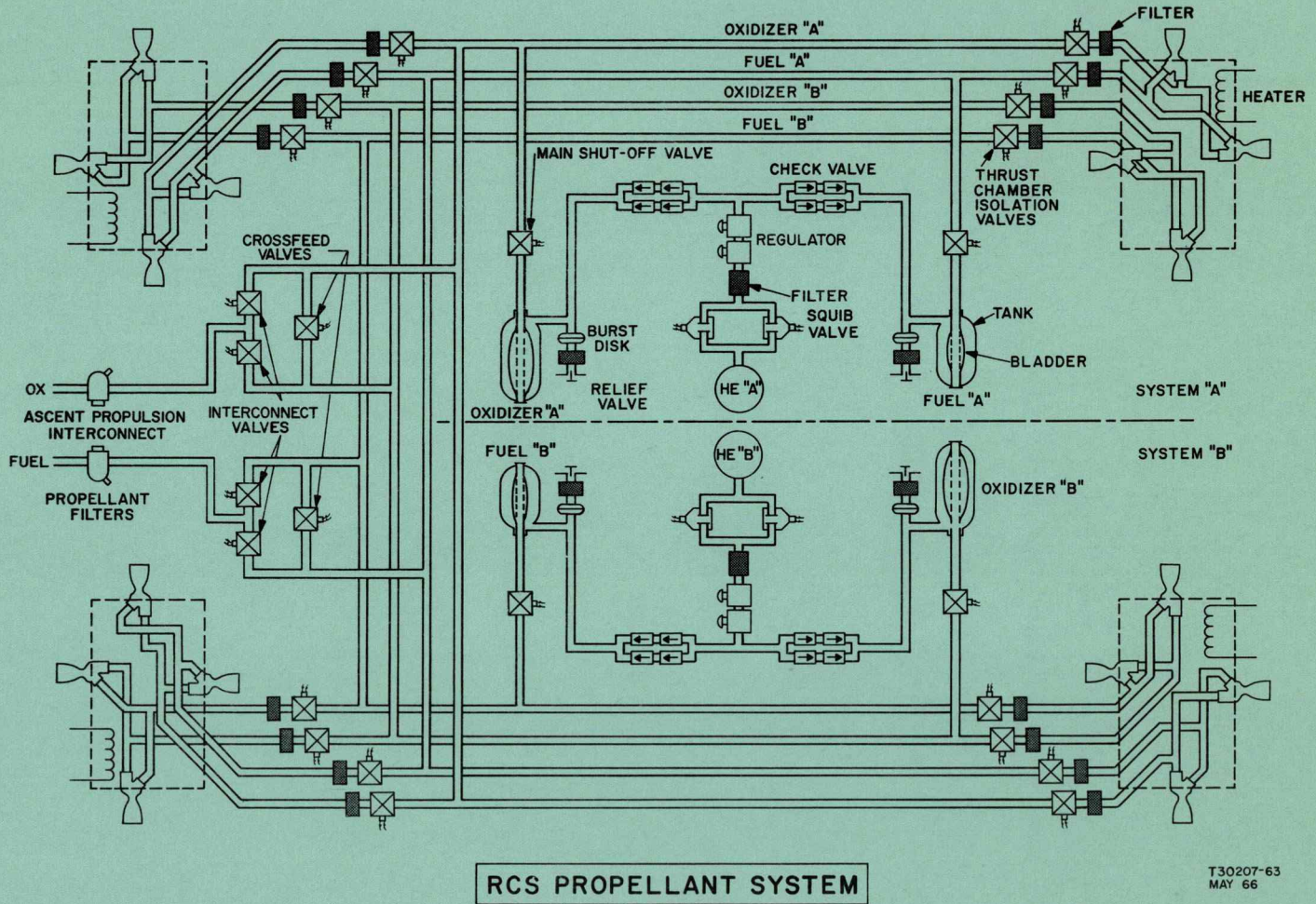




**PROPELLANT SHUT-OFF VALVES  
ELECTRICAL SCHEMATIC**

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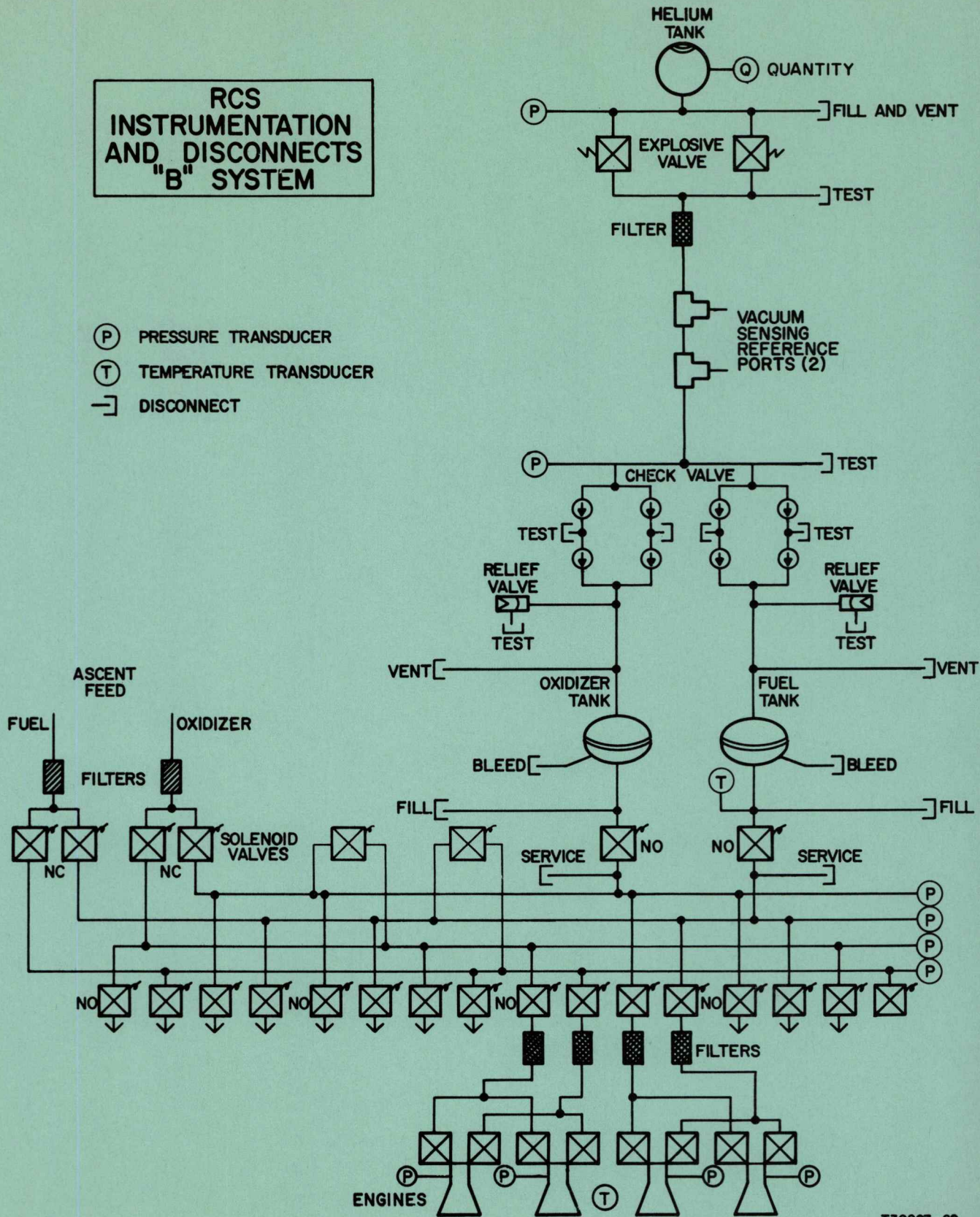






**RCS  
INSTRUMENTATION  
AND DISCONNECTS  
"B" SYSTEM**

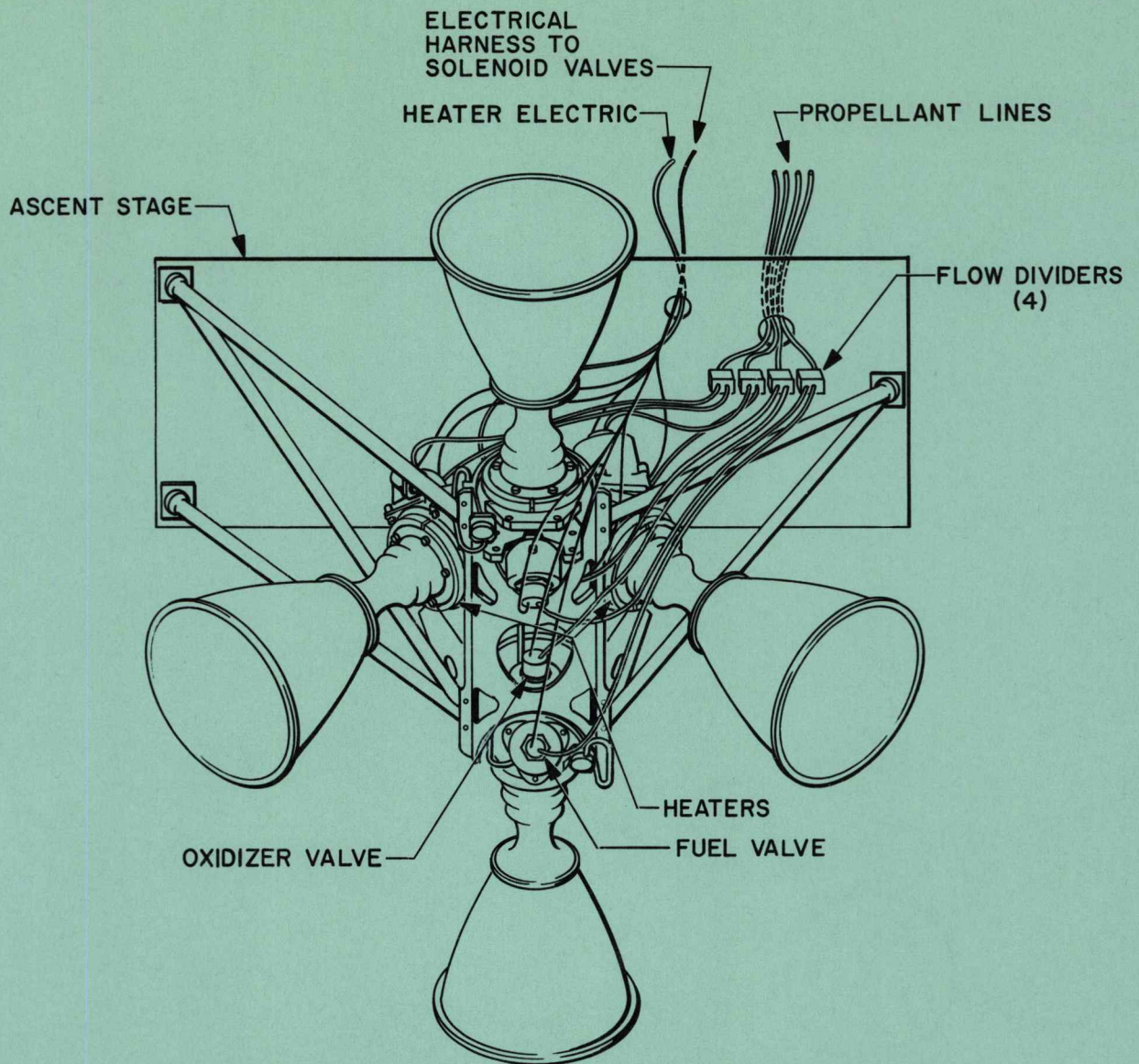
- (P) PRESSURE TRANSDUCER
- (T) TEMPERATURE TRANSDUCER
- ] DISCONNECT



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FEB 67

Figure 47





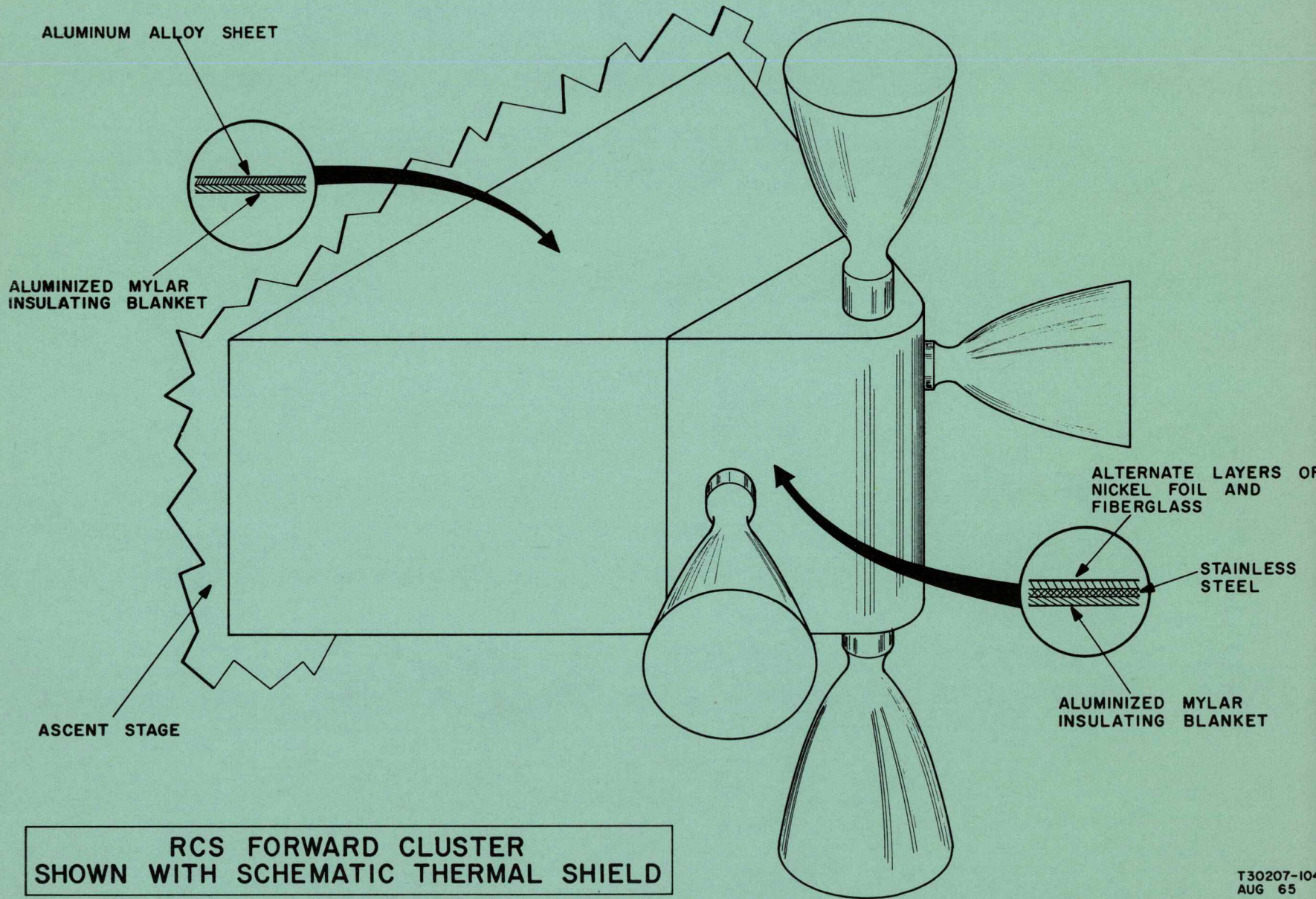
**RCS FORWARD CLUSTER SHOWN  
WITH THERMAL SHIELD REMOVED**

T 30207-71  
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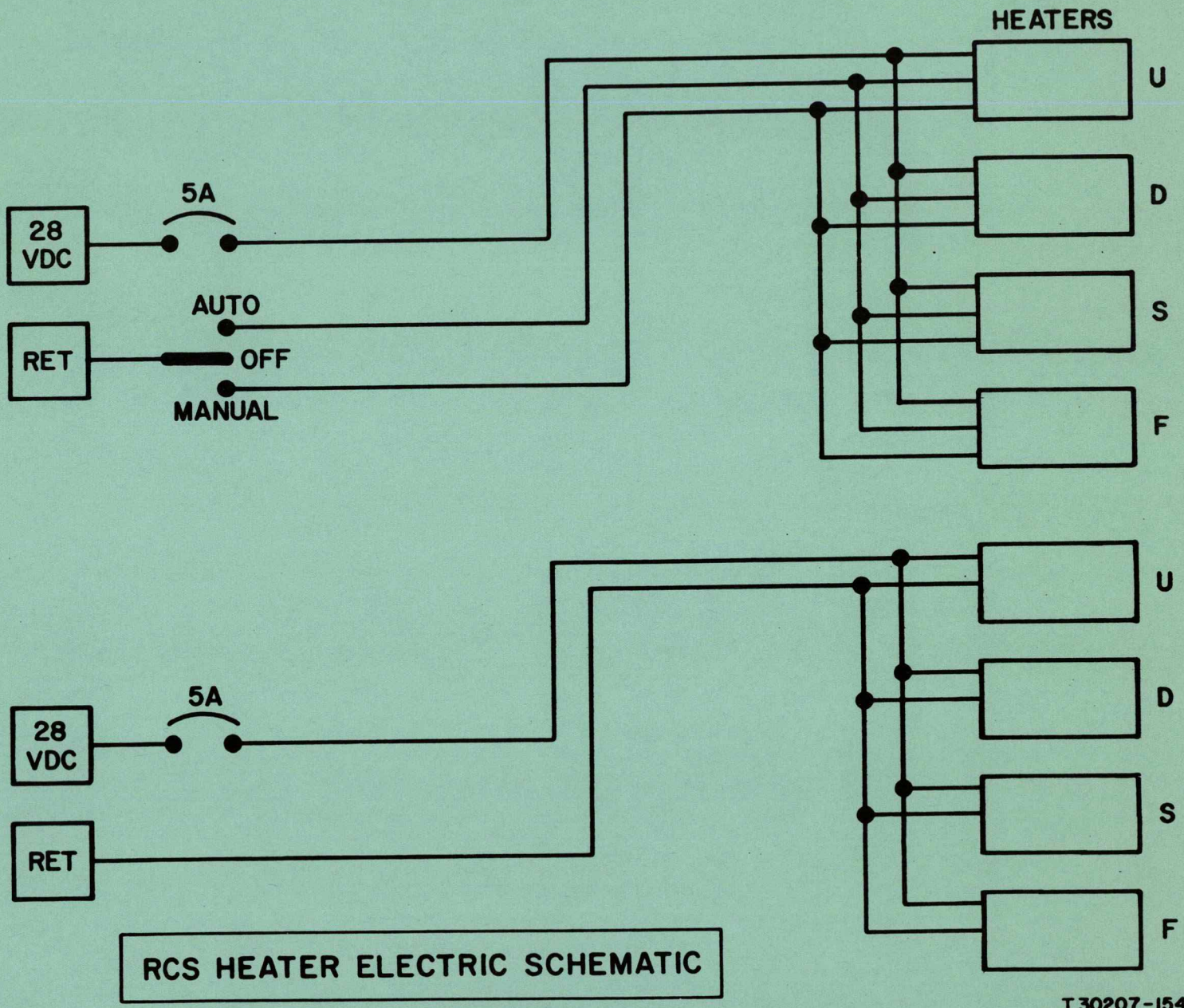
94

Figure 49



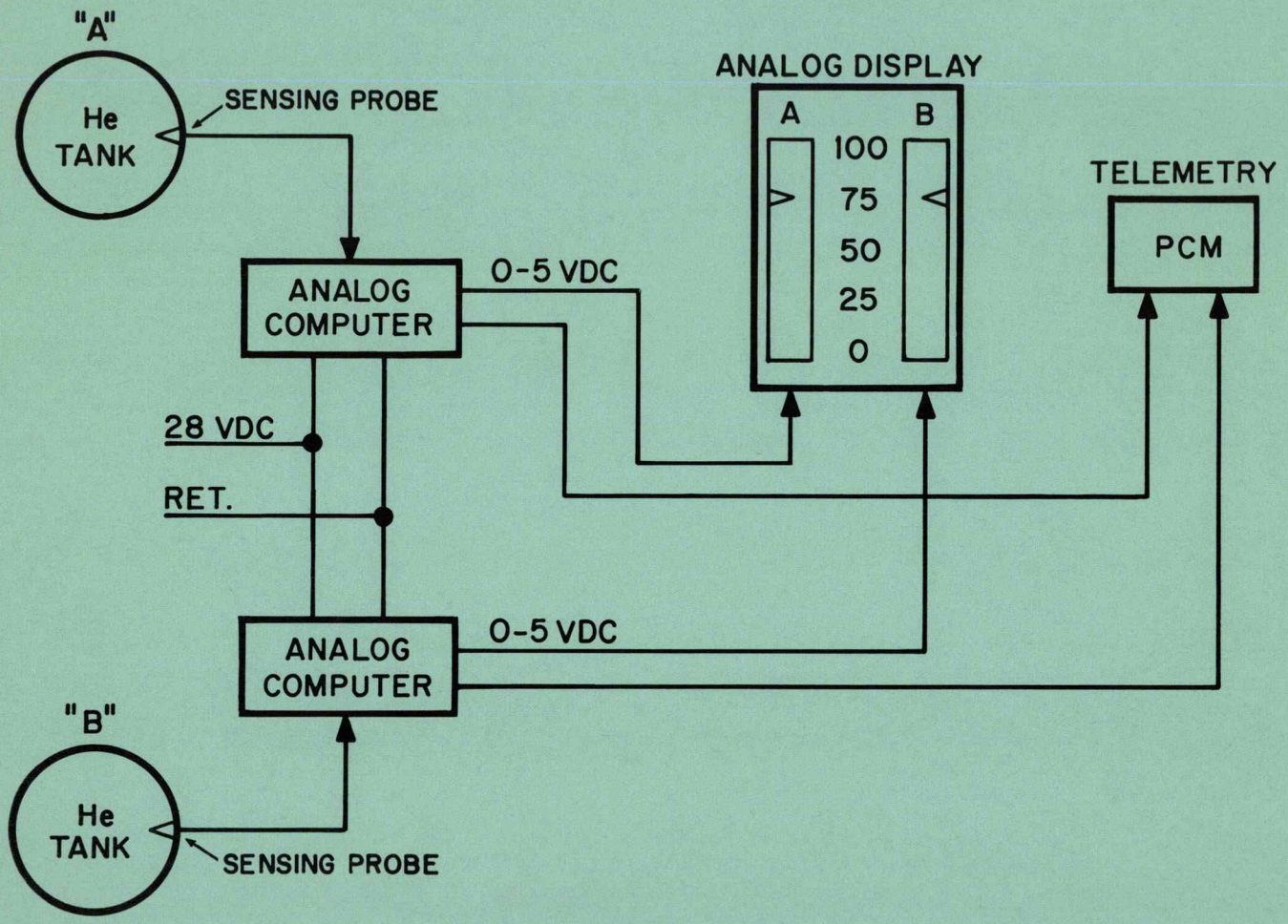
RCS FORWARD CLUSTER SHOWN WITH SCHEMATIC THERMAL SHIELD





RCS HEATER ELECTRIC SCHEMATIC

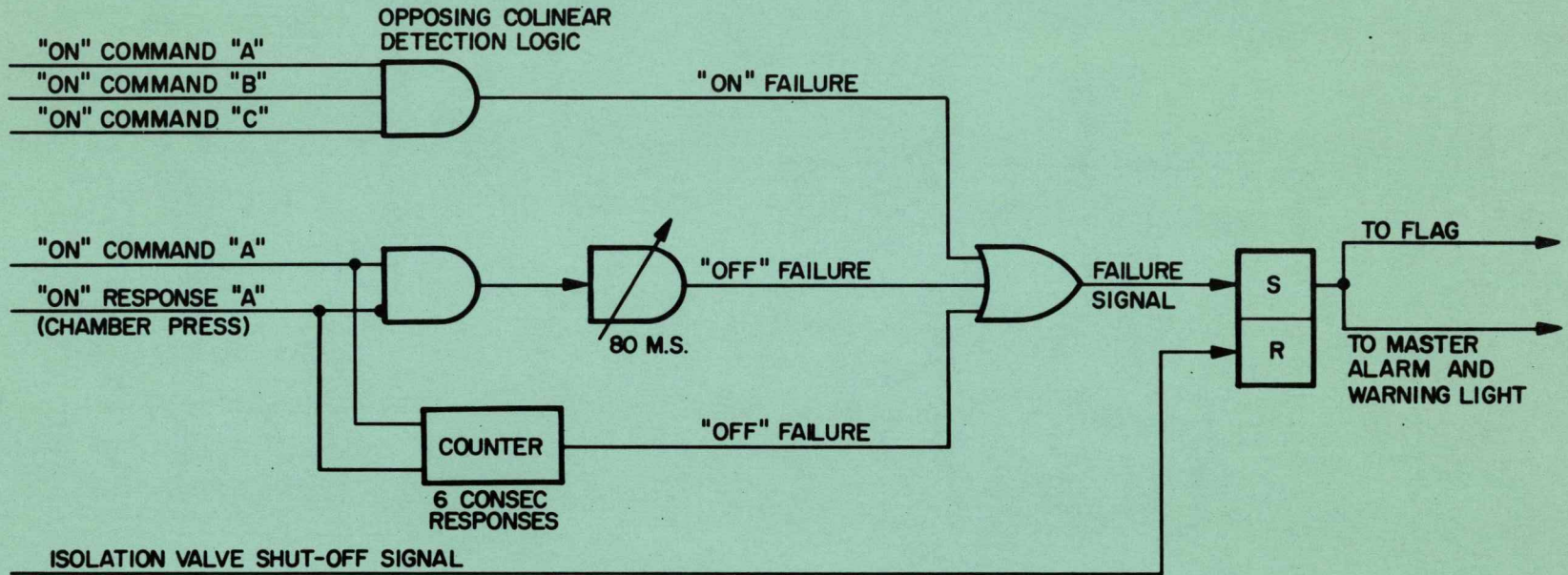




RCS PROPELLANT QUANTITY GAGING SYSTEM  
SCHEMATIC

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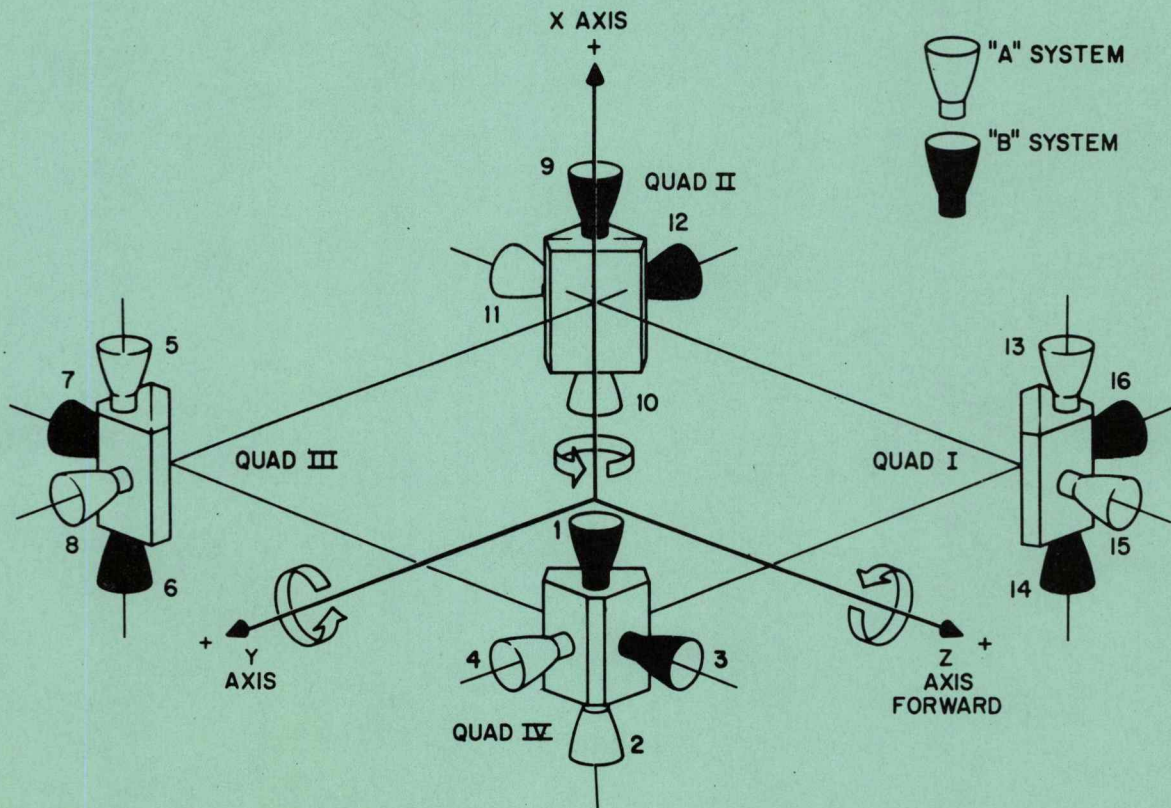




RCS TCA FAILURE DETECTION



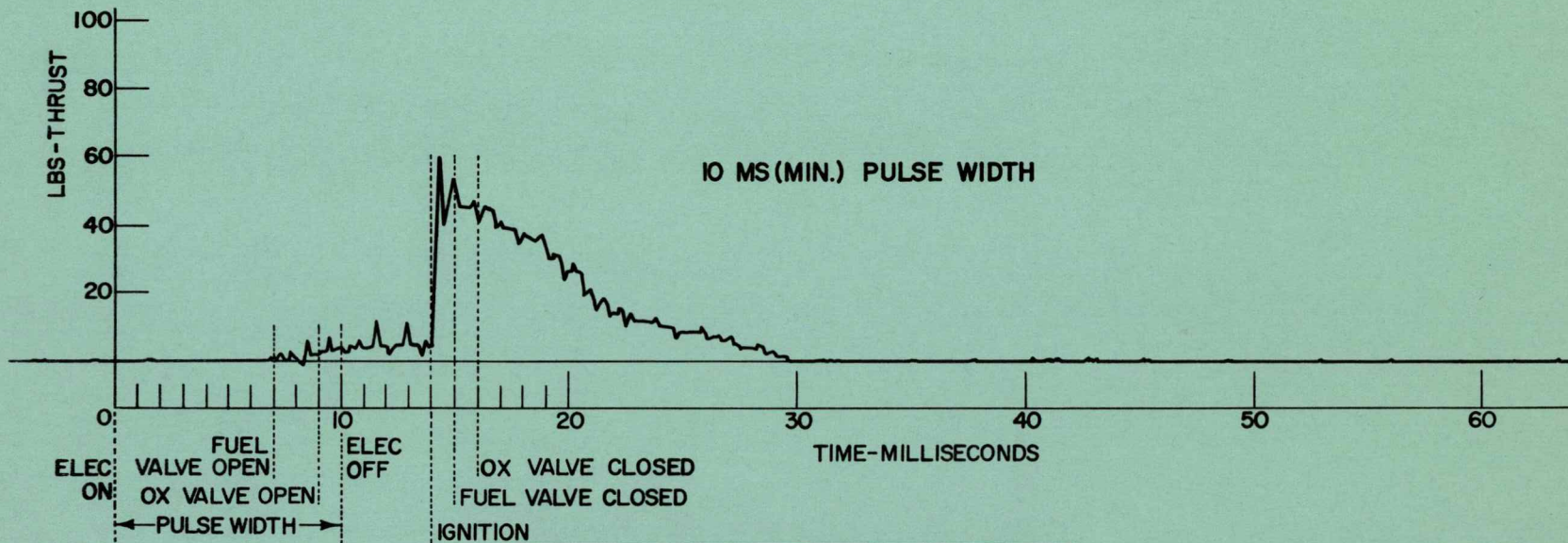
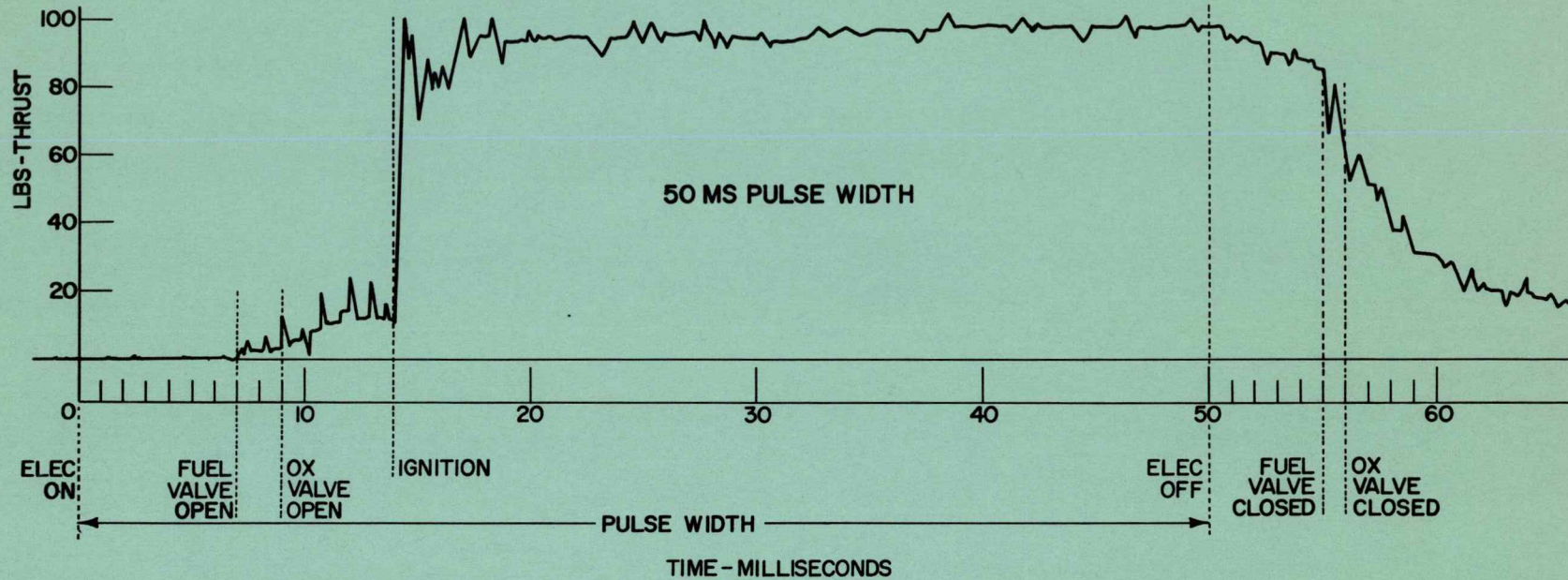
"ON" FAILED ENGINE	"ON" COMMAND SIGNALS															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	•	•						•								
2	•	•							•							
3			•				•							•		
4				•				•								•
5					•	•						•				
6					•	•							•			
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14						•						•	•			
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16				•								•				•



RCS TCA "ON" FAILURE DETECTION

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MAY 66



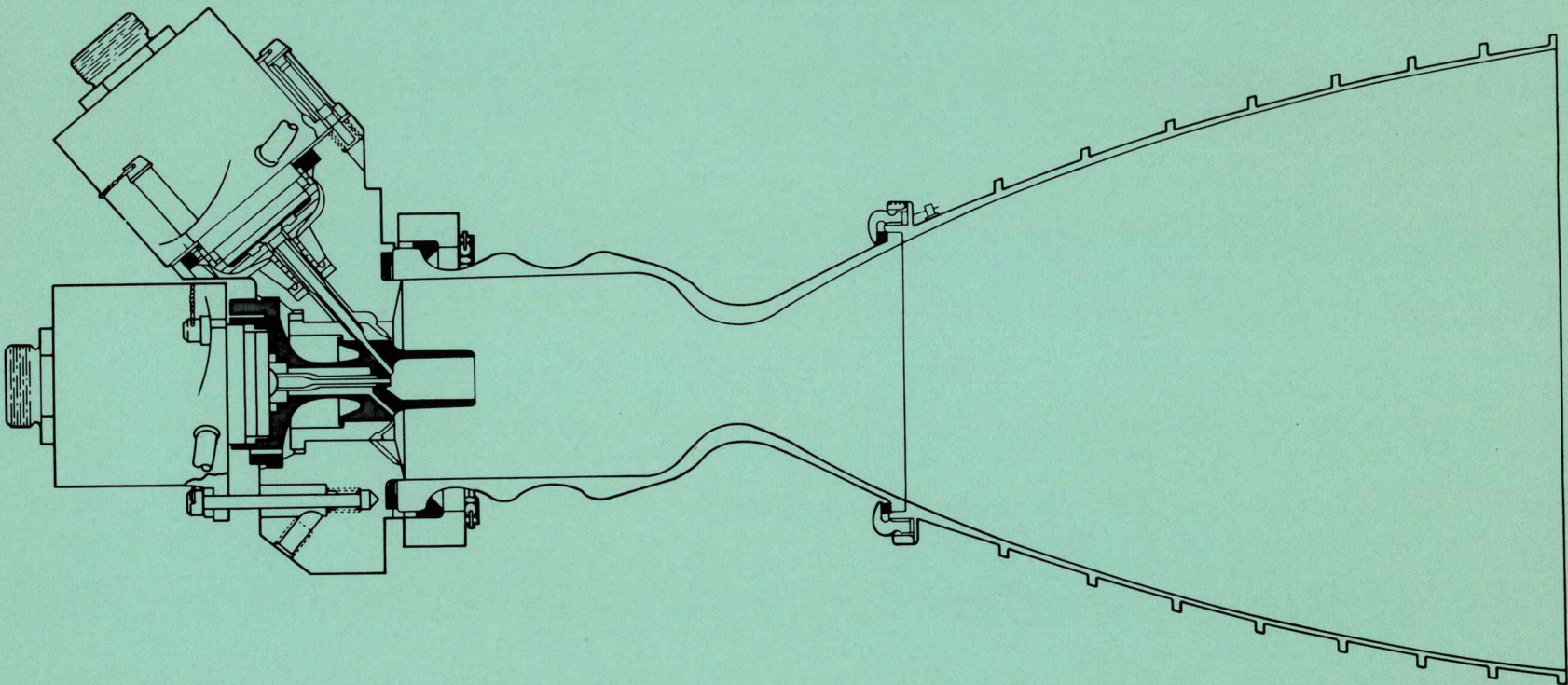


**GRAPH, THRUST VS. TIME, RCS**



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JAN 66

RCS ENGINE CROSS-SECTION



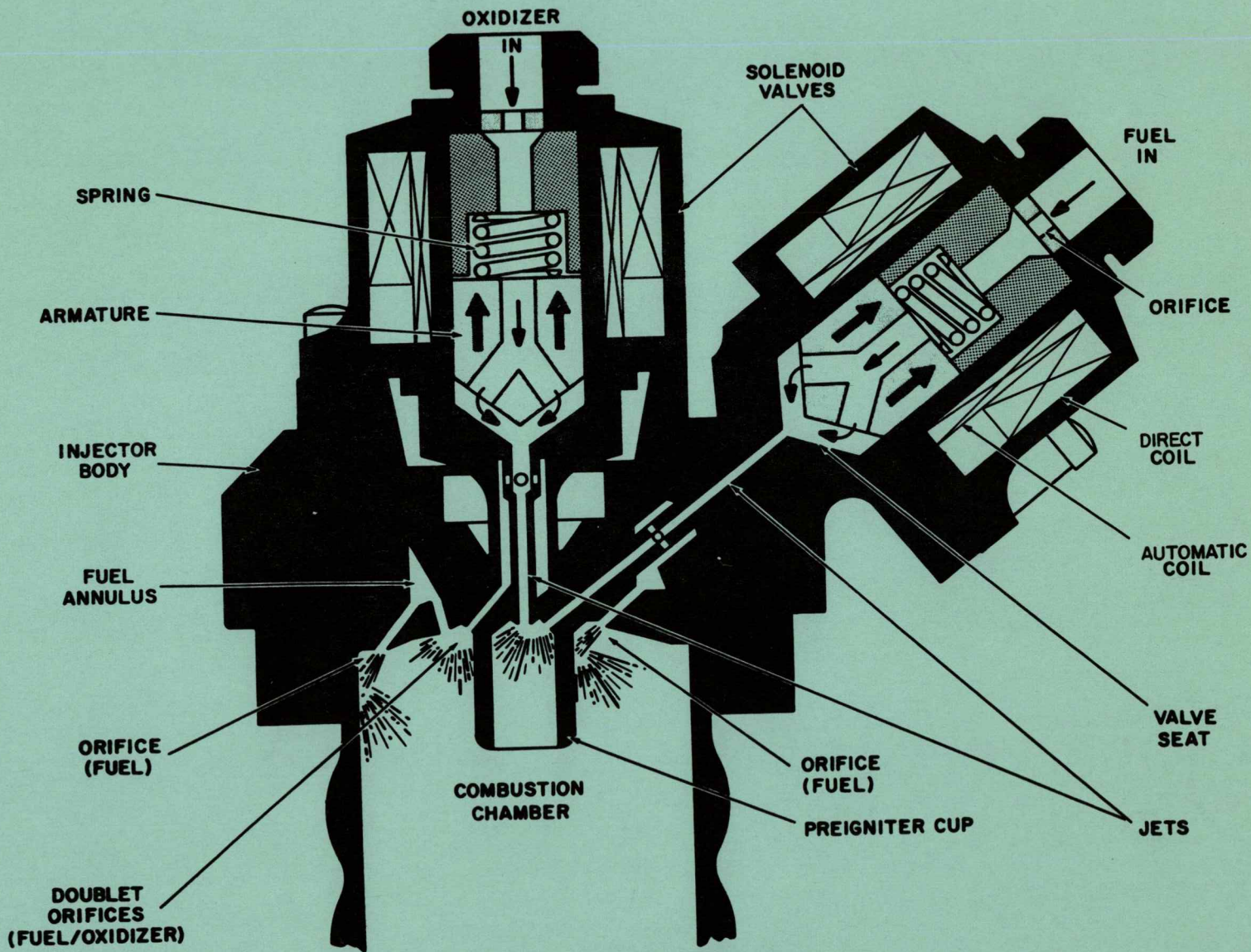
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Figure 55





RCS INJECTOR AND VALVES

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MAR 66

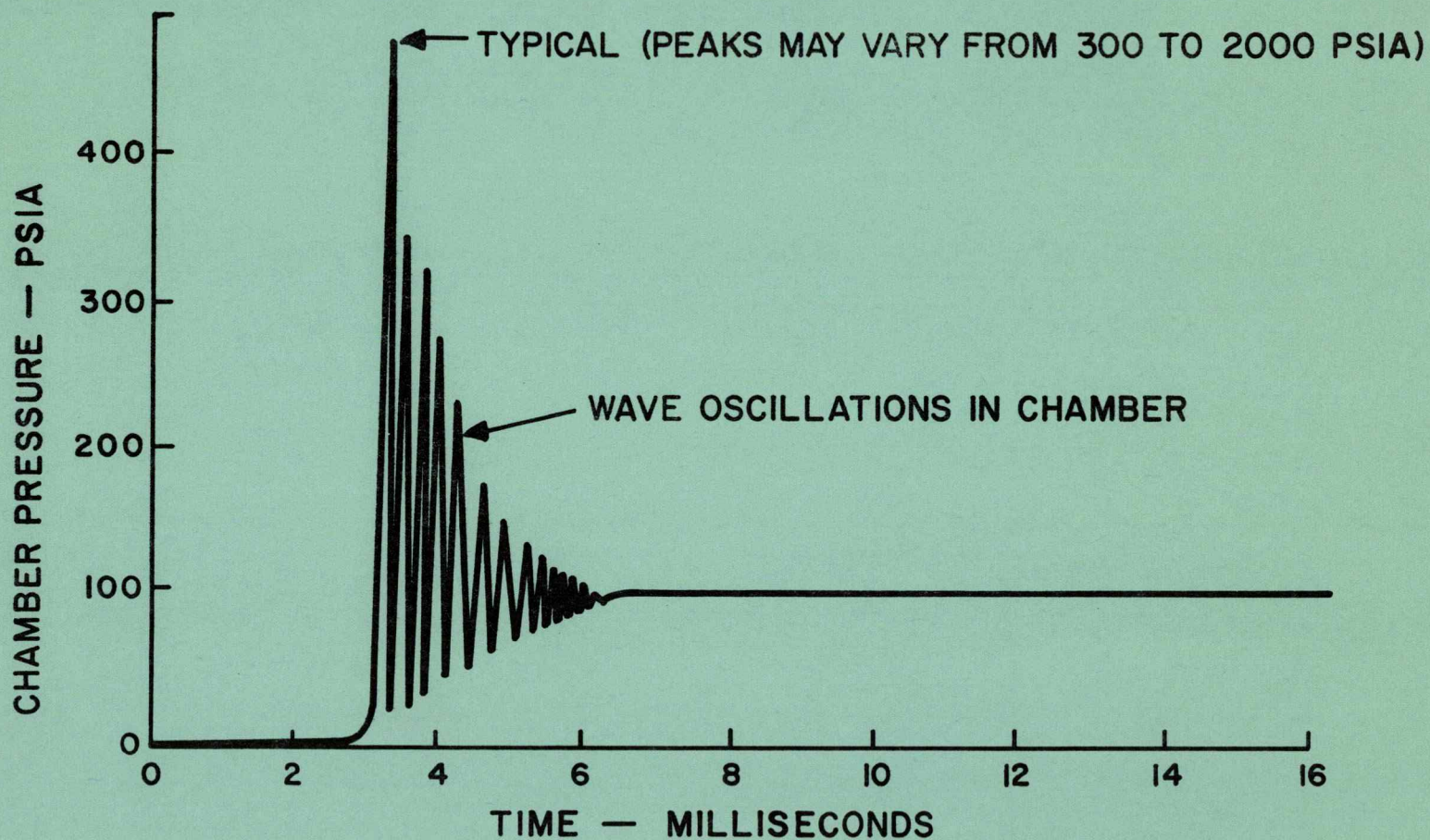
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Figure 56

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CHAMBER PRESSURE DURING A HARD START



## Chapter IV

### Controls and Displays

#### Introduction.

The LM, with its many subsystems, is a manned vehicle, designed to support two astronauts from lunar orbit until rendezvous with the CSM is completed. Since the LM is manned, the crew must be furnished data relative to the status of the subsystems, be warned of malfunctions, and once supplied this information, be able to take the required action.

Many considerations and principals went into the layout and design of the control and display panels. Controls and displays relating to a particular function are generally grouped together. Thought was given to the 0 and 1/6 "G" environments to be encountered, as well as to space suit limitations.

Controls are selected to suit their function. For instance, a common toggle switch may be found in various configurations. There are two, three, and four position toggles. Each position may be a "Maintain" (MAIN), in which the toggle will stay in the position selected, a "Momentary" (MOM), where the lever is spring loaded to return to its original position, or a "LOCK", where a mechanical restraint must be released in order to move the lever. Rotary selector switches, as well as other specially designed devices, are employed where their use is indicated.

Displays may be described as devices used to exhibit information. Several types are used. These may be indicators, lights, a digital display, or status flags, whichever are best suited to the purpose.

Every control and display is assigned an alpha numeric designator. These are selected to indicate the related subsystem. The type of device, and a sequentially assigned number. However, for the purposes of this manual these designators will serve the function of allowing a rapid cross-reference between the illustrations and the text, and vice versa. The alpha numeric designators do not appear on the actual spacecraft control and display panels.

The first three illustrations of this chapter, (See Figures 58, 59 and 60) serve to cross-reference controls and displays with subsystem components, during classroom instructions, and will not be further mentioned in the text.



The next illustration, (Figure 61.) serves to locate the various control and display panels in the LM cockpit. Much thought has been given to the relative location of these panels and to the arrangement of each individual panel. It should be noticed that, in many cases, controls and displays relating to more than one subsystem are located on the individual panel, also that panels I and II, the largest ones, contain most of the displays and controls pertaining to the propulsion subsystem and the RCS, and are located in the center between the LM windows. This location makes all panel components readily visible and accessible to both the LM commander and the pilot (system engineer).

Also, only those controls and displays on the panels which pertain to the Propulsion Subsystems and the RCS will be described.

Panel I (See Figure 62.)

6-DS-2 ASCENT PROPULSION LOW PRESS WARNING LIGHT (Red)

The (ASC PRESS) warning light is illuminated if either: (1) the pressure in either of two ascent helium tanks fails below 3000 psia prior to staging; or (2) if the blanket pressure in the fuel or oxidizer lines at the bi-propellant valves of the ascent stage decays below 120 psia. If illuminated by a low helium pressure, this light is extinguished by a signal from a deadface switch resulting from separation of the descent and ascent stages; if illuminated by low fuel or oxidizer pressure the light is extinguished only by restoration of pressure.

6-DS-3 HI/LOW HELIUM REG OUTLET PRESS WARNING LIGHT (Red)

The (DES REG) warning light is illuminated if the pressure within the descent helium lines downstream of the regulators rises above 260 psia or falls below 220 psia. The light is extinguished when nominal pressures are restored or staging is accomplished (deadface switch). This signal will be enabled by a delayed DES ENG "ON" command.

6-DS-4 DESCENT PROPELLANT LOW QUANTITY WARNING LIGHT (Red)

The (DES QTY) warning light is illuminated if, prior to staging, the fuel or oxidizer in the descent tanks falls below a quantity such that approximately 2 minutes of burning time at a thrust level of about 24% remains. This low level signal is enabled only if a descent engine "ON" command is present.



#### 6-DS-11 RCS TCA WARNING LIGHT (Red)

The (RCS TCA) Warning Light is illuminated if there is a primary coil command to fire a specific thruster, but no chamber pressure at that thruster. Additionally, a failure such that opposing co-linear jets are on simultaneously, illuminates the light. The light is extinguished when the isolation valve associated with the failed TCA is closed.

#### 6-DS-12 RCS "A" REGULATOR FAILURE WARNING LIGHT (Red)

#### 6-DS-13 RCS "B" REGULATOR FAILURE WARNING LIGHT (Red)

The (RCS "A" REG) Warning Light is illuminated if the pressure in the helium line of the pressurized RCS System "A" rises above 205 psia or falls below 165 psia. The light is extinguished when the nominal pressure is restored or if the main shut-off switch is closed. The (RCS "B" REG) Warning Light for System "B" is illuminated and extinguished in an identical manner as the (RCS "A" REG) Warning Light.

#### 10-M-5A OXIDIZER QUANTITY INDICATOR

#### 10-M-5B FUEL QUANTITY INDICATOR

These two-phase digital displays indicate the percentage of usable oxidizer and fuel quantities remaining in the descent tanks only, as selected by the propellant quantity monitor switch.

#### 10-M-1 HELIUM INDICATOR

This four-place digital display indicates descent ambient and supercritical helium tank temperatures and pressures as selected by the helium monitor switch.

#### 9-M-7 THRUST INDICATOR

This indicator displays descent engine chamber pressure (left pointer), and manual throttle commands or LGC thrust commands (right pointer), as selected by the thrust control switch. If the manual mode is selected the right pointer will indicate either the Commander's or Systems Engineer's throttle commands depending on the position of the manual throttle select switch. The display range is 0-100% thrust. Under normal operation of LGC command authority both pointers will be aligned at the same scale reading. A divergence between needle settings will indicate a malfunction,



or that the manual throttle authority is being introduced to enable a smooth transition to full manual control. If the latter is true, then the thrust control switch will be switched to MAN when the command pointer reaches 10% thrust. After switching to MAN, both pointers should be aligned if the system responds correctly.

#### 16-DS-92 THRUST INDICATOR POWER FAILURE LIGHT

This red incandescent light will illuminate when there is a 28V DC power interruption to the display.

#### 10-M-4 TEMPERATURE INDICATOR FUEL - OXIDIZER

This dual scale indicator displays fuel and oxidizer temperatures for the ascent or descent propellant system as selected by the propellant temperature/pressure monitor switch.

#### 10-M-3 PRESSURE INDICATOR FUEL - OXIDIZER

This dual scale indicator displays fuel and oxidizer pressures for the ascent or descent propellant system as selected by the propellant temperature/pressure monitor switch.

#### 16-DS-90 PRESSURE INDICATOR POWER FAILURE LIGHT

This red incandescent light will illuminate when there is a 28V DC power interruption to the display.

#### 9-M-4 THRUST WEIGHT INDICATOR

This indicator is a self-contained accelerometer which displays instantaneous X-axis acceleration in lunar "g" units (1 "G" = 5.23 ft/sec<sup>2</sup>). The instrument may be used to provide a gross check on engine performance since any given thrust level will provide a specific acceleration when the vehicle has a given mass.

#### 10-FL-1 ASCENT HELIUM REGULATOR STATUS NO. 1

#### 10-FL-2 ASCENT HELIUM REGULATOR STATUS NO. 2 TWO TWO-POSITION STATUS FLAGS

Each of these two-position flags (GREY - BARBER POLE) indicates the open (GREY) or closed (BARBERPOLE) status of its respective latch-type solenoid-operated valve, as controlled by its respective ascent helium regulator switch.

#### 10-S-3 ASCENT HELIUM REGULATOR NO. 1 SWITCH



10-S-4 ASCENT HELIUM REGULATOR NO. 2 SWITCH  
TWO THREE-POSITION TOGGLES MOM-MAIN-MOM

Each of these three-position toggles (OPEN - CLOSE) controls is a latch-type solenoid-operated valve located upstream of each helium pressure regulator. The solenoid valves are normally in the "OPEN" position. Selecting the "OPEN" position will actuate the associated shutoff valve, opening it, and enabling helium to flow through the regulator. Selecting the "CLOSE" position will actuate the associated shutoff valve, closing it and isolating the leg. Positive feedback of the solenoid valve position is provided by the ascent helium regulator status flags.

10-FL-3 DESCENT HELIUM REGULATOR STATUS NO. 1

10-FL-4 DESCENT HELIUM REGULATOR STATUS NO. 2  
TWO TWO-POSITION STATUS FLAGS

Each of these two-position flags (GREY - BARBERPOLE) indicates the open (GREY) or closed (BARBERPOLE) status of its respective latch-type solenoid-operated valve, as controlled by its respective descent helium regulator switch.

10-S-5 DESCENT HELIUM REGULATOR NO. 1 SWITCH

10-S-7 DESCENT HELIUM REGULATOR NO. 2 SWITCH  
TWO THREE-POSITION TOGGLES MOM-MAIN-MOM

Each of these three-position toggles (OPEN - CLOSE) controls a latch-type solenoid-operated valve upstream of each helium pressure regulator. The solenoid valve associated with the number one regulator switch is normally in the "OPEN" position, while the solenoid valve associated with the number two regulator switch is normally in the "CLOSE" position. This enables helium flow through the number one pressurization leg only. Selecting the "CLOSE" position with the number one regulator switch and the "OPEN" position with the number two regulator switch will actuate the associated solenoid valves and isolate the number one pressurization leg while enabling helium flow through the alternate number two leg. Positive feedback of the solenoid valve position is provided by the descent helium regulator status flags.

10-S-8 PROPELLANT QUANTITY MONITOR SWITCH THREE-POSITION TOGGLE  
MAIN-MAIN-MAIN

This three-position toggle (DES 1 - DES 2 - OFF) selects a pair of descent tanks for monitoring the percent of oxidizer and fuel quantities remaining in the tanks on the oxidizer and fuel



quantity indicator. Selecting the "DES 1" position enables the discrete outputs from the quantity gaging sensor probe of oxidizer tank No. 1 and fuel tank No. 1 to be displayed on this indicator. Selecting the "DES 2" position enables the discrete outputs from the quantity gaging sensor probe of oxidizer tank No. 2 and fuel tank No. 2 to be displayed. In the "OFF" position, DC power is removed from the gaging system and the quantity indicator is blank.

10-S-1 PROPELLANT TEMPERATURE/PRESSURE MONITOR SWITCH  
THREE-POSITION TOGGLE MAIN-MAIN-MAIN

This three-position toggle (ASC - DES 1 - DES 2) selects for monitoring on the temperature and pressure indicators, the propellant tank pressures and temperatures. In the "ASC" position, ascent propellant tank pressures and temperatures are displayed. In the "DES 1" position, the descent propellant No. 1 values are displayed, and in the DES 2 position, the descent propellant No. 2 values are displayed. Propellant No. 1 values and propellant No. 2 values are in each case one fuel tank and one oxidizer tank temperature and pressure.

10-S-6 HELIUM MONITOR SWITCH  
SEVEN-POSITION ROTARY

This seven-position rotary switch enables monitoring temperatures and pressures on the helium indicator. In the "OFF" position, power to the display is interrupted. In the "AMB PRESS" position, pressure in the descent ambient helium tank is monitored; in the "SUPCRUT PRESS" position, pressure in the descent supercritical helium tank is selected for monitoring. Selection of the ascent switch positions permits monitoring of both the pressure and the temperature of the ambient helium in each of the ascent helium tanks.

1-S-13 ABORT SWITCH  
GUARDED PUSHBUTTON MAINTAIN

This pushbutton is activated to initiate an abort using the descent engine. Activation of this switch causes the following events to occur at the appropriate time: (a) a command signal is sent to arm the descent engine, (b) a signal is sent via instrumentation to telemetry indicating that the vehicle is preparing for an abort, and (c) a signal is sent to the LGC and AGS to compute and execute the abort trajectory by using the abort program.



1-S-14 ABORT STAGE SWITCH  
GUARDED PUSHBUTTON MAINTAIN

This pushbutton is activated to initiate an abort using the ascent engine. Activation of this switch will cause the following events to occur at the appropriate times: (a) a command signal is sent to the electro-explosive devices to pressurize the ascent engine, (b) a signal is sent to the LGC and AGS to compute and execute the short trajectory using the abort stage program, (c) a signal is sent via instrumentation to telemetry indicating that the vehicle is preparing to stage for an abort, (d) the descent engine is shut down, and (e) an ascent engine "ON" command is enabled which, in turn, fires the appropriate electro-explosive devices to initiate vehicle staging. At the same time the LGC will turn on the ascent engine and signal telemetry via the serial down-link that the ascent engine has been started. At some point in the abort stage sequence, electrical power is transferred automatically from descent batteries to ascent batteries.

1-S-11 THRUST CONTROL SWITCH  
TWO-POSITION TOGGLE LOCK-LOCK

This two-position toggle (AUTO - MAN) provides the capability of switching from automatic throttle control (LGC) to manual throttle control. In the "AUTO" position, LGC command signals are summed with the manual command signals, but only the LGC command signals are displayed on the Thrust Indicator. In the "MAN" position, LGC throttle command signals to the descent engine are interrupted. The thrust indicator shows manual throttle commands only, and the descent engine throttle is fed only by the manual throttle command signals.

1-S-10 MANUAL THROTTLE SWITCH  
TWO-POSITION TOGGLE LOCK-LOCK

This two-position toggle (CDR - SE), selects the controller which will be used for manual descent engine thrust level adjustment if its corresponding select lever is in the "THROTTLE" position. Thus, in the "CDR" position only the Commander's Controller is enabled to adjust descent engine thrust level, and the "SE" position only the Systems Engineer's Controller is enabled.

1-S-1 ENGINE ARM SWITCH  
THREE-POSITION TOGGLE LOCK-LOCK-LOCK

This three-position toggle (ASC - OFF - DES) provides arming signals to the engines. The "ASC" position provides an arming signal enabling firing of the ascent engine while simultaneously signaling



the LGC that the engine is armed. In the "OFF" position the arming signals are removed from the engine valves and the LGC. In the "DES" position the descent engine is armed and the LGC is notified that the engine is armed. However, regardless of the position of this switch, the appropriate engine will be armed if either the abort switch or the abort stage switch are actuated.

1-S-6 X TRANSLATION SWITCH  
TWO-POSITION TOGGLE MAIN-MAIN

This two-position toggle (4 JETS - 2 JETS) selects the number of jets that will be utilized in X-axis translation maneuvers. This control can only be used with the AGS system.

1-S-9 BALANCED COUPLES SWITCH  
TWO-POSITION TOGGLE-LOCK-LOCK

This two-position toggle (ON - OFF) selects either balanced pairs of RCS jets in a couple or unbalanced X-axis RCS jets for use in maintaining pitch and roll attitude during the ascent engine thrust phase when the AGS is in the guidance loop. This switch is normally in the "ON" position (balanced couples) during the initial phases of lunar ascent. This provides maximum stabilization and control over any center of gravity thrust vector misalignment. After some minimum burn time (to be determined), when the balanced couples operation is no longer required, the switch can be positioned to "OFF" to conserve propellants.

6-S-2 MASTER ALARM LIGHT-COMMANDER

This pushbutton indicator, along with the caution/warning array lights, and the audible tone, is actuated by a malfunction condition or an out-of-tolerance condition. Depressing of either this master alarm light or the System Engineer's master alarm light, will extinguish both master alarm lights and terminate the audible tone, but will have no effect on the individual illuminated annunciator light(s).

1-DS-1 LUNAR CONTACT LIGHT-CDR

One light is located at the Commander's station and one is located at the Systems Engineer's station. Both illuminate red when the probe(s) on the vehicle's landing gear touch the lunar surface. They provide positive feedback to the crew that the descent engine should be turned off. These lights will extinguish when either engine stop switch is actuated, and the engine stops.



Panel II (See Figure 63.)

6-DS-21 HIGH He REG OUTLET PRESS CAUTION LIGHT (YELLOW)

The (ASC HI REG) Caution Light is illuminated if the helium pressure downstream of the regulators in the ascent helium lines is greater than 220 psia. The light is extinguished when pressure is reduced to a nominal value.

6-DS-22 ASCENT PROPELLANT LOW QUANTITY CAUTION LIGHT (YELLOW)

The (ASC QTY) Caution Light is illuminated if the level of ascent fuel or oxidizer in the ascent tanks reaches a value such that approximately 10 seconds burning time remains. The signal is intended to permit the crew to manually shut down the ascent engine to avoid possible explosive effects resulting from depletion of either fuel or oxidizer before the other, and to indicate that ascent engine thrusting is not available for midcourse correction or rendezvous braking. These low level signals are enabled only if the ascent engine is on.

6-DS-23 AUTOMATIC GIMBAL FAILURE CAUTION LIGHT (YELLOW)

The (ENG GIMBAL) Caution Light is illuminated if a difference between the gimbal drive signal and gimbal response from the Y or Z-axis trim function is sensed. This signal is enabled only if the descent engine is armed. Additionally, the signal is disabled following staging (deadface switch).

6-DS-32 RCS FAILURE CAUTION LIGHT (YELLOW)

The (RCS) Caution Light is illuminated if the pressure of the helium tank in either RCS system drops below 1700 psia. The light is extinguished by selecting the "He" position of the RCS Temp/Press Monitor Switch.

6-DS-33 HEATER FAILURE CAUTION LIGHT (YELLOW)

The (HEATER) Caution Light is illuminated by an out-of-tolerance temperature condition in any of the four RCS thruster quads, (120°F to 190°F), or the S-band antenna assembly (-60°F to 1550°F), or the rendezvous radar assembly (-50°F to 150°F), or the landing radar antenna assembly (-15°F to 150°F). The light is extinguished by placing the Temperature Monitor switch to the "AFFECTED HEATER ASSEMBLY" position. Note: Figures given in the parentheses are the in-tolerance limits.



## 8-M-2 TEMPERATURE INDICATOR

This indicator displays the temperatures in the fuel tanks of System A and B as selected by the temperature/pressure monitor select switch.

## 8-M-1 PRESSURE INDICATOR

This indicator displays the pressures in the helium tanks, or at the fuel or oxidizer tanks, or in the fuel or oxidizer manifolds of System A and B, as selected by the temperature/pressure monitor select switch.

## 8-M-4 QUANTITY INDICATOR

This indicator displays the propellant quantity in System A and B continuously.

## 16-DS-96 RCS PRESSURE INDICATOR POWER FAILURE LIGHT

This red incandescent light will illuminate when there is a power interruption to the display.

## 16-DS-98 RCS QUANTITY INDICATOR POWER FAILURE LIGHT

This red incandescent light will illuminate when there is a power interruption to the display.

## 8-FL-5 MAIN SHUT-OFF VALVE STATUS-SYSTEM A

## 8-FL-7 MAIN SHUT-OFF VALVE STATUS-SYSTEM B TWO TWO-POSITION STATUS FLAGS

Each of these two-position flags (GREY - BARBERPOLE) indicates the open (GREY) or closed (BARBERPOLE) status of its respective pair of latch-type solenoid-operated valves as controlled by its respective main shut-off valve switch.

## 8-S-7 MAIN SHUT-OFF VALVE SWITCH - SYSTEM A

## 8-S-9 MAIN SHUT-OFF VALVE SWITCH - SYSTEM B TWO THREE-POSITION TOGGLES SWITCHES MOM-LOCK-MOM

Each of these three-position toggles (OPEN - CLOSE) simultaneously actuates a pair of latch-type, solenoid-operated fuel and oxidizer shut-off valves which control the flow of propellant downstream of the propellant tanks. These valves are opened for system operation by moving the toggle to the "OPEN" position; however, if a



malfunction exists in one of the systems (either "A" or "B"), propellant flow in the malfunctioning system can be interrupted by moving the toggle to the "CLOSE" position. These switches are spring loaded to the center position, and only momentarily held in the "OPEN" or "CLOSE" position. Positive feedback of the solenoid valve position is displayed by the main shut-off valve status flags.

8-FL-6 ASCENT FEED STATUS - SYSTEM A

8-FL-8 ASCENT FEED STATUS - SYSTEM B  
TWO TWO-POSITION STATUS FLAGS

Each of these two-position flags (GREY - BARBERPOLE) indicates the open (GREY) or closed (BARBERPOLE) status of its respective pair of latch-type solenoid-operated valves as controlled by its respective ascent feed switch.

8-S-8 ASCENT FEED SWITCH - SYSTEM A

8-S-10 ASCENT FEED SWITCH - SYSTEM B  
TWO THREE-POSITION TOGGLE SWITCHES MOM-LOCK-MOM

Each of these three-position toggles (OPEN- -CLOSE) actuates a pair of latch-type, solenoid-operated fuel and oxidizer valves which ties the RCS propellant lines to a manifold which may be connected to the ascent tanks. These solenoid valves are normally closed. However, they may be opened during periods of ascent engine thrusting to allow the use of ascent subsystem propellants in the RCS for the purpose of conserving RCS propellants. This can be accomplished by placing the Ascent Feed switch for either System "A" or "B" or both to the "OPEN" position and placing the main shut-off valve switch(es) to the "CLOSE" position. The status of the solenoid valves is displayed by the ascent feed status flags.

8-FL-9 THRUSTER PAIR STATUS  
QUAD NO. 1; SYSTEM A

8-FL-10 THRUSTER PAIR STATUS  
QUAD NO. 2; SYSTEM A

8-FL-11 THRUSTER PAIR STATUS  
QUAD NO. 1; SYSTEM B

8-FL-12 THRUSTER PAIR STATUS  
QUAD NO. 2. SYSTEM B



- 8-FL-13 THRUSTER PAIR STATUS  
QUAD NO. 3; SYSTEM A
- 8-FL-14 THRUSTER PAIR STATUS  
QUAD NO. 4; SYSTEM A
- 8-FL-15 THRUSTER PAIR STATUS  
QUAD NO. 3; SYSTEM B
- 8-FL-16 THRUSTER PAIR STATUS  
QUAD NO. 4; SYSTEM B  
EIGHT THREE-POSITION FLAGS

Each of these flags (GREY - BARBERPOLE - RED), normally indicates the open (GREY) or closed (BARBERPOLE) status of its respective pair of latch-type solenoid-operated isolation valves. In addition, a third position (RED) will automatically appear (in conjunction with the RCS TCA warning light) to indicate a TCA failure. In the event of such a failure, the Thruster Pair Switch associated with the red flag would be actuated to the "CLOSE" position. This action will shut down the malfunctioning TCA and display the barberpole position.

- 8-S-11 THRUSTER PAIR SWITCH  
QUAD NO. 1; SYSTEM A
- 8-S-12 THRUSTER PAIR SWITCH  
QUAD NO. 2; SYSTEM A
- 8-S-13 THRUSTER PAIR SWITCH  
QUAD NO. 1; SYSTEM B
- 8-S-14 THRUSTER PAIR SWITCH  
QUAD NO. 2; SYSTEM B
- 8-S-15 THRUSTER PAIR SWITCH  
QUAD NO. 3; SYSTEM A
- 8-S-16 THRUSTER PAIR SWITCH  
QUAD NO. 4; SYSTEM A
- 8-S-17 THRUSTER PAIR SWITCH  
QUAD NO. 3; SYSTEM B
- 8-S-18 THRUSTER PAIR SWITCH  
QUAD NO. 4; SYSTEM B  
EIGHT THREE-POSITION TOGGLES MOM-MAIN-MOM



Each of these three-position toggles (OPEN- -CLOSE) activates two latch-type, solenoid-operated TCA isolation valves controlling fuel and oxidizer flow to a pair of TCA's. Activation of the switch provides a pulse to trigger the valve to the "OPEN" or "CLOSED" position. The valves are normally in the "OPEN" position. The toggles can be used for emergency shutdown of the thrust chambers during flight. Positive feedback of the solenoid valve position is displayed by the thruster pair status flag.

8-FL-17 CROSSFEED STATUS  
ONE TWO-POSITION FLAG

This two-position flag (GREY - BARBERPOLE) indicates the open (GREY) or closed (BARBERPOLE) status of the latch-type solenoid-operated fuel and oxidizer crossfeed valves as controlled by the crossfeed switch.

8-S-20 CROSSFEED SWITCH  
ONE THREE-POSITION TOGGLE MOM-LOCK-MOM

This three-position toggle (OPEN- -CLOSE) controls two latch-type solenoid-operated fuel and oxidizer valves located in a cross-feed piping arrangement between System A and System B. They are normally closed. However, if the feed section of either System A or System B malfunctions upstream of the main shut-off valves the appropriate main shut-off valve is closed (by moving the main shut-off valve switch to the "CLOSED" position), and the crossfeed valves are opened by moving the crossfeed switch to the "OPEN" position. This permits fuel and oxidizer to flow from the operative system to the thrust chambers of both systems. The cross-feed status flag indicates the status of the crossfeed valves.

8-S-19 TEMPERATURE/PRESSURE MONITOR SELECT SWITCH  
FOUR-POSITION ROTARY

This four-position rotary (He - PRPLNT - FUEL MANF - OXID MANF), is used to monitor pressures and temperatures of Systems A and B on the temperature indicator and the pressure indicator. In the "He" position, it monitors the helium tank pressure. In the "PRPLNT" position, it monitors the fuel and oxidizer tank pressures as sensed at the helium regulator outlet and the propellant temperature as sensed in the fuel tank. The System A and B fuel and oxidizer manifold pressures are monitored in the "FUEL MANF" and "OXID MANF" positions respectively. The temperature pointers on the temperature indicator will deflect to the lowest graduation mark when temperatures are not being sensed.



## 6-S-3 MASTER ALARM LIGHT-SYSTEMS ENGINEER

This pushbutton indicator, along with the caution/warning array lights, and the audible tone, is actuated by a malfunction condition or an out-of-tolerance condition. Depressing of either this master alarm light or the Commander's master alarm light, will extinguish both master alarm lights and terminate the audible tone, but will have no effect on the individual illuminated annunciator light(s).

### Panel III (See Figure 64.)

#### 1-S-8 ENGINE GIMBAL ENABLE TWO-POSITION TOGGLE LOCK-LOCK

In the "ENABLE" position, gimbal trim signals are enabled to position the descent engine on both Y and Z axes. In the "OFF" position, power is interrupted to the gimbal drive actuators, thus disabling the gimbal drive capability.

#### 1-S-19 DESCENT ENGINE COMMAND OVERRIDE SWITCH TWO-POSITION TOGGLE LOCK-LOCK

This switch, in the "ON" position, provides a 28V DC alternate power source to the descent engine shut-off valves to prevent engine shut-down should a loss of power occur in the control electronics. The "OFF" position interrupts the alternate power path.

#### 18-M-1 TEMPERATURE INDICATOR

This indicator displays the temperature, in degrees Fahrenheit, of the radar antenna assemblies or RCS quads or S-band antenna assembly selected by the temperature monitor select switch.

#### 18-S-10 TEMPERATURE MONITOR SELECT SWITCH SEVEN-POSITION ROTARY

This seven-position rotary (RADAR: RNDZ - LDG; RCS: QUAD 1 - QUAD 2 - QUAD 3 - QUAD 4; S-BAND) selects the rendezvous or landing radar antenna assembly, the RCS quads, or the S-band antenna assembly for temperature monitoring.

#### 18-S-4 RCS QUAD 1 HEATER SWITCH

#### 18-S-5 RCS QUAD 2 HEATER SWITCH

#### 18-S-6 RCS QUAD 3 HEATER SWITCH



18-S-7 RCS QUAD 4 HEATER SWITCH  
FOUR THREE-POSITION TOGGLES MAIN-MAIN-MAIN

Each of these switches controls one of two heaters that are mounted on each of the RCS thrusters. In the "AUTO" position the heaters will cycle on and off, as required to maintain the desired temperature (approx. 128°F). In the "OFF" position the circuit is interrupted and the heaters are inoperative. In the "MAN" position the heater temperature control mechanism is bypassed, and the heating element remains energized regardless of the temperature. The other heater on each RCS thruster is not controlled through switches. It cycles, as required, to maintain the required temperature, but the only manual control is to render these heaters inoperative by pulling the circuit breakers.

1-DS-2 LUNAR CONTACT LIGHT-SYSTEMS ENGINEER

One light is located at the Systems Engineer's station and one is located at the Commander's station. Both illuminate red when the probe(s) on the vehicle's landing gear touch the lunar surface. They provide positive feedback to the crew that the descent engine should be turned off. These lights will extinguish when either engine stop switch is actuated, and the engine stops.

Panel V (See Figure 65.)

1-S-5 RATE OF DESCENT SWITCH  
THREE-POSITION TOGGLE MOM-MAIN-MOM

This switch enables the establishment of a vehicle rate of descent under PGNS authority. Each switch actuation provides a discrete pulse changing the rate of descent by 1 ft/sec. A switch actuation in the +X direction decreases the rate of descent by 1 ft/sec. A switch actuation in the -X direction increases the rate of descent by 1 ft/sec.

1-S-3 ENGINE STOP SWITCH  
GUARDED PUSHBUTTON MAINTAIN

This pushbutton sends a discrete stop signal to the descent and ascent engines independent of the position of the engine arm switch. When actuated, the button illuminates red. It is reset by depressing it a second time.

1-S-2 ENGINE START SWITCH  
GUARDED PUSHBUTTON MAINTAIN

This pushbutton provides a manual override capability for immediate firing of either the descent or ascent engine, depending upon



the position of the engine arm switch. Once actuated, the engine fire command continues, and the button is illuminated red. Activation of either engine stop switch interrupts the override function and extinguishes the light.

1-S-12 +X AXIS TRANSLATION SWITCH  
GUARDED PUSHBUTTON MOMENTARY

This pushbutton is located at the Commander's station. When it is held in the depressed position, it provides four jet translation in the +X direction by energizing the RCS secondary coils. Upon release of the button the signal is removed from the coils, terminating the jet firings.

Panel VI (See Figure 66.)

1-S-4 ENGINE STOP SWITCH  
GUARDED PUSHBUTTON MAINTAIN

This pushbutton sends a discrete stop signal to the descent and ascent engines independent of the position of the engine arm switch. When actuated, the button is illuminated red. It is reset by depressing it a second time.

Panel VIII (See Figure 67.)

10-FL-5 FUEL VENT STATUS  
10-FL-6 OXID VENT STATUS  
TWO TWO-POSITION STATUS FLAGS

Each of these two-position flags (GREY - BARBERPOLE) indicates the open (GREY) and closed (BARBERPOLE) status of its respective latch-type, solenoid-operated valve as controlled by its respective vent switch.

10-S-9 FUEL VENT SWITCH  
THREE-POSITION TOGGLE MOM-MAIN-MOM

This three-position toggle (OPEN- -CLOSE) enables venting of the descent fuel tanks and helium pressurization section. Normally, it is in the "CLOSE" position. Selecting the "OPEN" position will actuate the associated shutoff valve, opening it, and enable venting. Selecting the "CLOSE" position will actuate the associated shutoff valve, closing it, preventing venting. Positive feedback of the solenoid valve position is provided by the status of the fuel vent status flag.



10-S-10 OXID VENT SWITCH  
THREE-POSITION TOGGLE MOM-MAIN-MOM

This three-position toggle (OPEN- -CLOSE) enables venting of the descent oxidizer tanks and helium pressurization section. Selecting the "OPEN" position will actuate the associated shutoff valve opening it, and enable venting. Selecting the "CLOSE" position will actuate the associated shutoff valve closing it, preventing venting. Normally, it is in the "CLOSE" position. Positive feedback of the solenoid valve position is provided by the status of the oxidizer vent status flag.

2-S-9 DES PRPLNT ISO VLV SWITCH  
TWO-POSITION MOM-LOC

This two-position toggle (FIRE - SAFE) actuates the squib isolation valves downstream of the check valves prior to actuation of the descent pressurization switch.

2-S-7 MASTER ARM  
TWO-POSITION TOGGLE LOCK-LOCK

This two-position toggle (ON - OFF) enables the actuation of all vehicle explosive devices by actuating redundant relays that apply power to the EDS busses. Thus, this switch must be in the "ON" position in order for all other explosive devices fire switches to perform their designated functions.

2-S-6 DESCENT VENT SWITCH  
TWO-POSITION TOGGLE MOM-LOCK

This two-position toggle (FIRE - SAFE) actuates the squib valves which enable venting of the descent propulsion propellant tanks and the helium pressurization section through the subsequent activation of the descent fuel vent switch, and the descent oxidizer vent switch.

2-S-3 ASCENT HE SEL  
THREE-POSITION TOGGLE LOCK-LOCK-LOCK

This three-position toggle (TANK 1 - BOTH - TANK 2) selects the squib valves of either ascent helium tank 1 or 2, or both, for firing by use of the ascent helium pressurization switch.



2-S-2 RCS PRESSURIZATION SWITCH  
TWO-POSITION TOGGLE MOM-LOCK

This two-position toggle (FIRE - SAFE) actuates squib valves which permit helium to flow from the RCS helium tanks to pressurize the reaction control subsystem. Positive feedback of the firing of the squibs is provided by a nominal pressure reading on the reaction control subsystem's pressure indicator.

2-S-1 DESCENT PRESSURIZATION SWITCH  
TWO-POSITION TOGGLE MOM-LOCK

This two-position toggle (FIRE-SAFE) actuates the squib valves to permit helium flow from the ambient storage tank for start pressurization of the descent propulsion subsystem. The descent propellant isolation valve switch must be actuated prior to activating this switch to allow the helium regulators to see maximum ullage volume. Positive feedback of the firing of the squibs is provided by a nominal pressure reading on the main propulsion subsystem's pressure indicator.

2-S-4 ASCENT HELIUM PRESSURIZATION SWITCH  
TWO-POSITION TOGGLE MOM-LOCK

This two-position toggle (FIRE - SAFE) actuates the squib valves of the tank(s) selected by the ascent helium select switch. Actuation of these squib valves will pressurize the ascent propulsion subsystem. Positive feedback of the firing of the squibs is provided by a nominal pressure reading on the main propulsion subsystem's pressure indicator.



Panels XI and XVI (See Figures 68 and 69.)

<u>Subsystem/Code</u>	<u>Panel Nomenclature</u>	<u>Panel Location</u>		<u>Component(s) Served</u>
		<u>XI</u>	<u>XVI</u>	
<u>Main Propulsion</u>				
4-CB-32	PQGS		X	Main propulsion quantity gaging system.
4-CB-53	ASC He REG		X	Latching helium solenoid valves 1 and 2.
4-CB-74	DES He REG	X		Latching helium solenoid valves 1 and 2.
4-CB-103	TEMP/PRESS DISP- FLAGS		X	Fuel and oxidizer pressure indicator, fuel and oxidizer temperature indicator and all valve position status flags.
4-CB-169	He/PQGS Propul DISP	X		Helium temp/press indicator (AC), and descent propellant quantity gaging (AC)
<u>Reaction Control</u>				
4-CB-42	QUAD 4 - TCA		X	TCA fuel and oxidizer valves of Quad 4, System B.
4-CB-43	QUAD 3 - TCA		X	TCA fuel and oxidizer valves of Quad 3, System B.
4-CB-44	QUAD 2 - TCA		X	TCA fuel and oxidizer valves of Quad 2, System B.
4-CB-45	QUAD 1 - TCA		X	TCA fuel and oxidizer valves of Quad 1, System B.
4-CB-49	ISOL VLV		X	Oxidizer and fuel isolation valves of System B.



<u>Subsystem/Code</u>	<u>Panel Nomenclature</u>	<u>Panel Location</u>		<u>Component(s) Served</u>
		<u>XI</u>	<u>XVI</u>	
<u>Reaction Control</u> - continued				
4-CB-50	TEMP/PRESS DISP - FLAGS		X	All valve position status flags and temperature and pressure indicators.
4-CB-51	ASC FEED	X		Ascent interconnect oxidizer and fuel valves of System A.
4-CB-52	ASC FEED		X	Ascent interconnect oxidizer and fuel valves of System B.
4-CB-54	CRSFD		X	Oxidizer and fuel crossfeed valves.
4-CB-60	QUAD 4 - TCA	X		TCA fuel and oxidizer valves of Quad 4, System A.
4-CB-61	QUAD 3 - TCA	X		TCA fuel and oxidizer valves of Quad 3, System A.
4-CB-62	QUAD 2 - TCA	X		TCA fuel and oxidizer valves of Quad 2, System A.
4-CB-63	QUAD 1 - TCA	X		TCA fuel and oxidizer valves of Quad 1, System A.
4-CB-67	ISOL VLV	X		Oxidizer and fuel isolation valves of System A.
4-CB-72	MAIN SOV	X		Oxidizer and fuel main shutoff valves of System A.
4-CB-73	MAIN SOV		X	Oxidizer and fuel main shutoff valves of System B.
4-CB-121	PQGS/DISP		X	Propellant quantity gaging control unit and display.



<u>Subsystem/Code</u>	<u>Panel Nomenclature</u>	<u>Panel Location</u>		<u>Component(s) Served</u>
		<u>XI</u>	<u>XVI</u>	
<u>RCS Heaters</u>				
4-CB-218	QUAD 1	X		System 1 RCS A and B engine heaters in QUAD 1.
4-CB-219	QUAD 2	X		System 1 RCS A and B engine heaters in QUAD 2.
4-CB-220	QUAD 3	X		System 1 RCS A and B engine heaters in QUAD 3.
4-CB-221	QUAD 4	X		System 1 RCS A and B engine heaters in QUAD 4.
4-CB-222	QUAD 1		X	System 2 RCS A and B engine heaters in QUAD 1.
4-CB-223	QUAD 2		X	System 2 RCS A and B engine heaters in QUAD 2.
4-CB-224	QUAD 3		X	System 2 RCS A and B engine heaters in QUAD 3.
4-CB-225	QUAD 4		X	System 2 RCS A and B engine heaters in QUAD 4.

OBSOLETE

FOR TRAINING PURPOSES ONLY



## Telemetry

Transducers and position sensors located throughout the Propulsion Subsystems and the RCS are used to sense physical data such as temperatures, pressures, quantities and valve positions. Critical data is displayed on the caution and warning panels; less critical data is displayed on analog and digital displays.

Most of this data that is made available to the flight crew, plus certain additional data not made available to them, is collected within the LM and processed through the Instrumentation and Communication Subsystems for telemetry transmission to The Manned Space Flight Network. This information will be continuously available to MSFN as real time displays and will allow them to:

- a. Assist in spacecraft management, especially during crew high activity phases.
- b. Participate in major decisions to modify the mission, or abort.
- c. Maintain a detailed system status/performance flight history record.

The referenced figures indicate the sensor locations in the basic systems used for this real time telemetry and describe the physical data so obtained. (See Figures 70, 71 and 72.)

In addition to the data utilized for real time telemetry there are many locations through the subsystems where additional data of lesser importance may be sensed. This information is of particular importance for the purpose of post-flight analysis of the first LM flights. It is available on tape only.

The referenced figures indicate the sensor locations in the basic systems used for this purpose and in addition provide the measurement identification; description; sensor range, and low, nominal and high measurement values. Those measurements also used for real time telemetry are marked with an R. (See Figures 73, 74 and 75.)

It should be emphasized that these secondary measurements (development flight instrumentation) will be used on LM 1, 2 and 3 only. Due to changes being made all information given in the figures may not be current.



## Summary

The IM controls and displays are primarily located on panels in the forward section of the crew compartment. These panels are designated with roman numerals. The panels shown in this chapter contain controls and displays pertaining to the propulsion subsystem and RCS; only these are explained in the text.

### Panel I

This panel contains the warning light display. These lights provide a red indication to warn of a malfunction that affects crew safety and requires immediate action to counter the emergency.

The controls and displays on this panel related to main propulsion are as follows: propellant quantity indicator; helium temperature and pressure indicator; thrust indicator; propellant temperature and pressure indicators; thrust/weight indicator; helium regulator switches and status flags; a propellant quantity monitor switch; a propellant temperature/pressure monitor switch; and a helium monitor switch.

Also included on this panel are two abort switches and engine thrust control switches.

### Panel II

This panel contains the caution light display. These lights provide a yellow indication to alert the crew to a situation or malfunction that is not time critical to their safety, but requires that they be aware of it.

Other controls and displays on this panel relate to the RCS. They include: a fuel temperature indicator; a helium and propellant pressure indicator; a propellant quantity indicator, main shut-off valve switches and status flags; ascent feed valve switches and status flags; thruster pair (isolation valve) switches and status flags; a crossfeed switch and status flat; and a temperature/pressure monitor switch.

### Panel III

This panel contains RCS heater controls and display. They are: a temperature monitor switch; a temperature indicator; and heater switches.



#### Panel V

The controls on this panel are a rate of descent switch; a start switch and a stop switch for the main propulsion engines; and a switch used for +X translation.

#### Panel VI

This panel contains just one control related to the propulsion subsystems. It is a main engine stop switch.

#### Panel VIII

Controls for pressurizing the main propulsion and reaction control subsystems, and for depressurizing the descent subsystem, are on this panel. They are: the descent propellant isolation valve switch; the master arm switch; the descent vent switch; the ascent helium select switch; three helium pressurization switches, one for each of the subsystems; and descent propulsion vent switches and status flags.

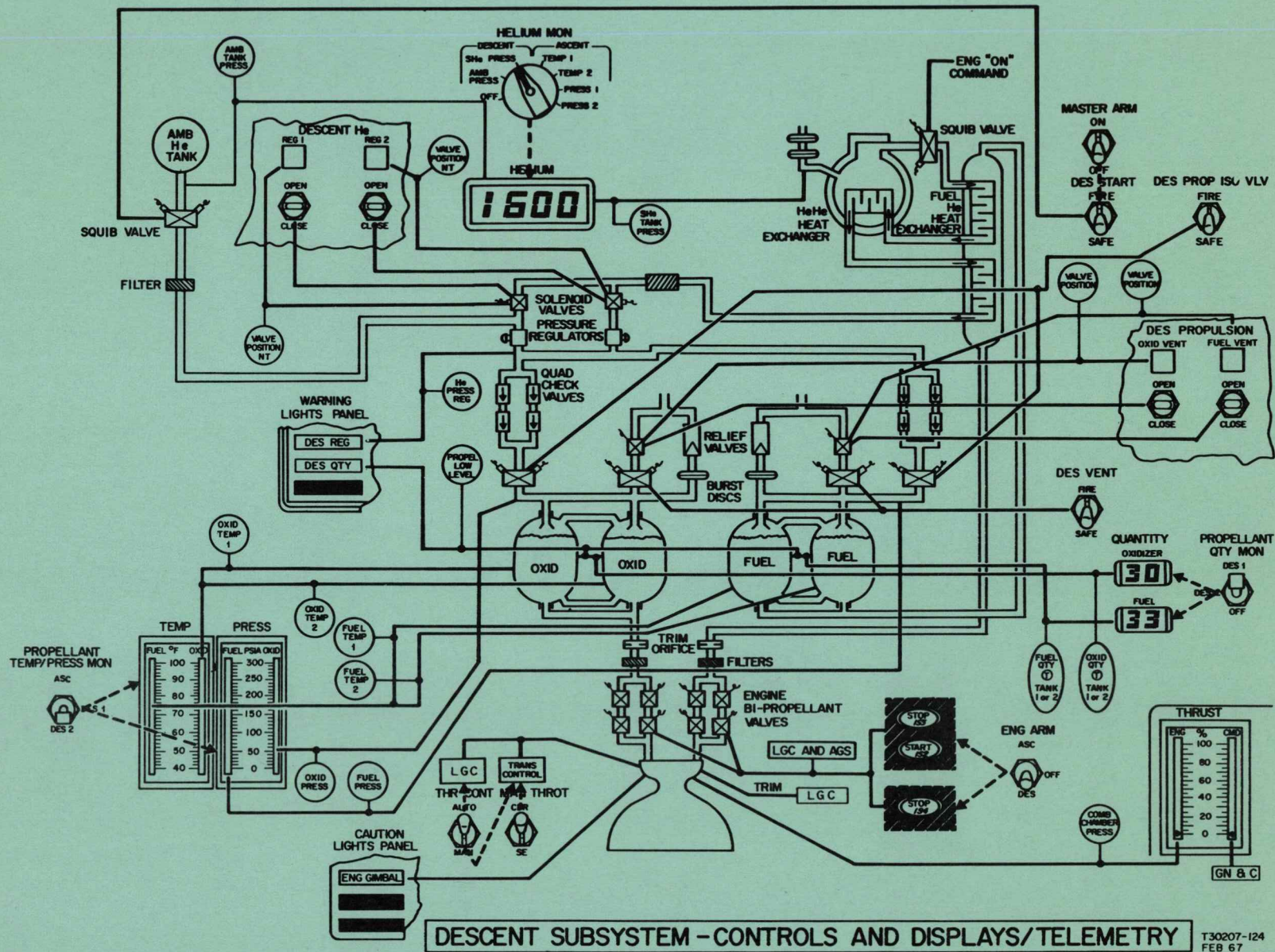
#### Panels XI and XVI

These two panels, located one at each side of the LM cabin, contain all the circuit breakers. These breakers are used to protect the displays on the other panels, and valves and other components throughout the subsystems.

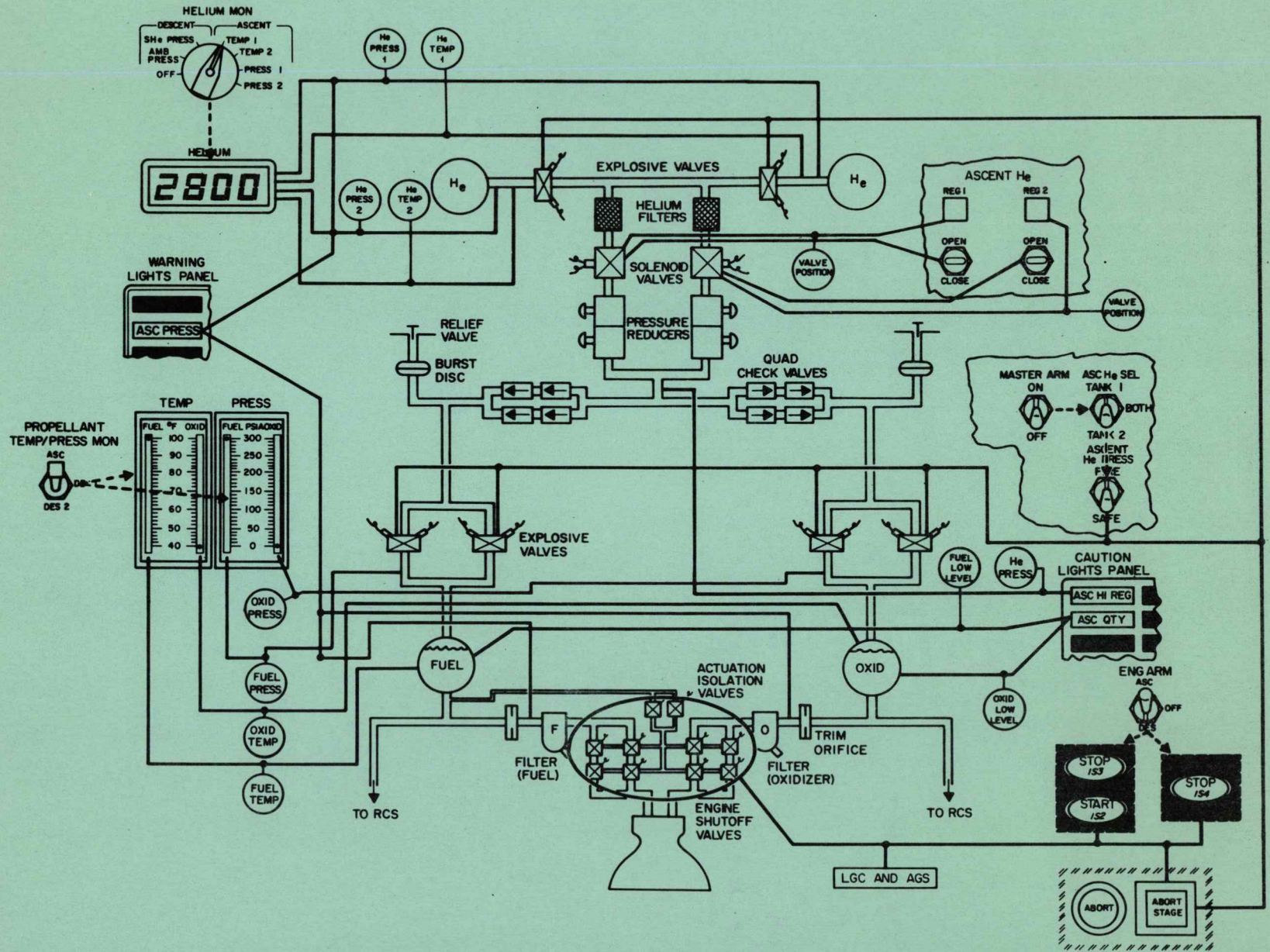
#### Telemetry

Sensors located throughout the subsystems sense physical data for cockpit display and telemetry purposes. Telemetry transmissions may be divided into two categories: real time telemetry used for ground station display during a flight; and in the early LM's, development flight instrumentation used for post flight analysis.







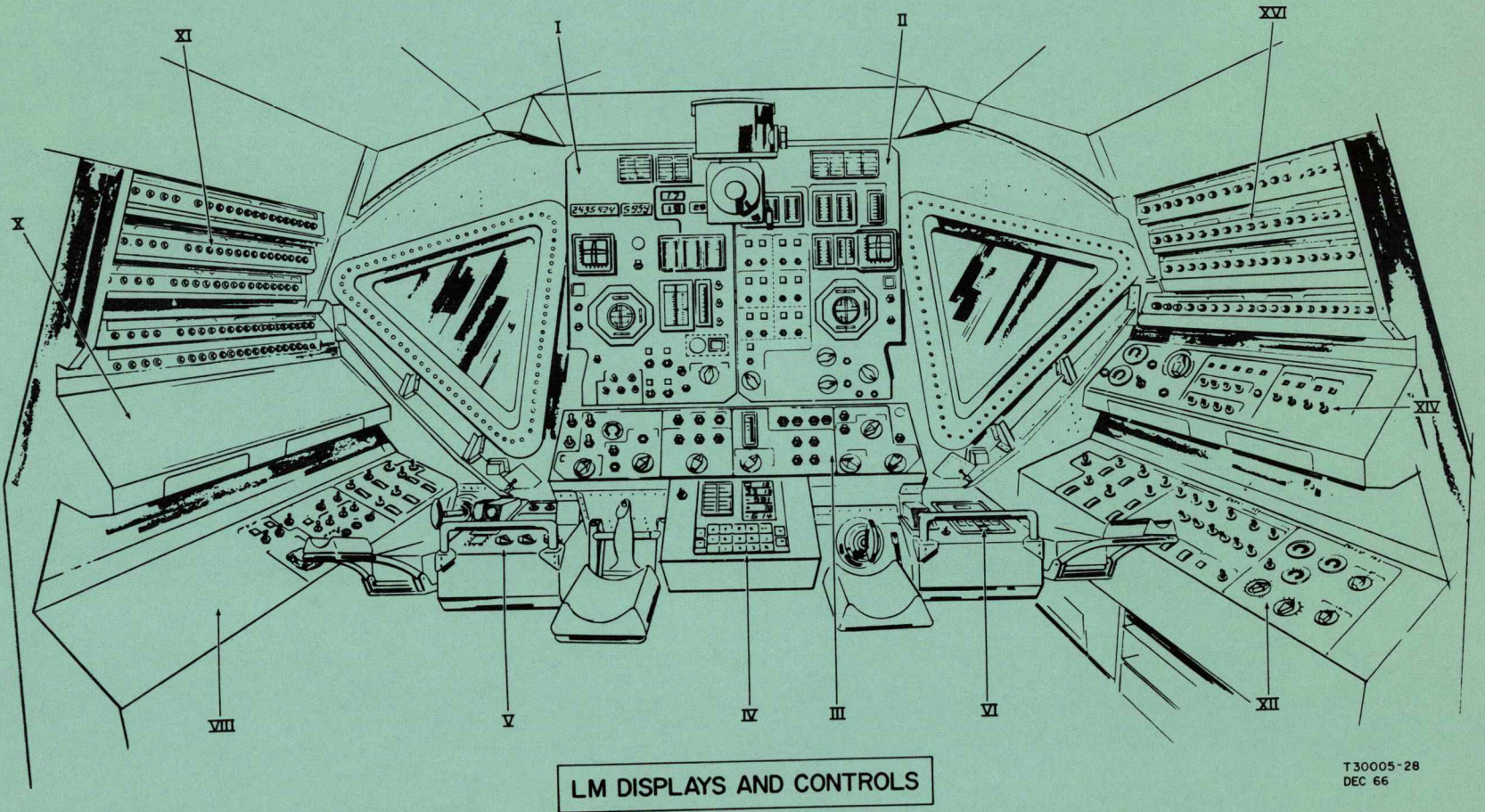


ASCENT SUBSYSTEM-CONTROLS AND DISPLAYS/TELEMETRY









T 30005-28  
DEC 66

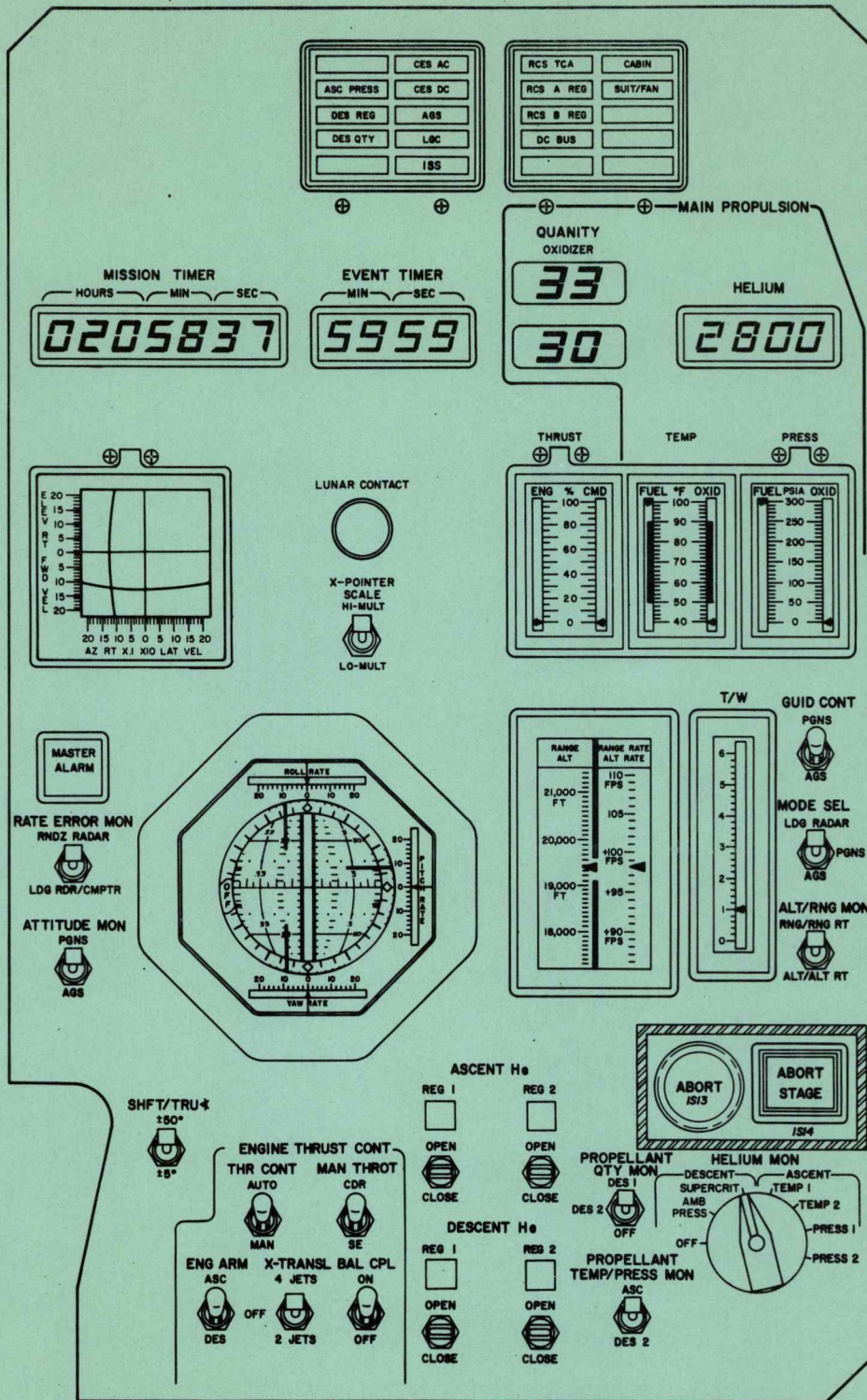
Figure 61

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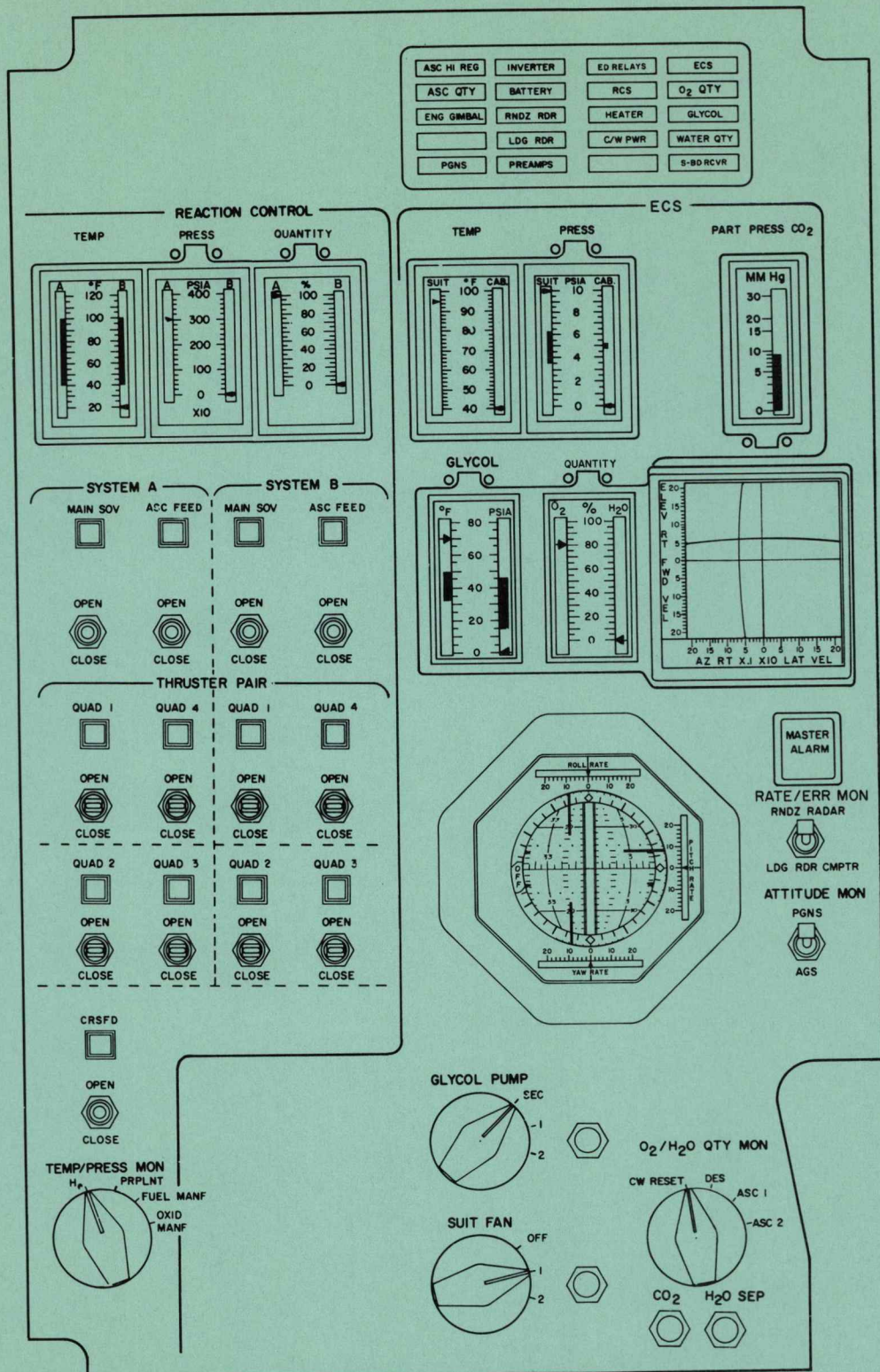




PANEL I

T30900-1  
JAN 67

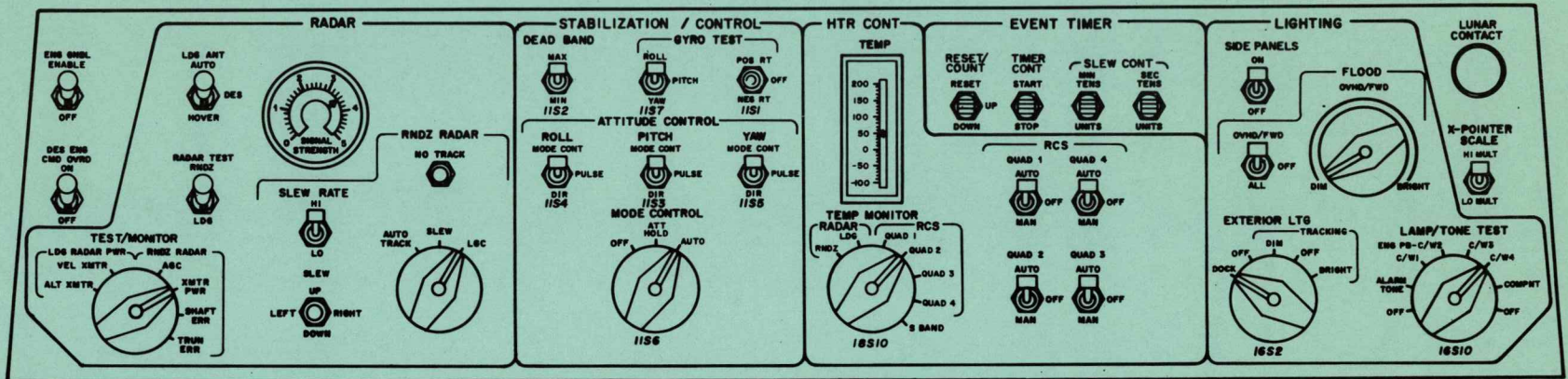




**PANEL 2  
LM3**

T30900-2  
MAY 67





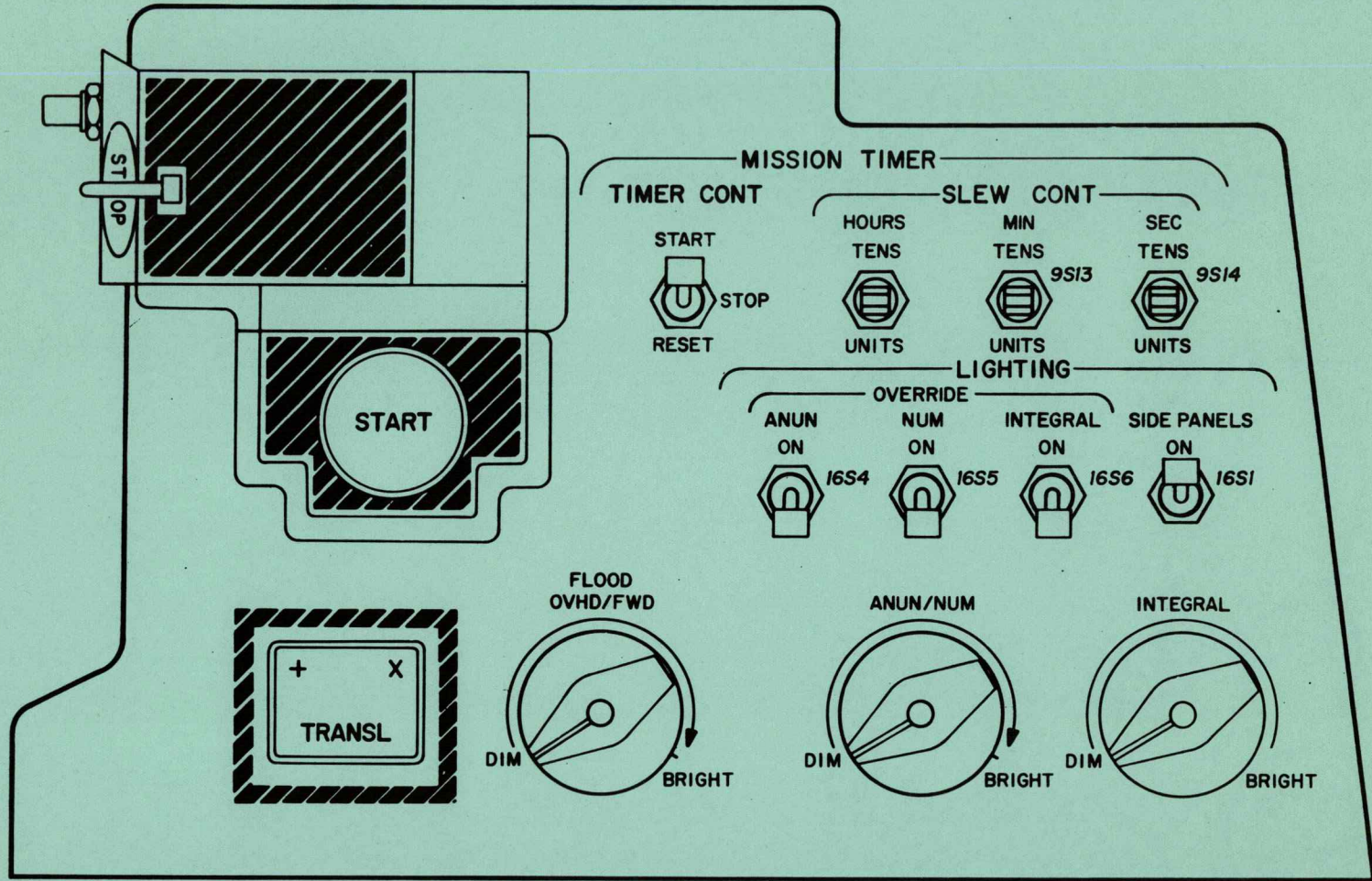
PANEL III



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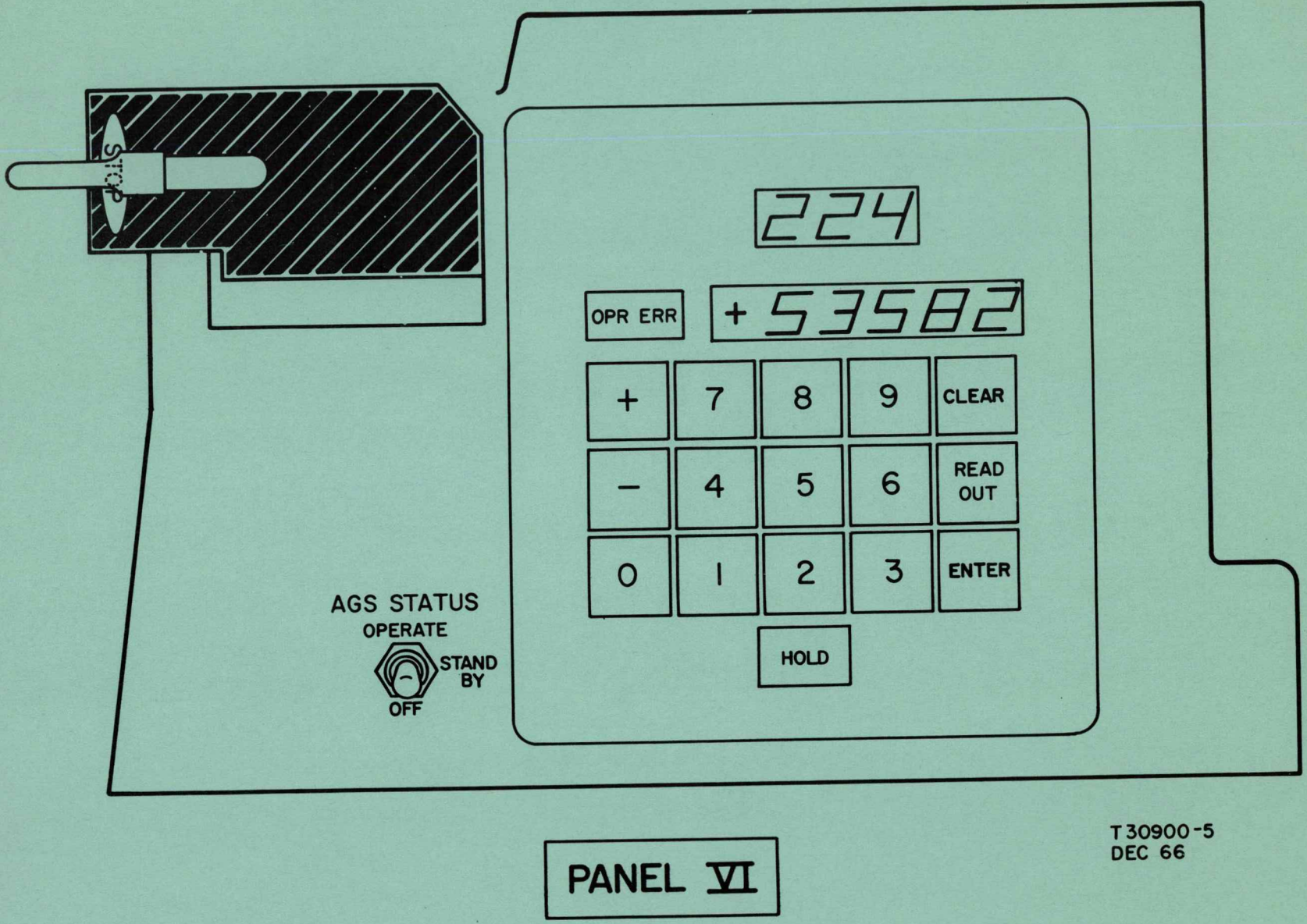


PANEL V

T30900-4  
DEC 66

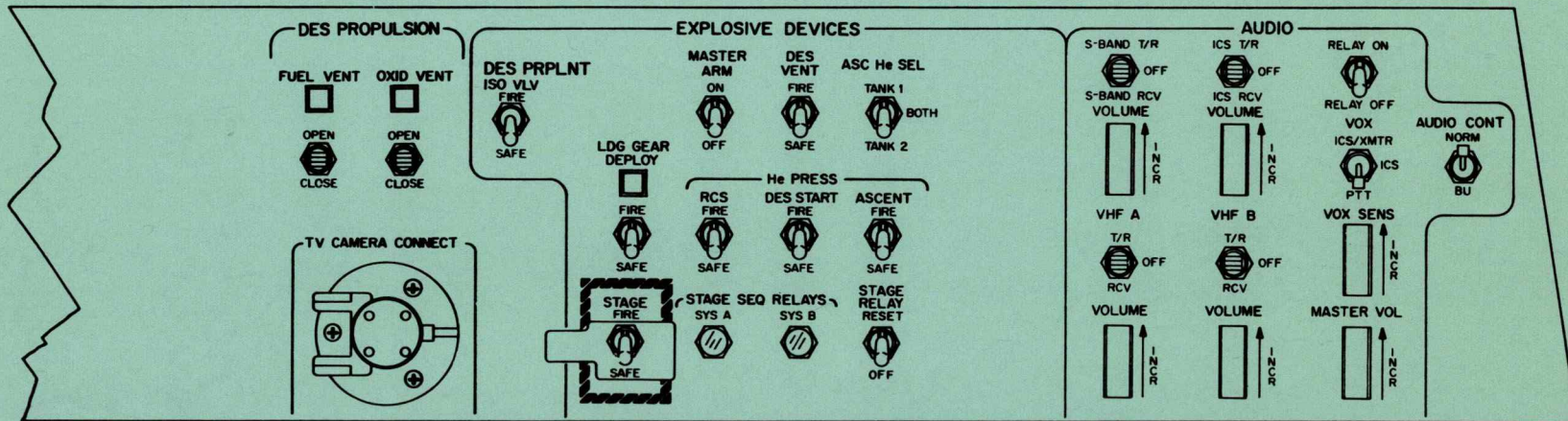
Figure 65





T 30900-5  
DEC 66



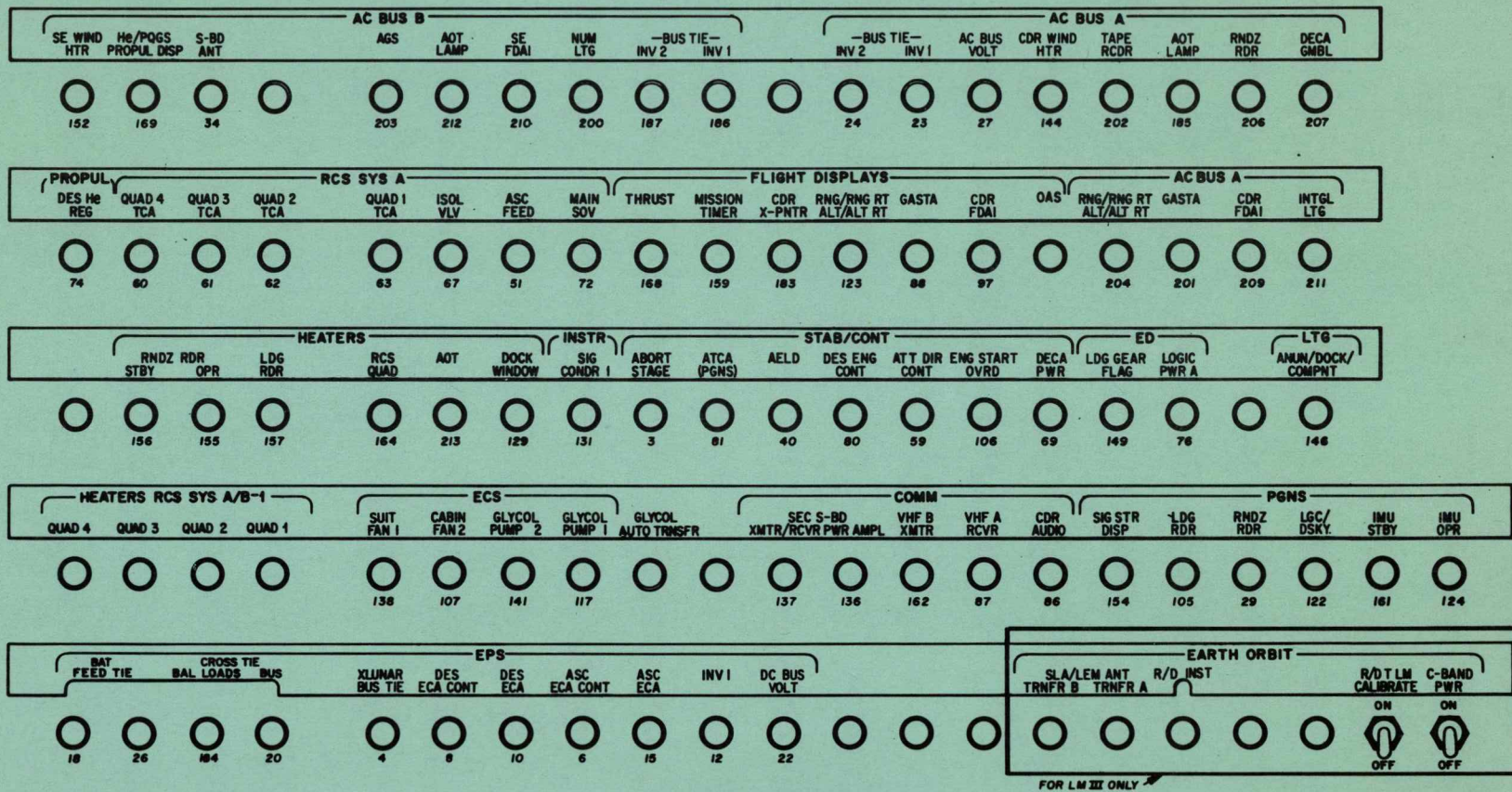


PANEL VIII

T30900-6  
DEC 66

Figure 67

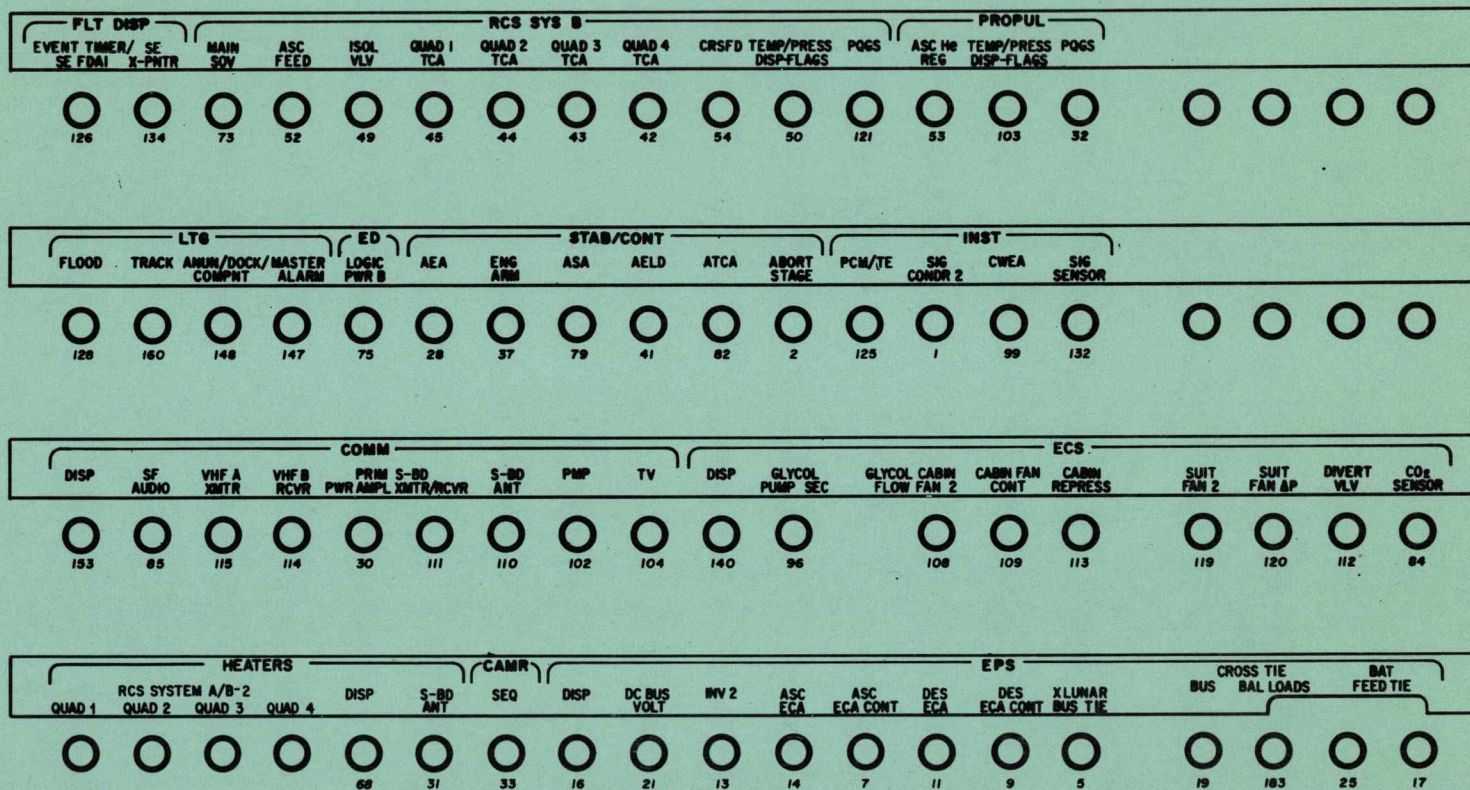




PANEL XI



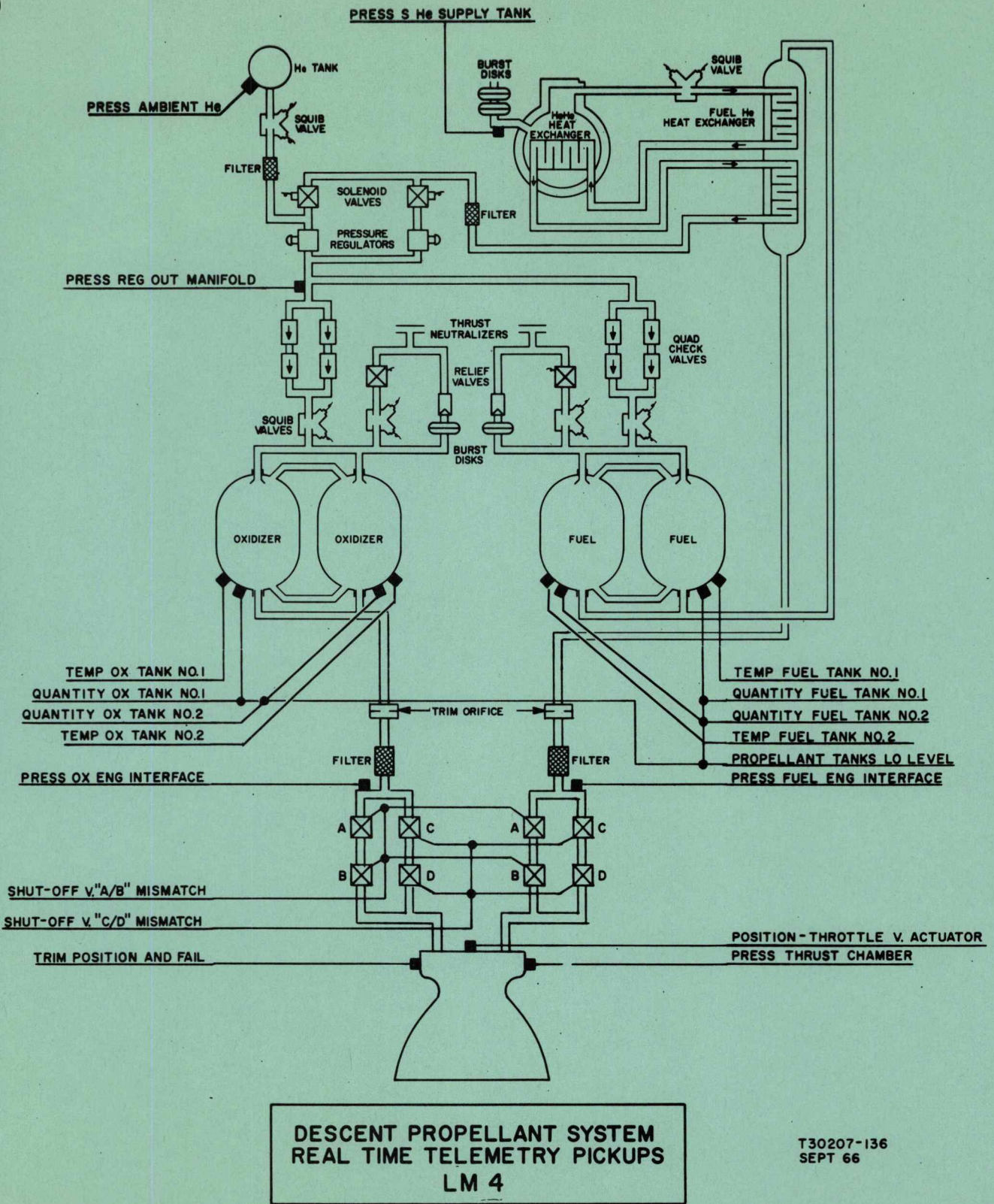
Figure 69



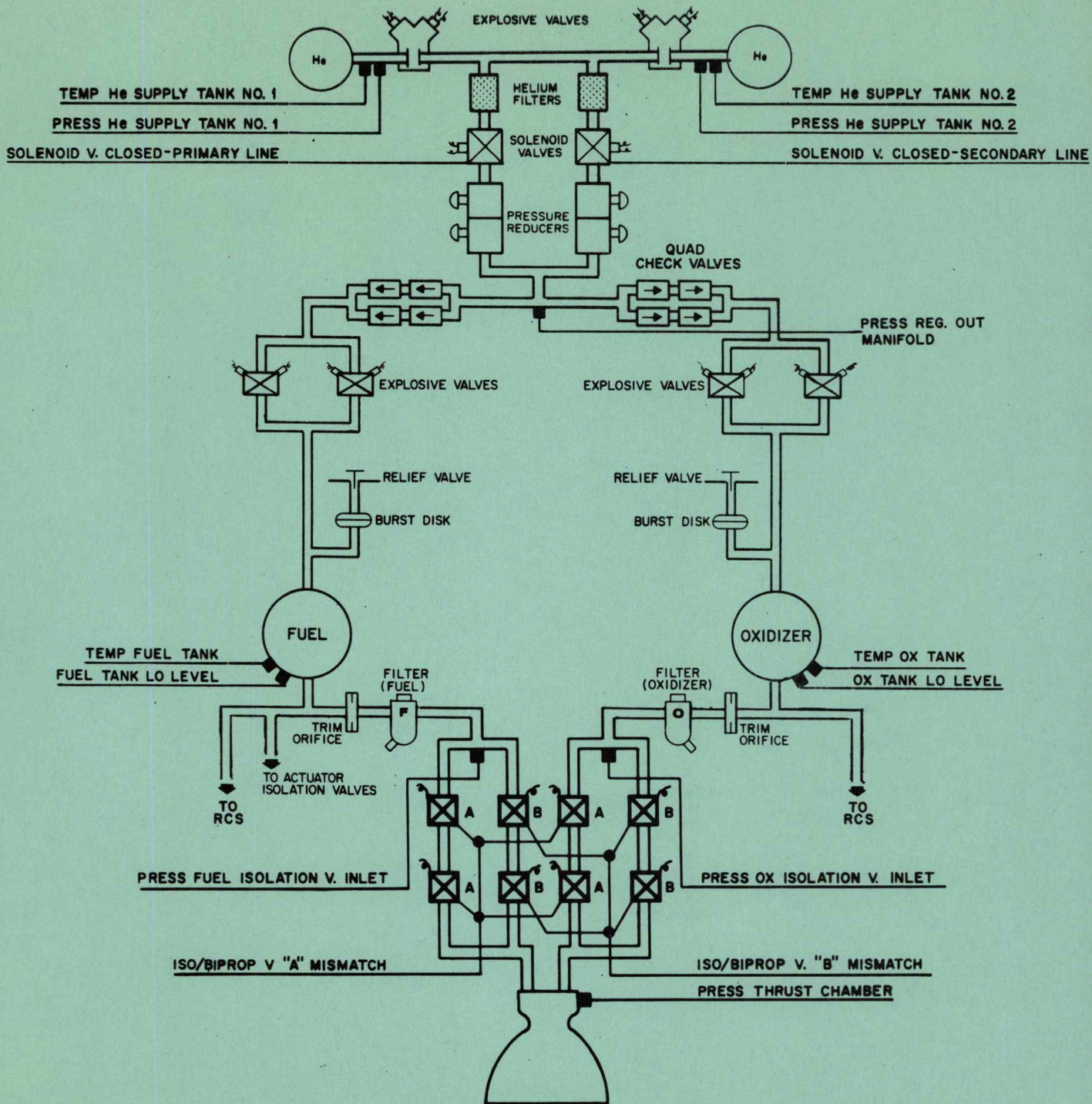
PANEL XVI  
LM 4

T30900-21  
JAN 67





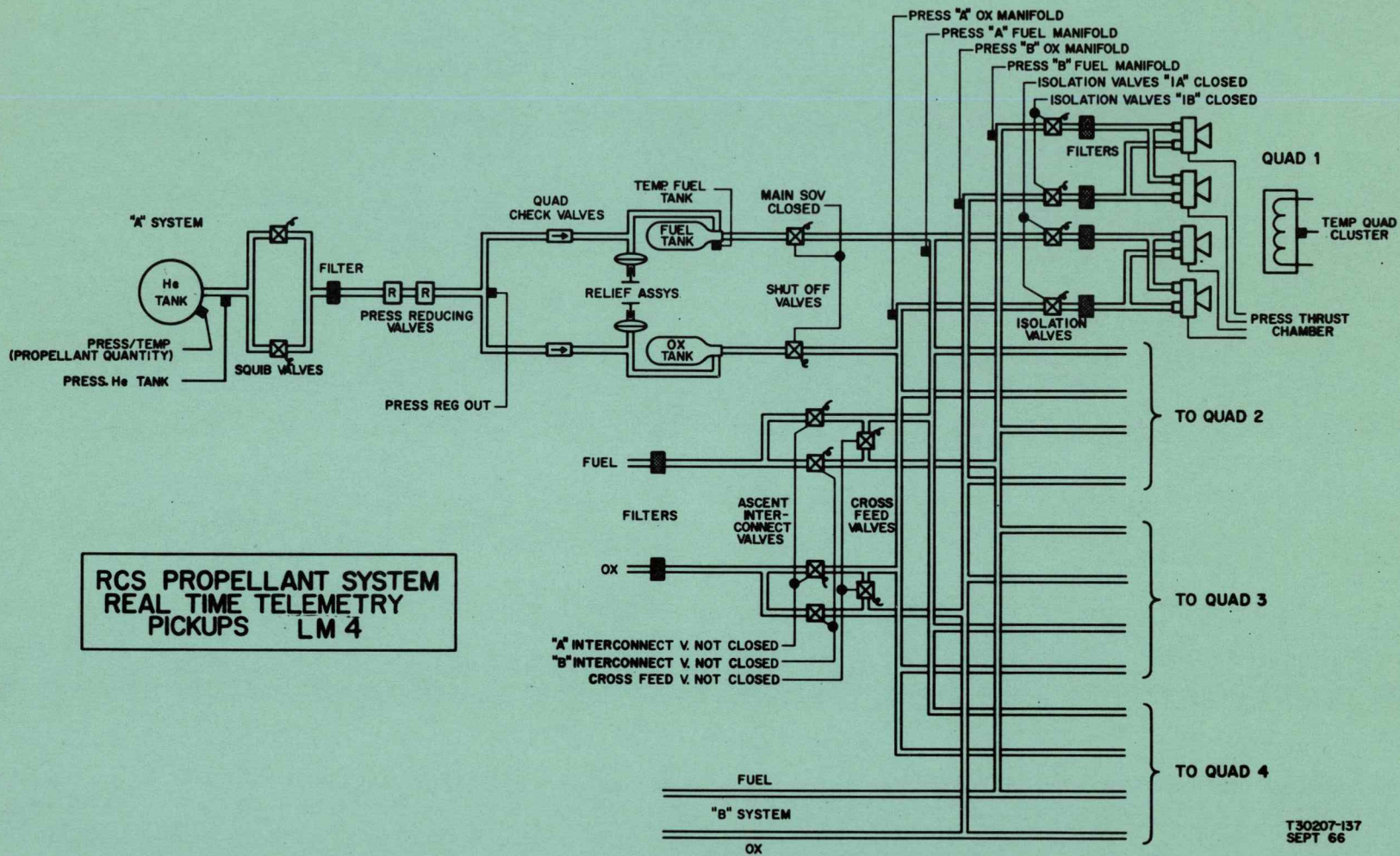




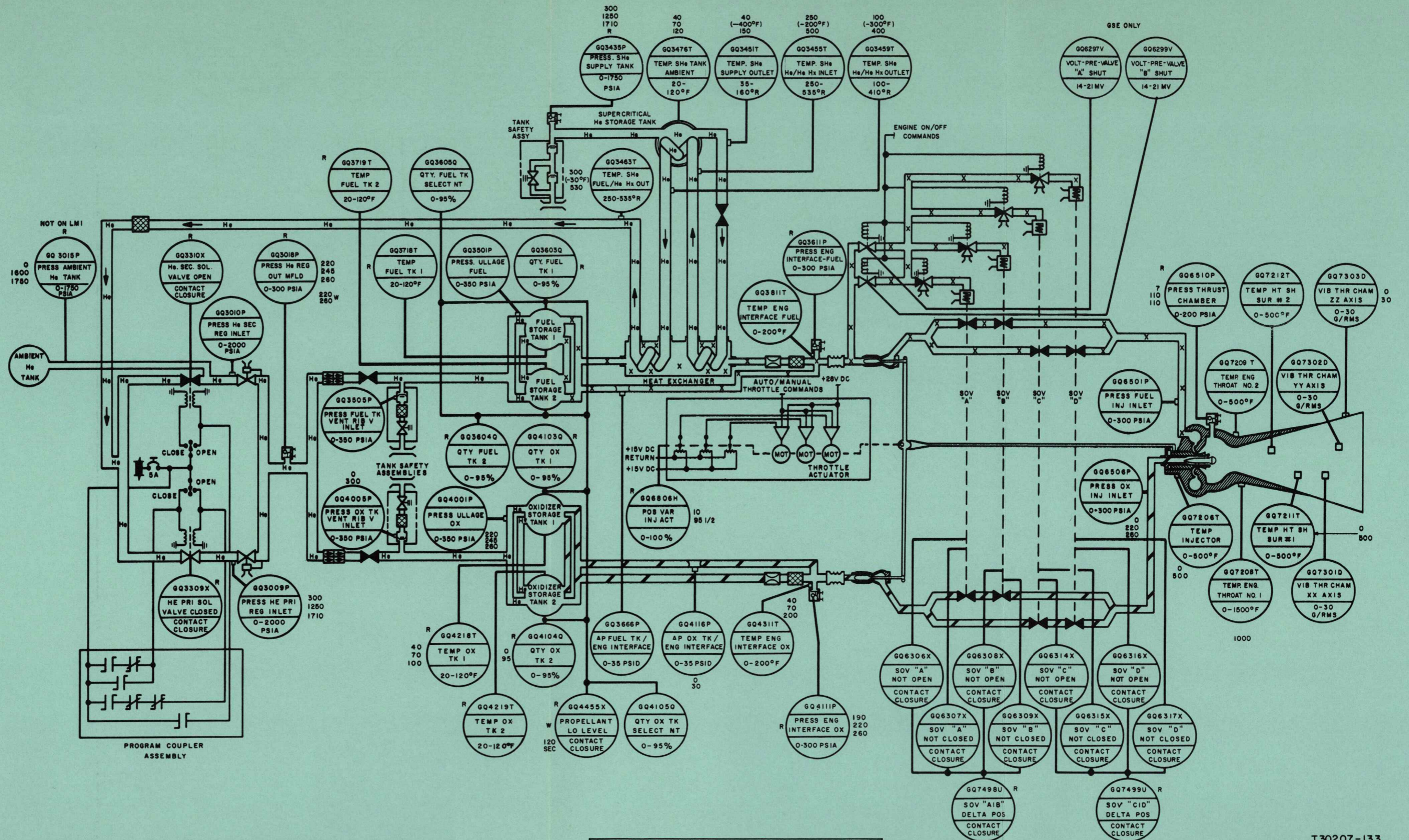
**ASCENT PROPELLANT SYSTEM  
REAL TIME TELEMETRY PICKUPS  
LM 4**

T 30207-135  
SEPT 66





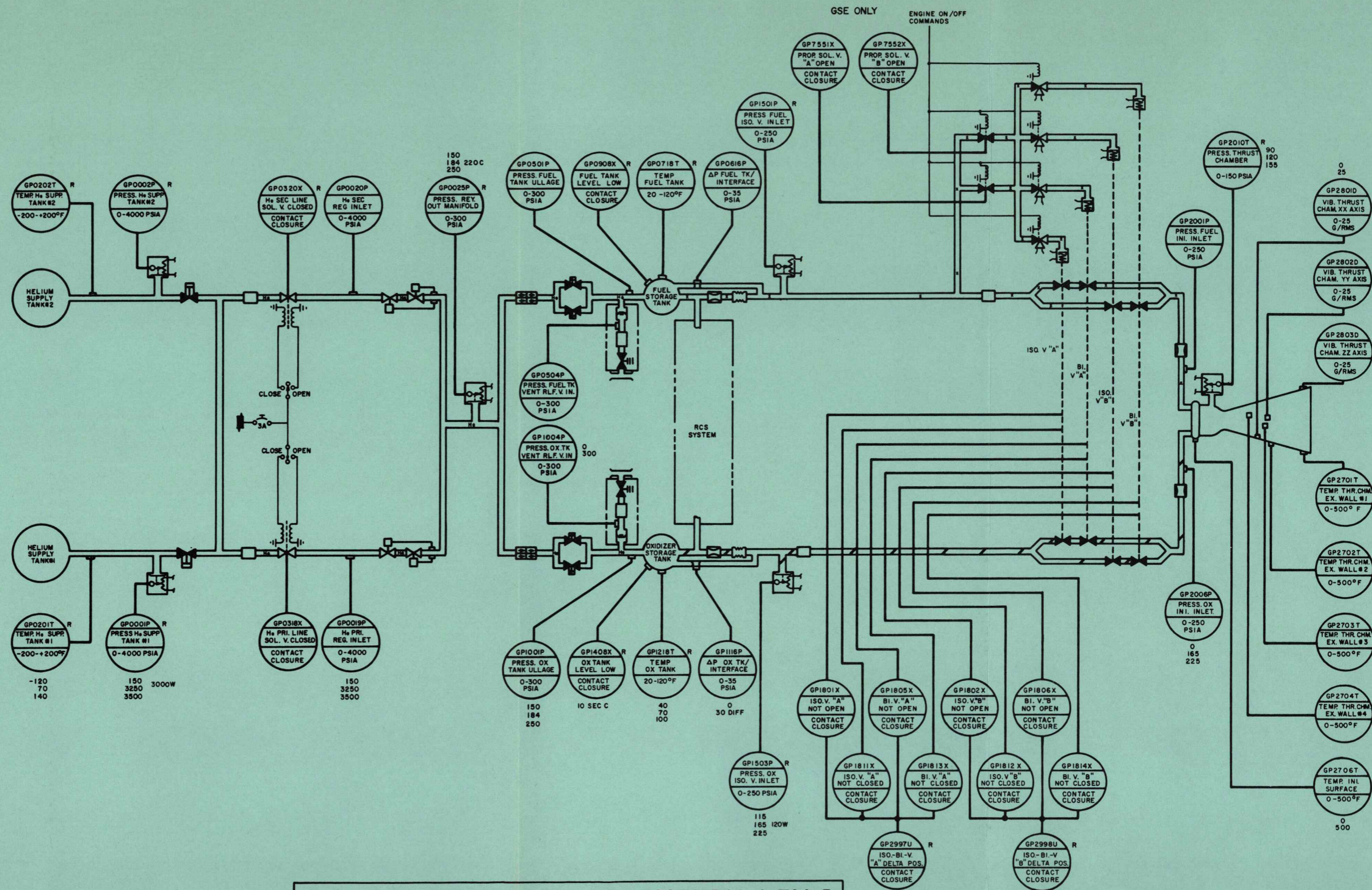




**DESCENT SUBSYSTEM  
TELEMETRY-LEM I**

T30207-133  
APR 67



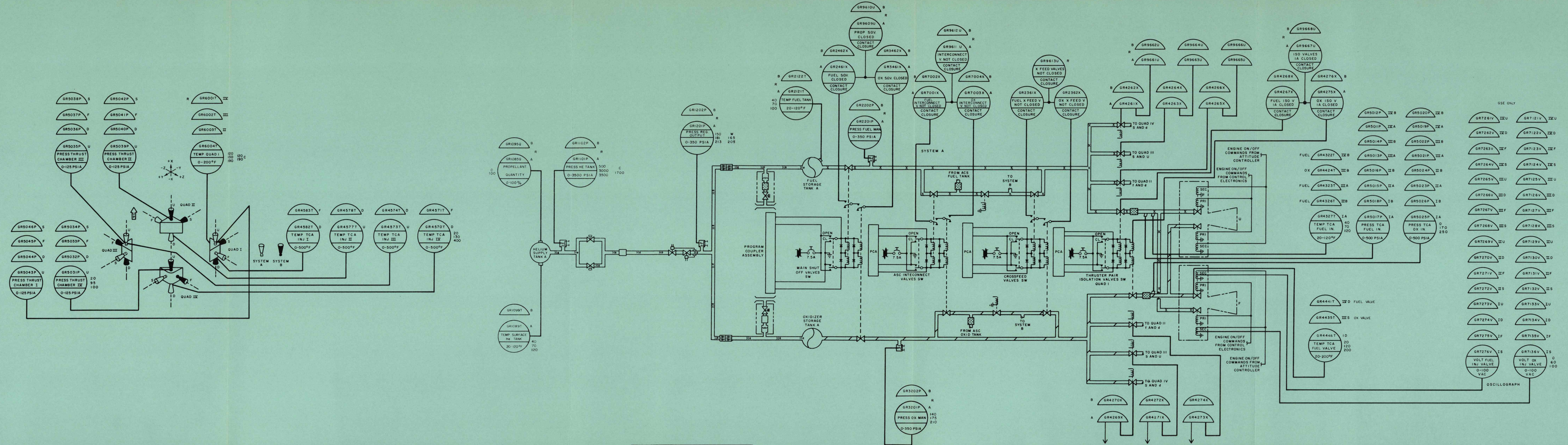


**ASCENT SUBSYSTEM TELEMTRY-LEM I**

Figure 74

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RCS TELEMTRY LEM I

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T 30207-134 APR 67

Figure 75



## Chapter V

### Control Electronics

#### Introduction

(See Figure 76.) The Guidance, Navigation and Control Subsystem provides signals to fire any combination of the sixteen Reaction Control Subsystem engines, and to stabilize the LM during all phases of the mission. These signals control attitude and translation, about or along all axes. They originate in any one of three places: the LM Guidance Computer during automatic operations; the attitude controllers and translational controllers during non-automatic operations; and the Abort Electronics in case of a failure of the LM Guidance Computer.

In addition all commands to the descent engine and the ascent engine, as well as descent engine gimbal commands, are processed by this subsystem.

It is an essential feature of the system that the crew can assume manual control at any time and provide commands that by-pass the automatic circuitry.

#### RCS Engine Control

##### Attitude Control

Attitude control is control around an axis: Yaw, or pitch, or roll. There are five modes of attitude control available, selectable by control panel switches.

##### Automatic Mode

The automatic mode provides fully automatic attitude control of the LM, and is the mode selected at all times, except for hover, landing and docking maneuvers. When this mode is selected attitude error signals originate in the LM Guidance Computer. These signals are processed and selection is made of the RCS engines that will fire to correct the attitude error.

A wide or narrow deadband can be selected. The wide deadband is used during coasting phases of the mission to conserve propellants; the narrow deadband is used whenever main engines are thrusting and accurate attitude control is required.



### Attitude Hold Mode

The attitude hold mode is used for the hover, landing and docking phases of the mission and is semi-automatic. When this mode is selected, attitude change commands may be given by displacing the attitude controller from the neutral position. The rate of change is proportional to the displacement of the controller. When the controller is in the neutral position, signals from the LM Guidance Computer will cause the LM to hold attitude. (See Figure 77.)

### Pulse Mode

The pulse mode is selectable on an individual axis basis and is used in conjunction with the Abort Electronics only. When this mode is selected, pulse signals, at the rate of about two per second, are sent to the RCS engines whenever the attitude controller is out of the neutral detent.

### Direct Mode

The direct mode is also selectable on an individual axis basis and used only in conjunction with the Abort Electronics. When this mode is selected and the attitude controller is moved from the neutral detent a continuous "fire" signal is sent to the direct coils of the RCS engines. The engines will continue to operate "steady state" until the controller is returned to neutral.

### Manual Override (Emergency)

This condition is not selectable on the control panel, but may be activated in any mode selection by displacing the attitude controller to its full travel. It commands continuous operation of the RCS engines through the direct coils.

### Translation Control

Translational control is control along an axis: forwards, backwards, to one side or the other, up or down. Two modes of translational control can be selected: automatic or manual.

### Automatic Mode

Automatic mode commands originate in the LM Guidance Computer. These commands are effective in the "X" (up and down) axis only and are used for LM/Command-Service Module separation and ullage requirements during engine start sequencing. (Provisions may be incorporated to make automatic mode commands effective along other axes as well.)



## Manual Mode

The manual mode is used during the hover, landing and docking maneuvers, and is effective in all three axes. Movement of the translational controller out of the neutral detent with the selector in the "jets" position will send a "fire" command to the RCS engines. (See Figure 78.)

## Direct (Emergency)

This condition is activated by a push button type switch on the control panel and is effective in the "plus X" axis only. It sends continuous "fire" commands to the direct coils of the RCS engines. (See figure 65.)

## Descent Engine Control

### Automatic

Automatic "on-off" commands, throttle commands, and trim commands to the gimbal drive actuators, originate in the LM Guidance Computer. On-off commands may also originate in the Abort Electronics.

### Manual

Manual "on-off" commands originate at control panel switches and manual throttle commands originate at the translational controller. There is no provision for manual trim commands. (See Figures 65, 66 and 78.)

## Ascent Engine Control

### Automatic

Automatic "on-off" commands originate in the LM Guidance Computer or the Abort Electronics.

### Manual

Manual "on-off" commands originate at control panel switches. (See Figures 65 and 66.)



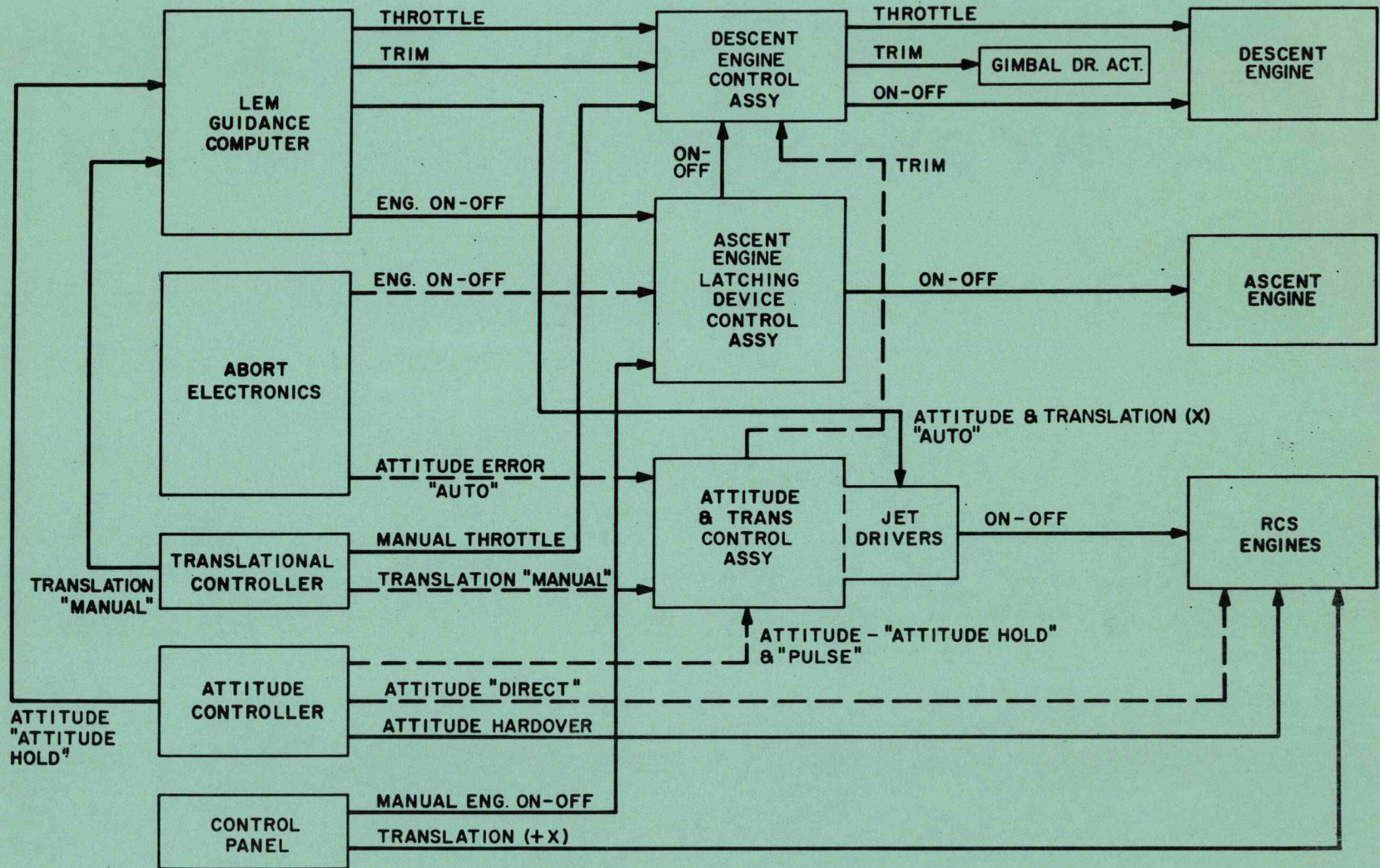
## Summary

The Guidance, Navigation and Control Subsystem interfaces directly with the Descent and Ascent Propulsion Subsystems and the Reaction Control Subsystem. All commands to the rocket engines of these subsystems originate in the GN&CS.

There are four modes of RCS engine attitude control, each serving a definite function in the performance of the mission. Likewise, there are two modes of RCS engine translation control. Manual (emergency) overrides are provided, sending commands directly to the RCS engines, thus by-passing the control electronics.

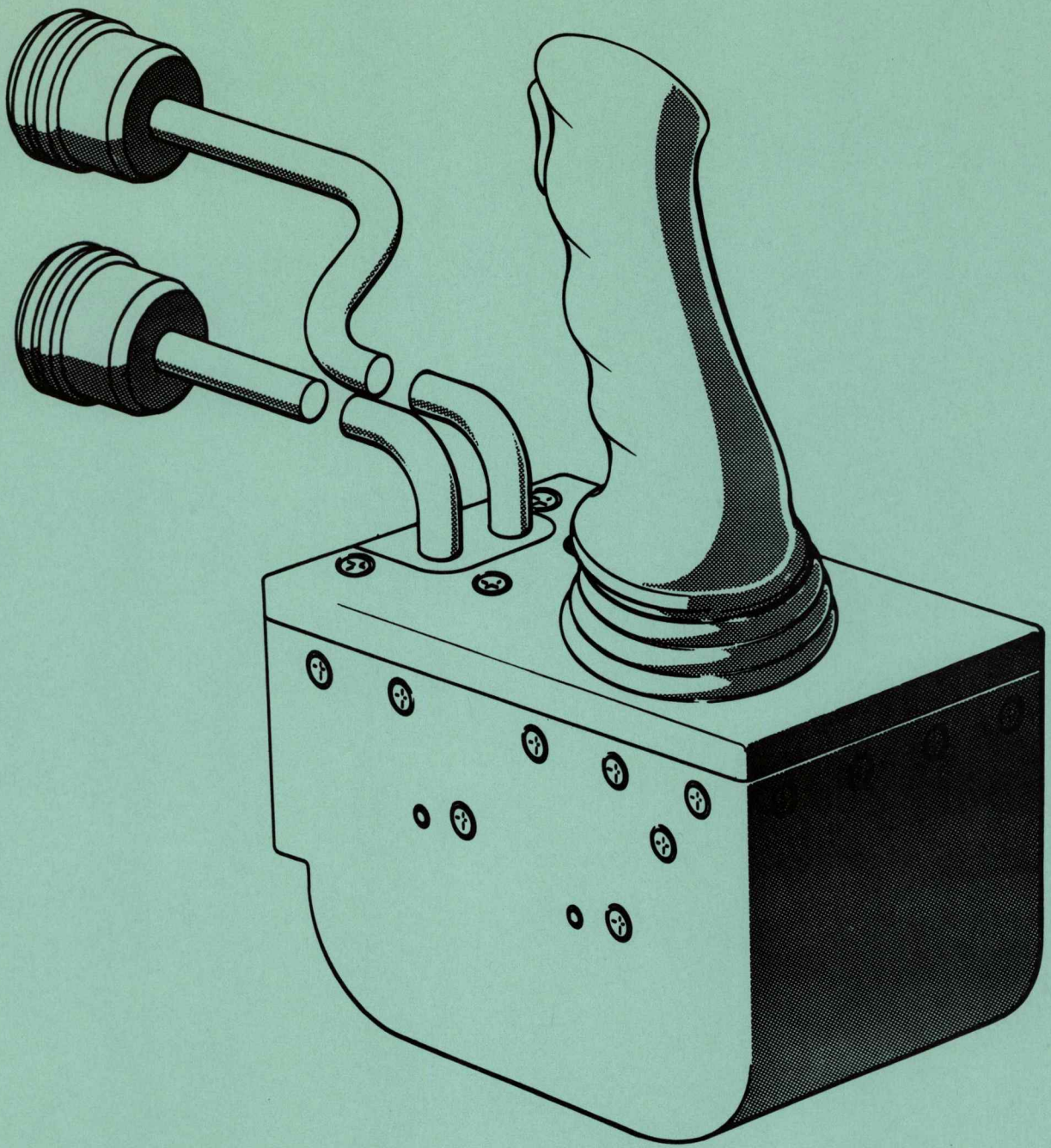
Provision is made for processing the automatic commands to the descent and ascent engines as well as enabling the crew to issue direct manual commands.





CONTROL ELECTRONICS - BLOCK DIAGRAM

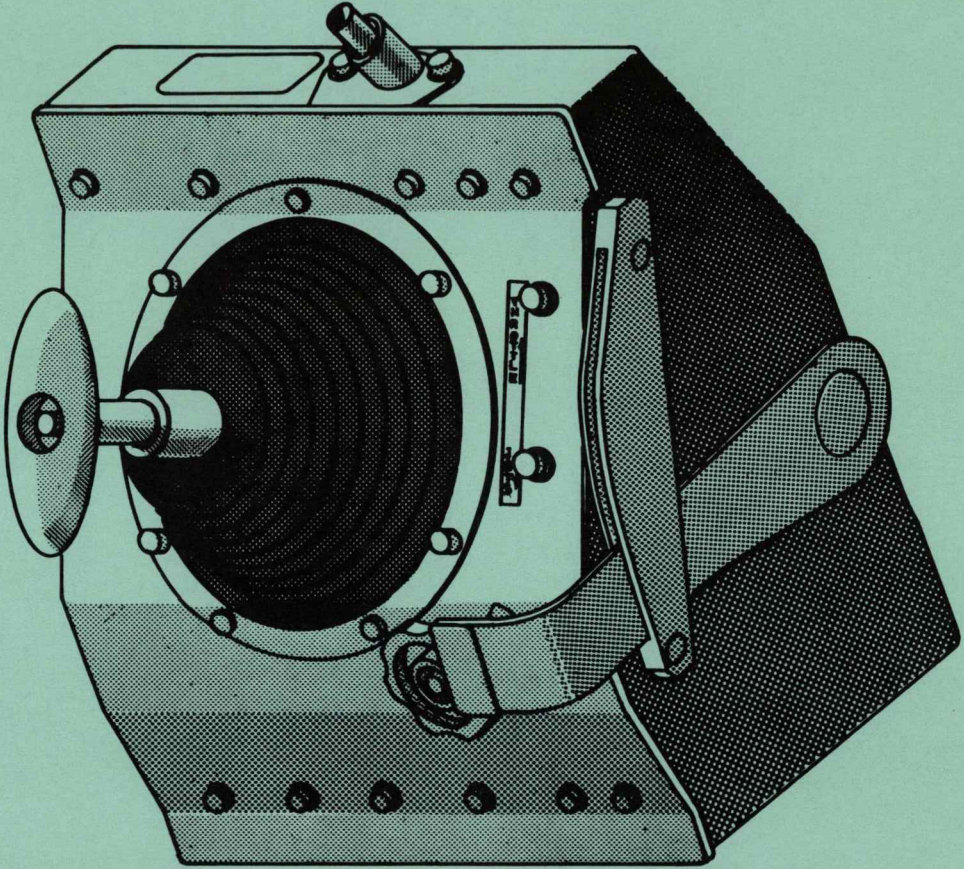




ATTITUDE CONTROLLER ASSEMBLY

T30900-15  
JAN 66





THRUST TRANSLATION CONTROLLER ASSEMBLY

T 30900-14  
OCT 66

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Figure 78



## Chapter VI

### Ground Support Equipment

#### Introduction

The primary goal of pre-launch checkout is to ascertain, on the ground, that the LM will have the maximum probability of achieving its intended mission. To ensure that this goal is reached it must be shown that no malfunctions exist in any of the many systems that make up the LM.

The best method of showing that any given LM system performs properly is to exercise it in as close to the same manner as possible, as it is used in flight. Wherever practical, this method will be used.

However, and particularly in the propulsion and RCS subsystems, a great deal of preliminary testing must be accomplished. The fluid portions of these subsystems must be meticulously tested for integrity under proof pressures. Fluids, both liquid and gaseous, must be loaded into the vehicle tanks and then unloaded. Engines must be operated, and following operation, the entire propellant system must be purged and flushed. These, and other tests, must be performed to ensure the maximum probability of success for the mission and the safe return of the crew.

It is towards this end that many individual items of ground support equipment have been devised and built. As time passes, and experience is gained, some of these items will be deleted and others will be added. The items of Ground Support Equipment listed on the following pages are not intended to be a complete list for propulsion and RCS subsystem checkout; rather, it is intended to be a representative list - to provide the reader with a concept of the large variety of GSE required.

#### Safety

Most of the pre-launch testing required and the handling of associated Ground Support Equipment is not hazardous. In every case, every effort has been expended to make the individual items of GSE as fool proof as possible to minimize any possibility of injury to personnel and/or damage to the GSE and systems under test.

In spite of this, there still remain certain operations which must be considered hazardous. These include any operation involving:



1. The loading of helium tanks or the use of helium or other gas for pressure checking when the pressure is 3000 psi, or over.
2. The loading or unloading of tanks with live propellants or any other operation involving the handling or transfer of live propellants.
3. Engine operation.
4. The purging and flushing of the propellant feed system and/or the engine following engine operation, or the use of live propellants.

Safety involves the observance of suitable precautions. It is a paradox that some of the most dangerous occupations are also the safest, precisely because the hazards are known and respected, and because safety precautions are strictly observed. An incomplete list of precautions would include:

1. Know first aid procedures.
2. Make sure that deluge showers and eye fountains work.
3. Wear protective clothing and/or breathing equipment, as required.
4. Have fire fighting equipment handy. Know what fires you can fight and what fires you cannot.
5. When performing hazardous duties keep the immediate area clear of unnecessary personnel.
6. Observe the "buddy" system. Never work alone.
7. Observe all normal and all special safety precautions.
8. Use common sense.

#### Numbering System

Every item of ground support equipment is numbered. The number consists of 3 digits, a dash, followed by 5 digits.

The first 3 digits indicate the general classification of the GSE:



410 - Electrical

420 - Handling and Transportation

430 - Fluid Support.

Of the last 5 digits, the first digit indicates the system or subsystem with which the GSE is intended to be used:

1. Structures - Landing gear
2. Stabilization and Control
3. Guidance and Navigation - Communications
4. Displays and Controls - Crew Provisions
5. Environmental Control
6. Propulsion - Reaction Control
7. Instrumentation
8. Electrical Power
9. NAA/GAEC Common Items

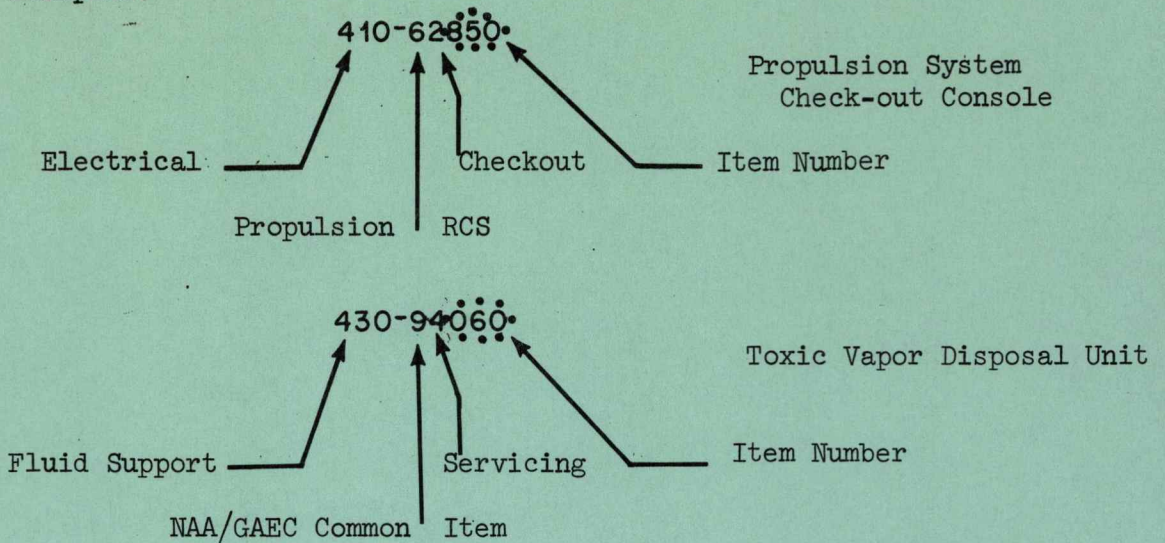
The second digit of the last 5 indicates the purpose for which the GSE is intended:

1. Auxiliary
2. Checkout
3. Handling
4. Servicing

The last 3 digits are unique to that particular piece of equipment.



Examples:



### Handling and Transportation Equipment

Equipment in this classification includes, but is not limited to the following:

Slings. These are required for the descent and ascent engines, as well as for the descent and ascent propellant tanks. Engine slings must be available to lift the engines in either a vertical or a horizontal position. (See Figure 79.)

Handling Dollies. These dollies are required to support the engines propellant tanks when they are being worked on. Engine dollies must be capable of turning the engine from a vertical to a horizontal position for easy accessibility. (See Figure 80.)

Transportation Dollies. These will be used to transport engines over reasonable distances. They will be equipped with large wheels and springs or other shock absorbing mechanism.

Installation Jacks. They will be used to raise the engines and descent propellant tanks into position for installation.

Covers - Plugs. Protective covers are available. Plugs will be used to seal the open ends of propellant lines.

Heavy Duty Equipment. This category includes large dollies, pallets, tractor trucks, semi-trailers, mobile hoists, and even a specially designed aircraft. (See Figure 81.)



Adapters. Adapters are used in the engine test chambers for the mounting of engines and test equipment. They serve a variety of purposes, such as alignment, force and vibration measurements and the support of special fixtures. (See Figure 82.)

### Electrical and Fluid Support Equipment

Equipment in this classification will be listed by part number and name, and a brief description of its function will be given. It is rare when one piece of equipment alone can perform any given function, rather several pieces are generally used together, as a functional set, to perform the task. Although the listing that follows is in a logical sequence, no effort has been made to group the various pieces of GSE into such functional sets, as this would exceed the intended scope of this chapter. It should also be noted that changes of equipment are still being made, therefore, the listing will be neither complete, nor perhaps accurate in its entirety. It is intended only to serve as a representative list of the large variety of GSE needed to accomplish the job.

#### 430-64500 Pressure Maintenance Unit

This is a portable unit that maintains the helium and propellant tanks and feed lines in a clean, dry, pressurized state to prevent contamination, and maintains pressure differentials to prevent collapsing of tanks during air and ground transportation and storage.

#### 430-62170 Propellant Section Check-out Assembly

This unit supplies gaseous nitrogen and freon at regulated pressures to the propellant systems of the LM. It is used for performing external and internal leak tests.

#### 430-62180 Propulsion System Check-out Cart

This unit is also used for performing external and internal leak tests. It supplies either helium or nitrogen to the helium pressurization systems or the propellant systems at regulated pressures. It is capable of supplying very high pressures for proof testing and is usually used in conjunction with a mass spectrometer leak detector.

#### 430-92075 Propulsion Check-out Unit

This common use item has been designed to perform the same functions as the above 430-62180.



#### 430-94022 Helium Booster Cart

This cart is connected between the helium supply source and the helium storage unit. It contains an electrically powered booster pump and boosts supply source pressure to the high pressure required at the storage unit.

#### 430-94062 Helium Storage Trailer

This is an 8 wheeled semi-trailer mounting high pressure gas cylinders and used to transport helium from the supply source. It contains sufficient gas to provide two fillings of all LM helium tanks at rated pressure.

#### 430-94009 Helium Transfer and Conditioner Unit

This unit contains a gas flow control system and heat exchangers. It takes helium from the storage trailer, reduces this pressure to that required for filling the tanks, conditions the helium to the desired temperature, filters it and then supplies it to the distribution unit.

#### 430-64570 Helium Pressure Distribution Unit

This is a unit containing a distribution manifold and 3 fill units: one for the ascent helium tanks and two for the RCS tanks. It monitors the flow and distributes the helium.

#### 430-62160 Ullage Simulation Cart

This cart has the ability to simulate the various ullage volumes of the descent and ascent subsystem fuel and oxidizer tanks. This is a requirement for the helium pressure regulator functional test.

#### 430-6599 Displacement Leak Meter

This is a light portable unit that is capable of accurately measuring the amount of a gas leakage, where a small leakage is allowable. A unit with like ability has been incorporated into the 430-92075 Propulsion Check-out Unit.

#### 430-82720 Helium-Hydrogen Mass Spectrometer Leak Detector

This portable unit is mounted on wheels. It is intended to check a system for minute leaks after the system has been pressurized with



helium gas. A sensing probe is passed over the suspect area and if a leak is present the unit provides both a visual and an audio signal. The sensitivity is high; leakage at the rate of  $1 \times 10^{-9}$  cc/sec. can be detected. (See Figure 83.)

#### 430-1150 Vacuum Cart

This cart has the ability to create a near vacuum. Its principle use is to simulate a space environment at the pressure regulator vent ports for the purpose of selective regulator testing.

#### 430-64200 Supercritical Helium Conditioning Unit

This unit is used for filling and leak checking the supercritical helium tank of the descent propulsion subsystem. The system is capable of local or remote operation. It consists of the following three separate subassemblies:

##### Helium Conditioning Assembly

This unit has separate pre-coolers containing LN<sub>2</sub> and LHe. It takes ambient helium from the facility supply or from the helium storage trailer and chills it. It also supplies helium to pressurize the storage dewar.

##### Fluid Distribution Subassembly

This unit accepts GHe or LHe from the conditioning subassembly and routes it to the vehicle helium tank at a controller pressure and flow rate. It can vent helium from the vehicle tank in an emergency.

#### 430-64200-17 Remote Control Console

This unit provides remote control of the above two fluid GSE subassemblies. It monitors all pressures and flow rates.

#### 430-64210 Liquid Nitrogen Supply Unit

This unit stores liquid nitrogen and supplies it to the Helium Conditioning Subassembly. It also maintains the nitrogen level in the conditioning unit sub-cooler.



430-64260 Helium Storage and Transfer Dewar

This unit is used for the transportation and storage of liquid helium. It has a capacity of 500 lbs. at a max. loss rate of 5% per day. It is pressurized by GHe from the conditioning subassembly and supplies LHe to the conditioning subassembly precooler and, by way of the Distribution Subassembly, to the vehicle helium tank.

430-62190 Supercritical Helium Check-out Test Unit

This unit supports the tests of the super critical helium system. It can supply ambient helium for heat leak tests and purging, and can act as a by-pass around closed valves or burst discs.

430-94058 Ready Storage Unit (Fuel) (Used with Descent and Ascent Subsystems)  
430-94059 Ready Storage Unit (Oxidizer)

These units are storage tanks on wheels. Each has a capacity of 3450 gallons and is used, together with subsequent units, to load and unload propellants. The storage tanks maintain a nitrogen blanket over the propellant to prevent vaporization and contain pumps to pressurize the propellant into the Transfer and Conditioning Unit.

430-94002 Transfer and Conditioning Unit (Oxidizer) (Used with Descent and Ascent Subsystems)  
430-94008 " " " " (Fuel)

These units receive propellant from the storage tanks and condition it to the required temperature for loading into the LM tanks. After conditioning the propellant, it pumps it to the Loading Control Assembly.

430-64430 Loading Control Assembly (Fuel) (Used with Descent and Ascent Subsystems)  
430-64450 " " " (Oxidizer)

These units direct the propellants into the LM tanks at a controlled pressure and rate of flow. They are capable of two fill rates; a normal rate for fast filling to near capacity and a fine rate to be used for topping off the tanks. (See Figure 84.)



430-94060 Vapor Disposal Unit (Fuel)

430-94061 " " " (Oxidizer) (Used with Descent and Ascent RCS Subsystems)

This is a skid mounted unit that processes propellant vapors by an air dilution method and then safely exhausts them into the atmosphere. It is used during propellant loading, unloading and thermal conditioning operations, as well as during propellant system purging.

430-94057 Servicing Unit (Oxidizer)

430-94063 " " (Fuel) (Used with the RCS)

These are multi-purpose, mobile units. They contain tanks with sufficient capacity to service both RCS system propellant tanks. The stored propellant is conditioned to the desired temperature, filtered and then pumped to the Transfer Control Assembly.

430-64230 Transfer Control Assy (Fuel)

430-64240 " " " (Oxidizer) (Used with the RCS)

These units are used to fill the RCS tanks to capacity and to simultaneously vent and maintain the correct pressure on the helium side of the tank bladder for the loading, unloading or ullage requirements.

430-94070 Engine Decontamination Unit

This unit is used to purge and flush the LM propellant systems subsequent to static engine firing. It will heat gaseous nitrogen to the required temperature and direct and control its flow. It will pump a series of flushing fluids through the propellant system at a controlled flow rate and pressure. Operation of the cart is local by means of valves and switches.

430-91146 Adapter Set, Fluid Disposal (RCS)

This is a multi-purpose unit. It is used to seal the throat of the RCS engine so the engine may be static tested for shut-off valve and chamber seal leakage, and, in addition, it can be used to direct residual propellants and flush fluids to a disposal system during the decontamination procedure. The set includes sixteen individual adapters. (See Figure 85.)



#### 430-62040 Scavenging Assembly (RCS)

This assembly is used in conjunction with the previously described RCS Fluid Disposal Adapter Set. Prior to the decontamination procedure the adapters are installed in each of the 16 RCS engines. The Scavenging Assembly interfaces with these adapters, collects residual propellants and flush fluids, and manifolds them to a waste disposal system. (See Figure 86.)

#### 430-62010 Injector Flow Sensor Unit (RCS)

This is a light weight, portable unit that will be used to confirm RCS thruster orifice integrity after fluid flow tests. It will be inserted into the nozzle end of each engine and will sense the impact pressure of a gas flow through each orifice of the injector. This pressure will be transmitted to an ACE, or equivalent readout.

#### 420-63420 Descent Engine Plug Assy.

This assembly is used to stopper the throat of the descent engine for leakage tests. It incorporates a pressure seal, a support and locking mechanism, and a relief valve. Manual operation is required to actuate the locking mechanism.

#### 420-63120 Ascent Engine Plug and Support

This unit is used to stopper the throat of the ascent engine for leakage tests. The plug is composed of expandable rubber and attached to a telescoping tube, which in turn is attached to a box type support. Mechanical operation is required to expand the plug in the engine throat. (See Figure 87.)

#### 410-62850 Propulsion Subsystem Check-out Station

This check-out station may be used in conjunction with the fluid check-out carts to perform end-to-end electrical and functional testing of the propulsion subsystems. It supplies primary power and all combinations of input stimuli, and scans outputs between pre-set "go"/"no-go" limits. The switching logic is such that inadvertent activation of a mode that would be dangerous to personnel or detrimental to the equipment is not possible.



## Part No. 410-64130 Fluid Distribution System Valve Box Controller

The fluid distribution system valve box controller is a manually operated portable electrical control and monitoring unit used with the following propulsion and RCS subsystem fluid distribution valve boxes: Propellant Loading Control Assembly (Fuel), Part No. 430-64430; Propellant Loading Control Assembly (Oxidizer), Part No. 430-64450; Helium Pressurization Distribution Unit, Part No. 430-64570, RCS Fuel Transfer Control Assembly, Part No. 430-64230; and RCS Oxidizer Transfer Control Assembly, Part No. 430-64240. The valve box controller controls and monitors the position of as many as 30 valves; monitors 9 transducer outputs (6 continuously, three on a time-shared basis); controls facility power to the controlled unit; provides indications of operating status and valve box purge pressure. Manually operated switches control valve positions, panel lamps indicate valve positions and event signals, and panel meters provide temperature and pressure indicators.

## 410-62050 Pyrotechnic Initiator Test Set

This is a self-powered, portable meter used to verify the integrity of squib valve igniter bridge wires prior to installation in the vehicle. Testing is non-destructive. The Test Set measures resistance and detects shorts and open circuits.

## 410-62220 Engine Firing Control Station (Used with Descent and Ascent Subsystems)

This control station is used to fire the descent or the ascent engines during sea level or simulated altitude static tests. It provides manual control when used alone, or automatic control when used in conjunction with an Engine Programmer. The switching logic is such that activation of a mode that would be dangerous to personnel or detrimental to the equipment is impossible. Emergency stop capabilities are provided.

## 410-62740 RCS Firing Control Station

This control station is used to fire the RCS engines. Its functions precisely parallel those of the preceding control station.

## 410-62800 Computer Tape Processor (Engine Programmer)

This unit is used in conjunction with the preceding two firing control stations. It automatically controls the static firing of the descent, ascent and RCS engines through a timed sequence of operations in simulated mission profiles.



## Acceptance Checkout Equipment - Spacecraft

The Acceptacne Checkout Equipment - Spacecraft (ACE-S/C) is a general-purpose spacecraft checkout system for automatic, semi-automatic or manually controlled prelaunch testing of the LM system. Its capabilities include generation of test commands and stimuli, monitoring spacecraft subsystem performance, conversion and processing of data, measurement of subsystem responses to test stimuli, diagnostic testing, and enabling communication between the LM and personnel at ACE-S/C controls. The ACE-S/C consists of an ACE-S/C Ground Station; ACE-S/C Carry-On Equipment, and ACE-S/C Peripheral Equipment.

The ACE-S/C Ground Station is adapted to specific LM subsystems by the ACE-S/C Carry-On Equipment, and to the LM servicing equipment by the ACE-S/C Peripheral Equipment. The ACE-S/C Carry-On Equipment comprises an Up-Link and a Down-Link. The Up-Link receives, decodes, conditions, and converts digital test commands from the ACE-S/C Ground Station and routes them to the proper input points of the subsystems undergoing test. The Down-Link monitors the performance of the LM subsystems, and conditions, codes, and multiplexes this data for transfer to the ACE-S/C Ground Station.

The following units are required to carry out the above listed capabilities:

410-11990	Ground Station - ACE
410-92241	Command System, Digital, Service Equipment
410-92240	Adapter, ACE, Servicing Equipment
410-92232	Data Interleaving System
410-92484	Signal Conditioning Unit
410-92200	Receiver and Baseplate Unit
410-92201	Command Unit, Carry On
410-92210	PCM System, Carry On
410-92211	Condition/Multiplexer, Digital Signal, Carry On
410-92212	Conditioner, Sampler, Analog Signal, Carry On
410-92213	Conditioner, Switching Matrix, G/N Signal, Carry On
410-11180	Switching Control Unit
410-12731	Junction Box, Carry On

### Summary

The highest possible reliability factors are built into all the subsystems and components of the LM. Continuous checking and testing, right up to the time of launch, as well as the performance of all necessary servicing will ensure the success of the mission. The accomplishment of this task is the function of Ground Support Equipment.



Testing and servicing the LM propulsion and RCS subsystems often includes the use of high pressure gas and the handling or transfer of live propellants. These are hazardous operations and the proper safety precautions must be observed to avoid injury to personnel and damage to equipment.

A numbering system is used to classify and identify individual units of GSE. An understanding of this system will make it possible to rapidly determine the general classification, the subsystem with which it will be used, and the general function of any given item of Ground Support Equipment.

General equipment classifications are: handling and transportation; electrical; and fluid support. Handling and transportation equipment includes such items as slings, dollies, jacks, covers, etc. These are generally items of a comparatively simple, mechanical nature. Their use does not require specialized knowledge or training.

Electrical and fluid support equipment, on the other hand, is generally of complex design and its use does require specialized knowledge and training. Some units can perform just one task; others can perform more than one; and in many cases the performance of the task requires that several units be utilized in conjunction with each other.

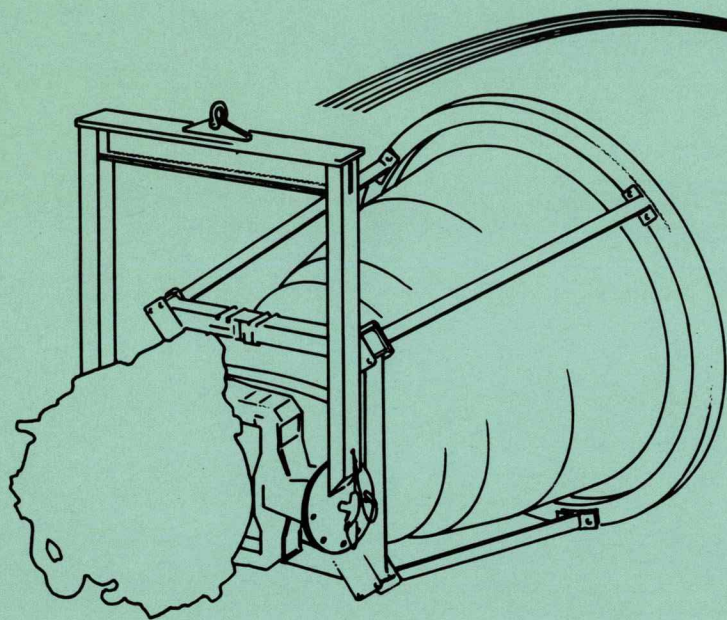
The Acceptance Checkout Equipment (ACE) may be used for Test Command generation and subsystem performance monitoring. Only those units pertinent to the Propulsion Subsystems and the RCS are listed, and, because of the complexity and nature of the equipment, no effort to describe its functions in detail is attempted.

A thorough understanding of each item of GSE will enable it to be used safely and effectively.

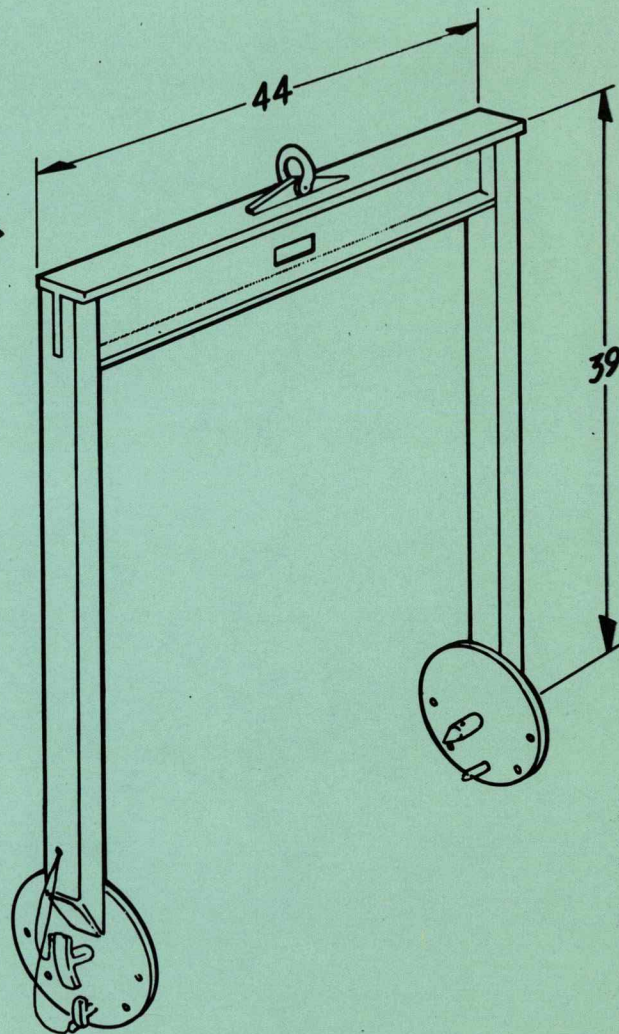


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Figure 79



DESCENT ENGINE  
TURNOVER SLING

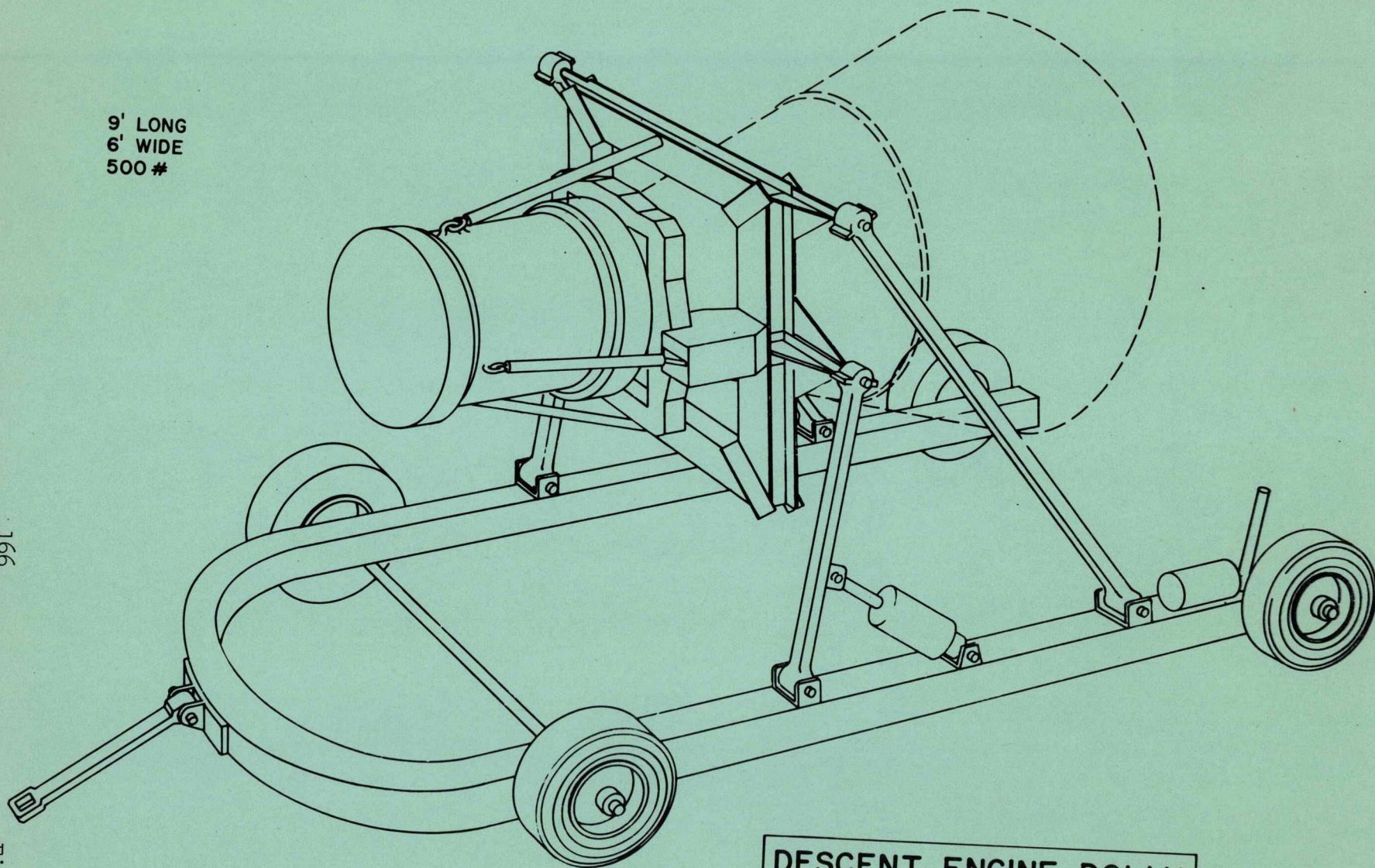


T30207-83  
AUG 65



OBSOLETE

9' LONG  
6' WIDE  
500 #



DESCENT ENGINE DOLLY

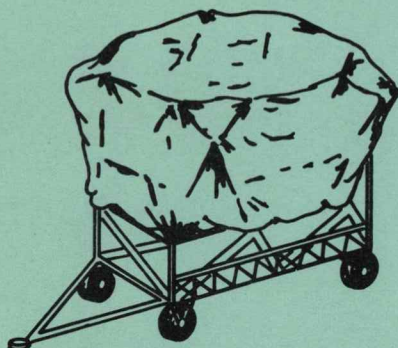
FOR TRAINING PURPOSES ONLY

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Figure 80

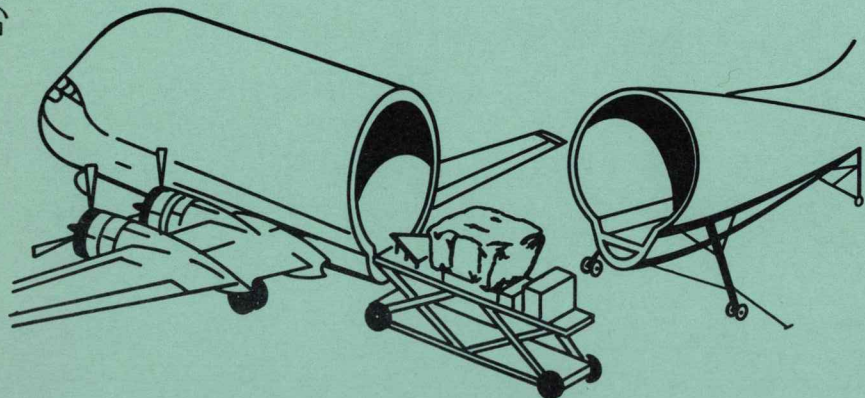
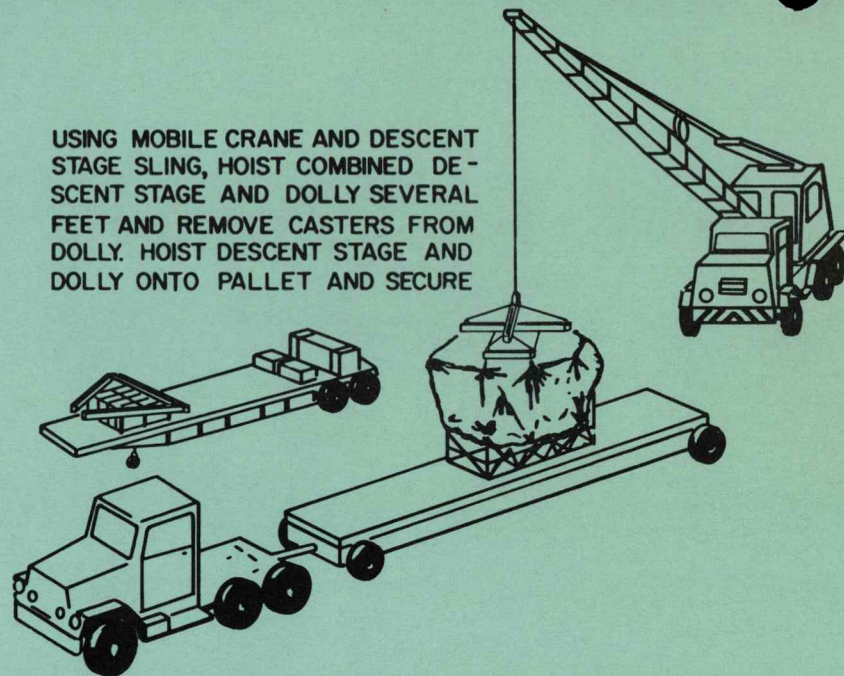
T30207-85  
SEPT 65



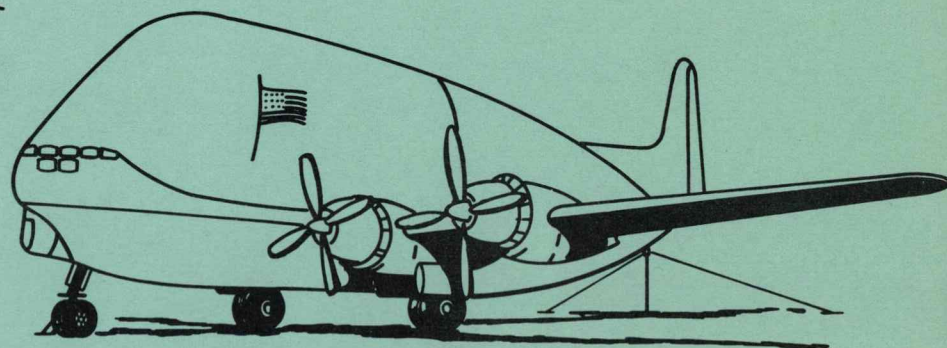


PREPARE DESCENT STAGE FOR AIR SHIPMENT

USING MOBILE CRANE AND DESCENT STAGE SLING, HOIST COMBINED DESCENT STAGE AND DOLLY SEVERAL FEET AND REMOVE CASTERS FROM DOLLY. HOIST DESCENT STAGE AND DOLLY ONTO PALLET AND SECURE



RAISE CLT TO HEIGHT OF AIRCRAFT DECK. PALLET IS THEN WINCHED INTO AIRCRAFT FROM CLT. PALLET IS SECURED IN AIRCRAFT.



AIRCRAFT TAIL SECTION ALIGNED WITH FORWARD SECTION AND IS SECURED WITH INTEGRAL DEVICES.

**B-377 PG AIRCRAFT LOADING**

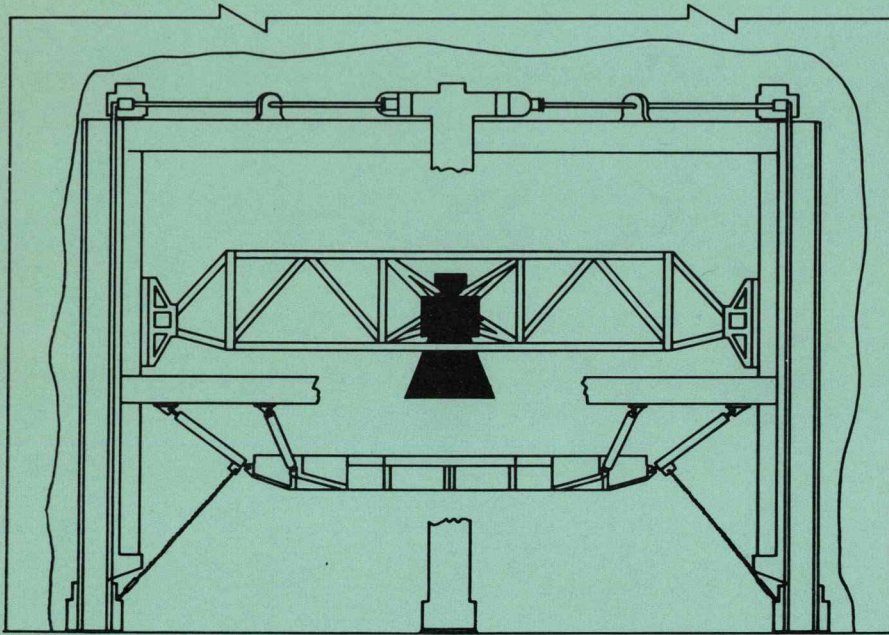


OBSOLETE

FOR TRAINING PURPOSES ONLY

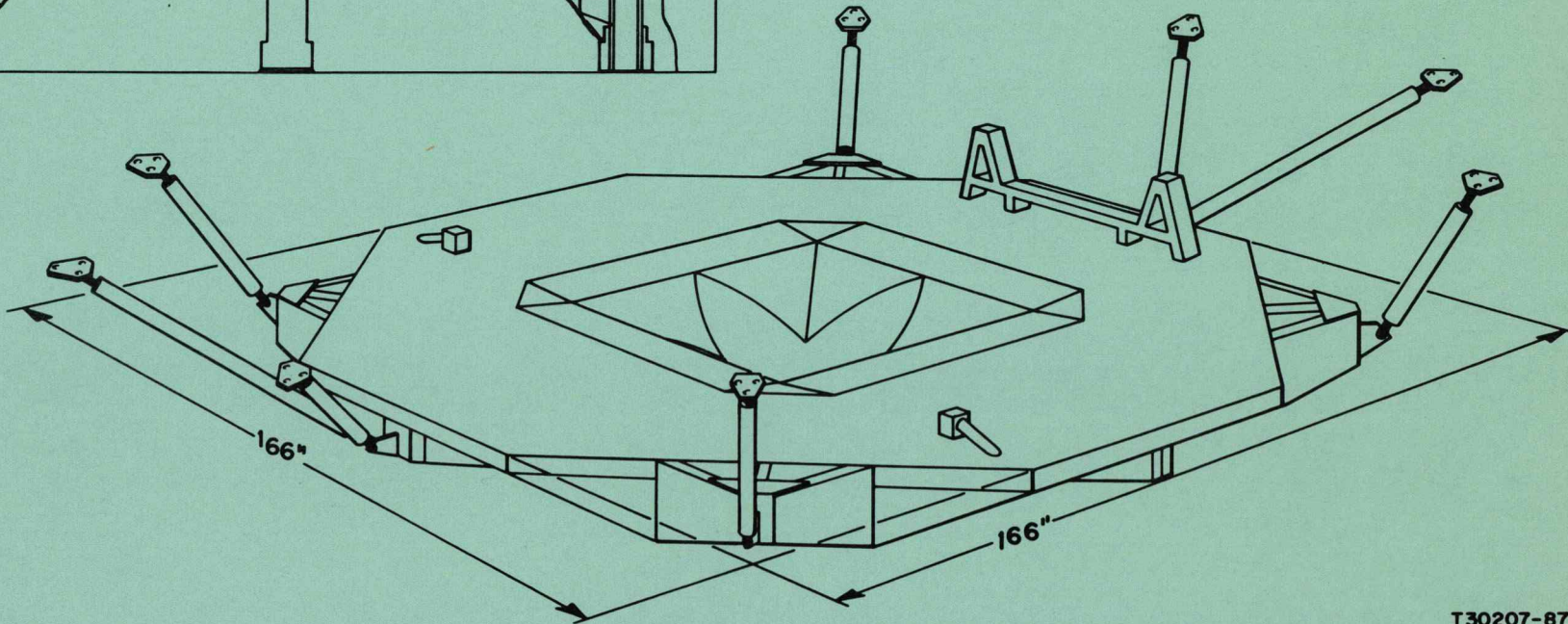
168

Figure 82

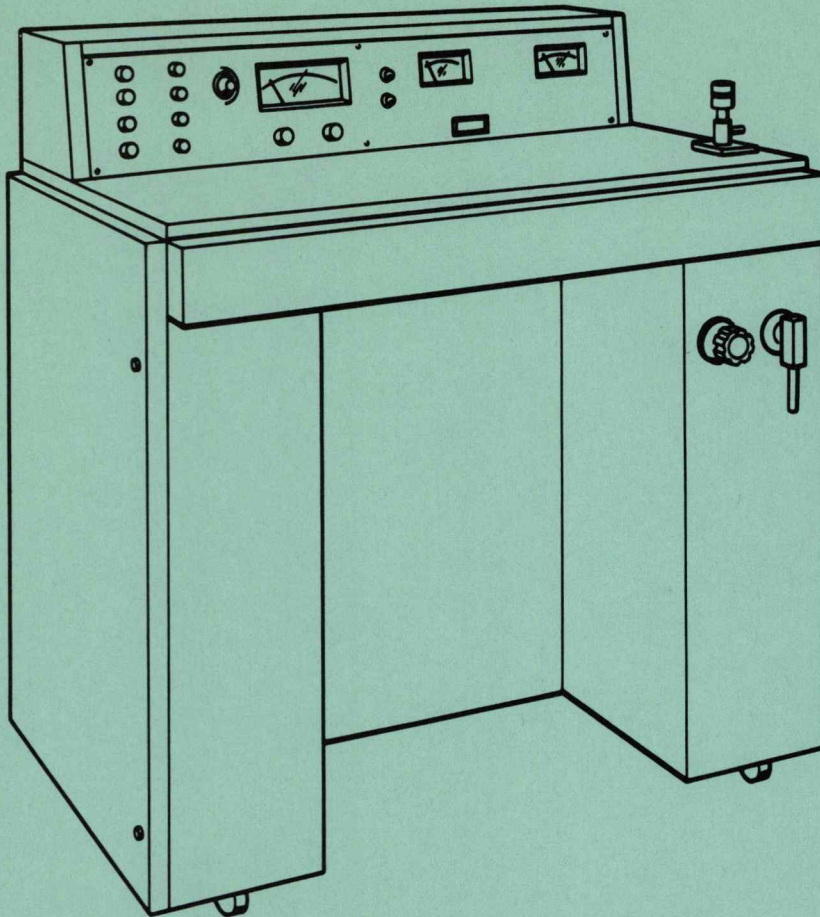


**FIRE-IN-THE-HOLE ADAPTER**

WEIGHT 1500#







HEIGHT 40"  
WIDTH 26"  
DEPTH 28"  
WEIGHT 310 LBS.

**HELIUM-HYDROGEN LEAK DETECTOR  
430-82720**

**HALOGEN AND HELIUM LEAK DETECTORS**

T30207-92  
FEB 67

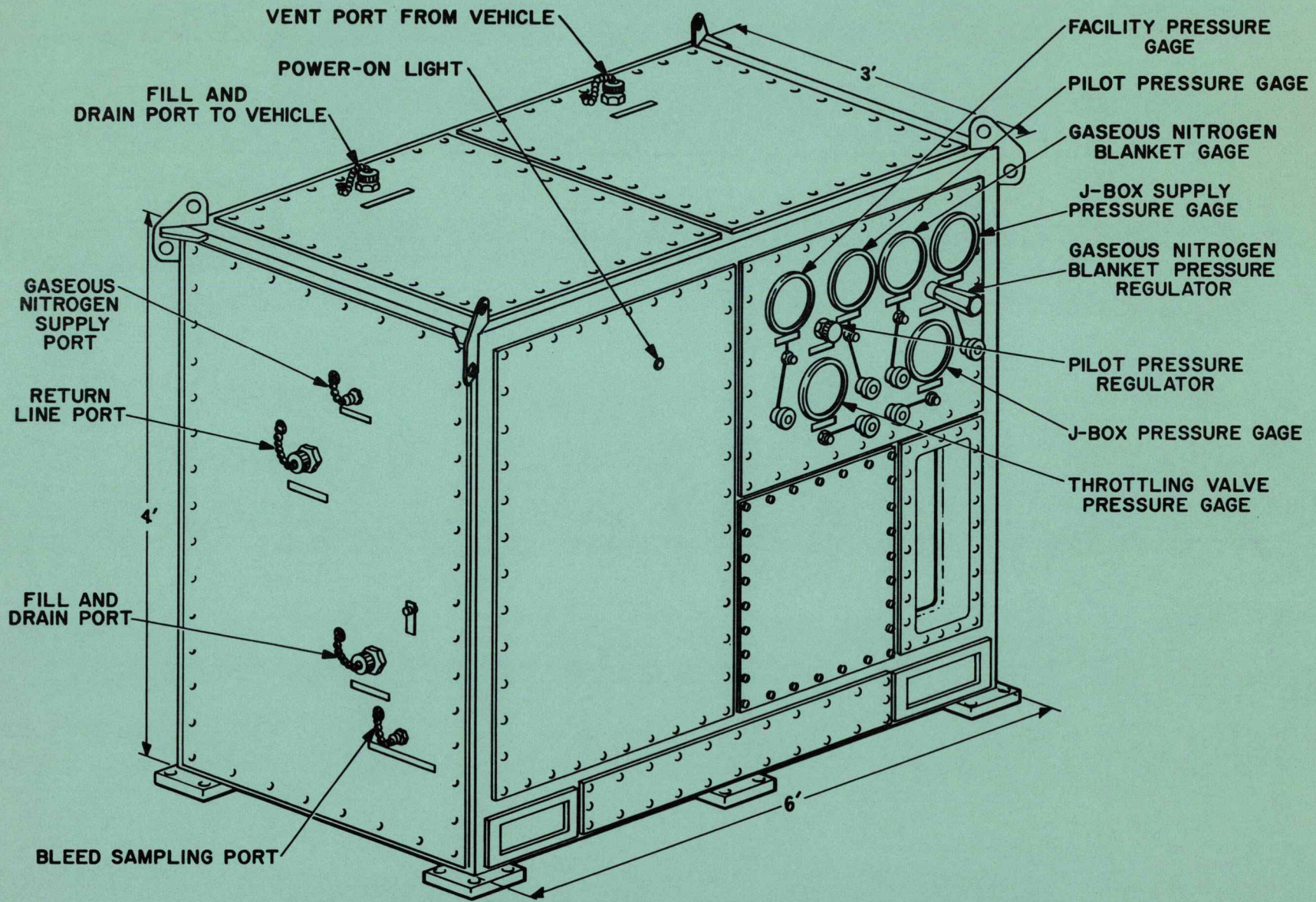


OBSOLETE

FOR TRAINING PURPOSES ONLY

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Figure 84



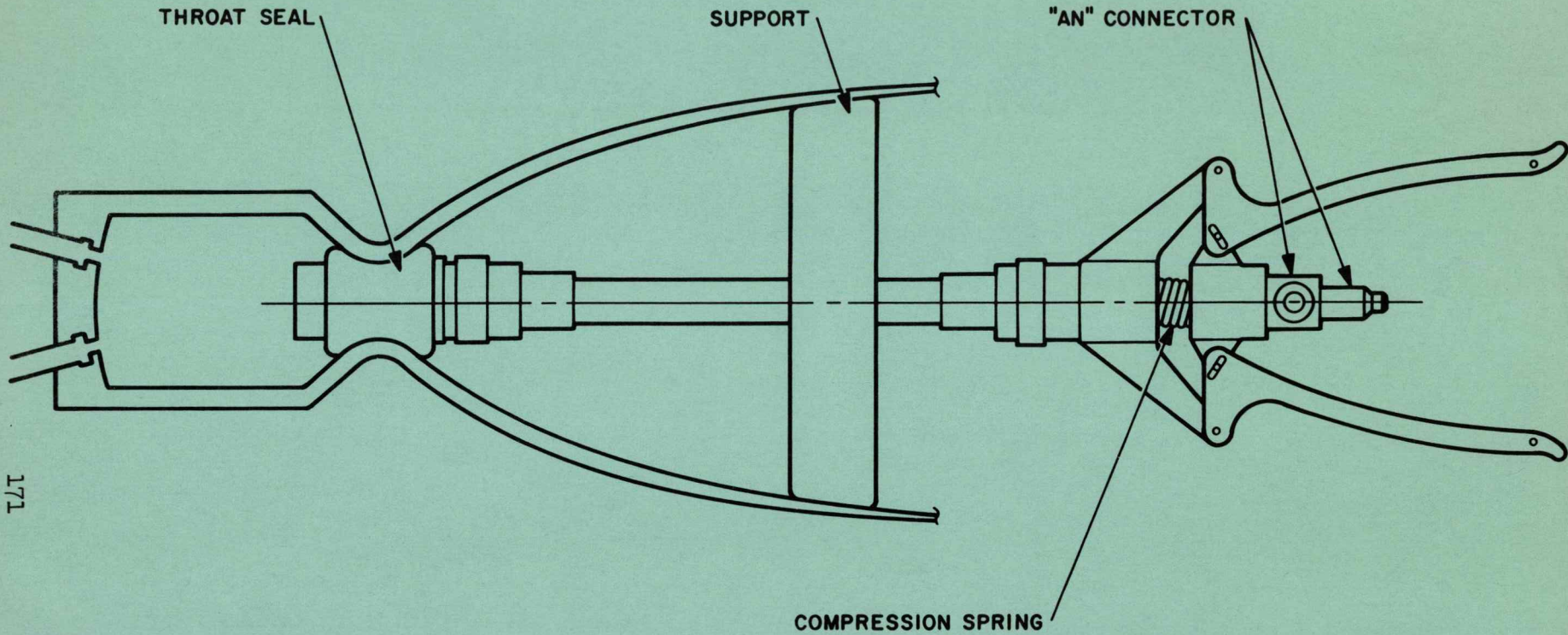
**PROPELLANT LOADING CONTROL ASSEMBLY**



OBSOLETE

FOR TRAINING PURPOSES ONLY

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RCS ENGINE THROAT PLUG AND FLUID DISPOSAL ADAPTER

Figure 85

T30207-116  
FEB. 66

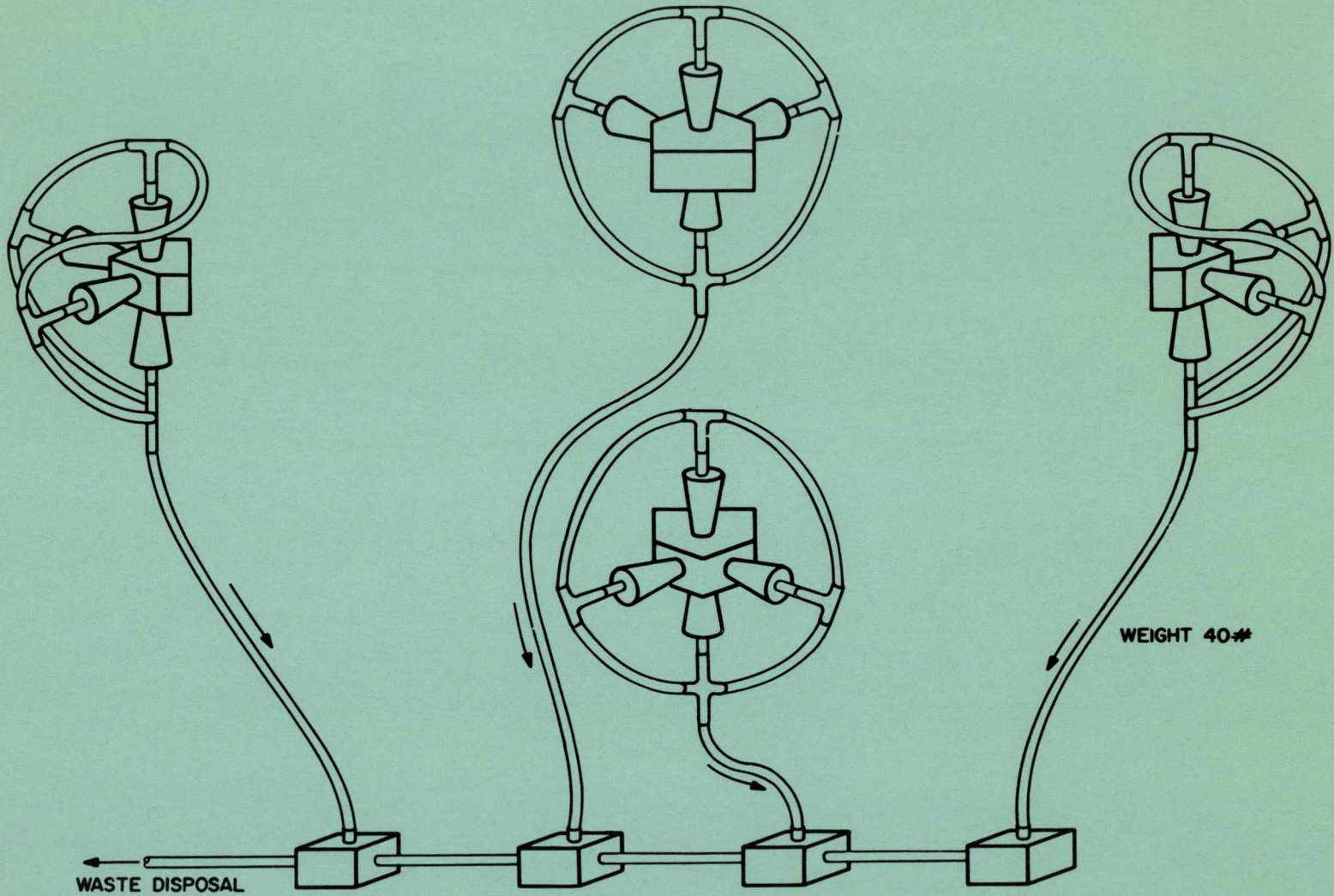


OBSOLETE

FOR TRAINING PURPOSES ONLY

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Figure 86



SCAVENGING ASSEMBLY R.C.S.  
430-62040

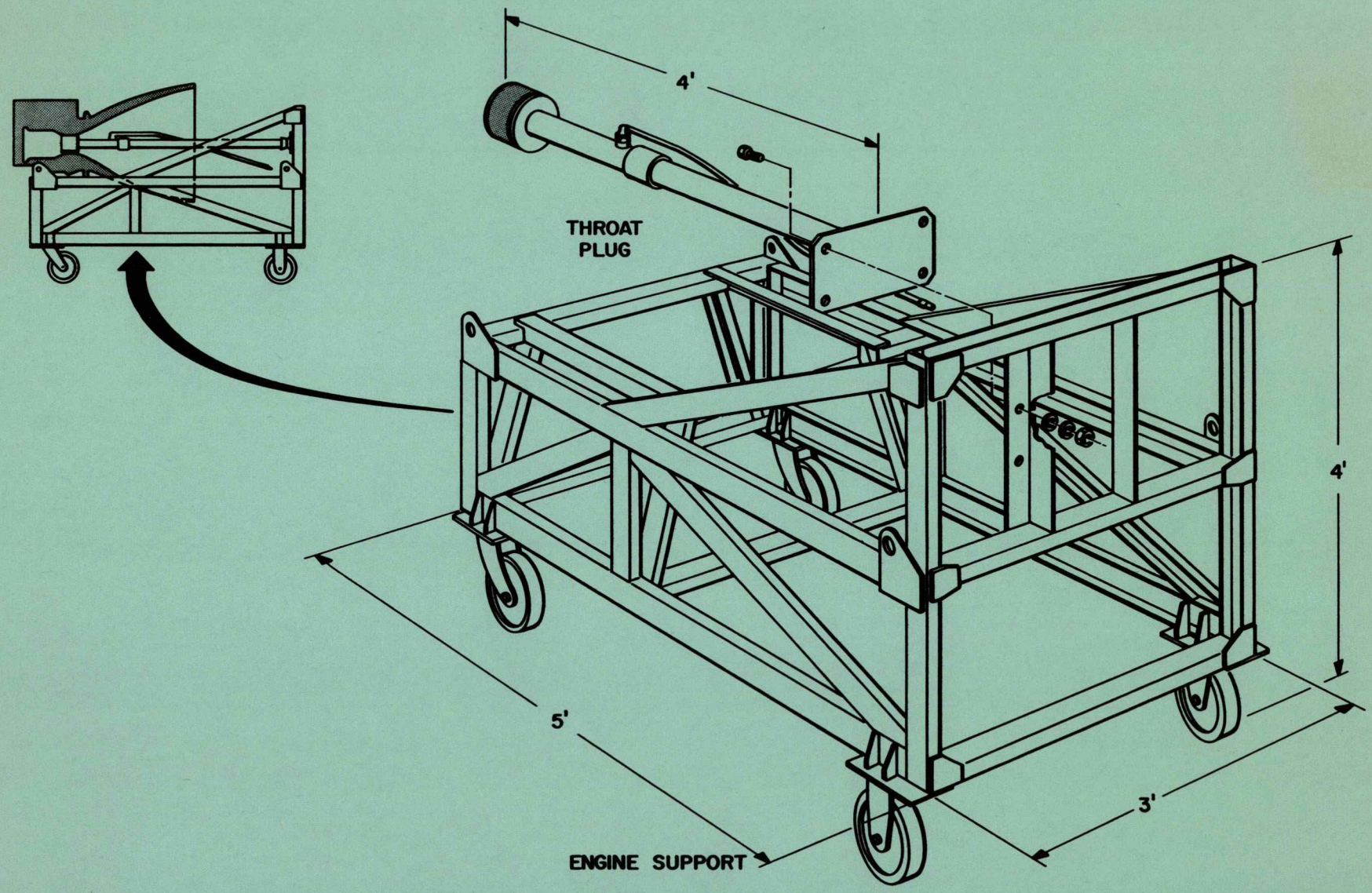
T30207-102  
AUG 65



OBSOLETE  
FOR TRAINING PURPOSES ONLY

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Figure 87



ASCENT ENGINE THROAT PLUG

T30207-93  
AUG 65