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Supplement 3

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

APOLLO 11 MISSION REPORT

PERFORMANCE OF THE COMMAND AND SERVICE MODULE REACTION CONTROL SYSTEM

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MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
DECEMBER 1971

Evaluation of spacecraft body rates indicates normal RCS performance throughout the flight.

A total of 560 pounds of SM RCS propellant was used during the mission. The predicted usage was 590 pounds. The secondary fuel-tank helium-isolation valves (VW valves) on all quads were opened prior to CM-SM separation although an empty primary tank had not been indicated by a drop in the fuel manifold pressure. An estimate for the total number of firings for the 16 SM RCS engines is 40 000.

Thermal control of the SM RCS was satisfactory throughout the flight. The maximum temperature reached because of boost heating was 152° F on quad B. The primary heaters on all quads were activated shortly after insertion and remained on for the remainder of the mission. During times of low engine activity, the primary heaters maintained the package temperature between 119° and 146° F. The SM RCS helium tank temperatures ranged from 52° to 97° F.

Both manual and automatic control were used during entry. Approximately 65 seconds after CM-SM separation, system 2 was deactivated, and the remainder of the entry was performed using system 1 only. Evaluation of the spacecraft body rates indicates normal CM RCS performance with the exception of the yaw engine. This engine did not respond to automatic commands but performed normally with manual, or direct coil, commands. During postflight investigation, the problem was traced to a faulty terminal board connector. (See "Anomalies" section of this report.)

A total of 41 pounds of CM RCS propellant was used for entry. The remaining 205 pounds were burned through the engines during the depletion burn following main parachute deployment. The time line of the depletion burn and purge operation is not available because of the failure of the onboard recorder used to record data during entry.

The CM RCS helium tank temperatures remained between 56° and 72° F prior to system activation. The instrumented CM RCS injectors were approximately 50° F at all times and the CM valve warmup procedure was not required.

INTRODUCTION

Apollo 11 was the fifth manned Apollo mission, the fourth manned Saturn V mission, the third manned LM mission, and the first manned lunar landing mission. Lift-off occurred at 13:32:00.6 G.m.t. on July 16, 1969, and the mission duration was approximately 195 hours. The spacecraft

PERFORMANCE OF THE CSM RCS DURING THE AS 506/CSM 107/LM 5 MISSION (APOLLO 11)

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SUMMARY

This report is published as Supplemental report no. 3 to the Apollo 11 mission report.

The Apollo 11 vehicle was launched from Kennedy Space Center (KSC) launch complex 39A at 13:32:00.6 Greenwich mean time (G.m.t.) on July 16, 1969. The command module landed in the Pacific Ocean recovery area at 16:50:35 G.m.t. on July 24, 1969.

The service module (SM) and the command module (CM) reaction control system (RCS) performed satisfactorily throughout the mission. Two anomalies which occurred were an inadvertent isolation valve closure during command and service module/Saturn S-IVB/lunar module (CSM/S-IVB/LM) separation and a failure of a CM thruster to respond to automatic commands. The isolation valves were later opened by the crew and remained open during the remainder of the mission. The cause of the closure has been determined to be the shock loads generated during separation. The CM engine malfunction was caused by a faulty terminal board connector. All system parameters were normal during the mission, and all mission requirements were satisfied.

The SM and CM RCS propellant loading was completed on June 22, 1969, and helium loading was completed on July 11, 1969. Approximately 18 pounds of oxidizer (9 pounds per system) were off loaded from the CM RCS. This was to prevent raw oxidizer from contacting the parachutes and risers during the propellant dump operation. Static firing of the SM RCS engines on the pad was not performed.

The SM RCS helium pressurization system maintained the helium and propellant manifold pressures constant at approximately 180 psia. No helium or propellant leakage was detected from the SM RCS during the mission.

FIGURES

TABLES

CONTENTS

MSC-00171
Supplement 3

APOLLO 11 MISSION REPORT

SUPPLEMENT 3

PERFORMANCE OF THE COMMAND AND SERVICE MODULE REACTION CONTROL SYSTEM

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landed in the Pacific Ocean at 16:50:35 G.m.t. on July 24, 1969. The crew consisted of Neil Armstrong, Commander; Michael Collins, Command Module Pilot; and Edwin Aldrin, Lunar Module Pilot.

This was designated as a G-type mission. The primary purpose was to perform a manned lunar landing and return. The major spacecraft events during the mission are listed in the following 12 periods of activity:

1. Launch to Earth Orbit
2. Translunar Injection
3. Translunar Coast
4. Lunar Orbit Insertion
5. Lunar Module Descent
6. Lunar Landing Site
7. Lunar Surface Operations
8. Lunar Module Ascent
9. Transearth Injection
10. Transearth Coast
11. Entry and Recovery
12. Post Landing Operations

There were no detailed test objectives (DTO's) involving the CSM RCS on this mission. Most of the DTO's dealt with lunar surface characteristics and are covered in detail in the Mission Requirements Document, "G" Type Mission, Lunar Landing.

SERVICE MODULE RCS FLIGHT PERFORMANCE

System Configuration

A schematic of the SC 107 SM RCS is shown in figure 1, and a view of the helium pressurization and propellant system on the interior side of quad panels B and D is shown in figure 2. Quads A and C are mirror images of quads B and D. The relative locations of the quads within the SM are shown in figures 3(a), 3(b), 3(c), and 3(d). The SM RCS quad engine package is shown in figure 4, and a cross section of the engine is shown in figure 5.

A summary of vehicle changes from SC 101 to SC 108 is presented in table I.

Instrumentation

The SC 107 SM RCS instrumentation list is shown in table II. Instrumentation locations are shown in figures 1, 2, 3, and 4.

Caution and Warning System

The SC 107 SM RCS caution and warning switch limits and redlines are shown in table III. None of these limits were exceeded during the mission.

Prelaunch Activity

The SM RCS fuel (MMH) was loaded on June 18, 1969, and the oxidizer (N_2O_4) was loaded on June 22, 1969. Helium servicing of the SM quads was accomplished on July 11, 1969. A detailed breakdown of propellant and helium servicing is shown in table IV. No helium or propellant leakage was detected prior to launch. The SM RCS was not static fired on the launch pad.

Flight Time Line

A listing of the times of major SM RCS events and activities of interest during the mission is given in table V. Due to a lack of data, several of the times are approximate.

Propulsion Performance

Table VI shows the velocity change obtained from several SM RCS translation maneuvers. The velocity change was calculated by summing the impulse of the four +X translation engines and then subtracting the summed impulse of the -X translation engines which were required for attitude control during the translation. Engine-on times, obtained from the bilevel data, and the average values for the RCS engine thrusts were used for this calculation. These data are compared with the measured velocity changes as calculated from the SC accelerometer (PIPA) data in table VI. The control mode used for the maneuvers is also shown in table VI.

Table VII identifies the angular accelerations achieved during various RCS control maneuvers. The effect of center-of-gravity offset, cross coupling, and propellant slosh can be seen in this tabulation.

Although the data were not available for this mission, previous flight data indicate that the magnitude of the pitch rates during +pitch maneuvers was consistently higher than those during the -pitch maneuvers for identical vehicle masses. This was caused by the location of the CSM umbilical, directly above the -X/-P engine on quad C as shown in figure 6. This resulted in an effective force reduction of approximately 20 percent based on theoretical calculated values as well as the rate data. All other rates indicate nominal performance by all 16 SM RCS engines throughout the mission.

Helium Pressurization System

The SM RCS helium pressurization systems for the four quads functioned normally throughout the flight. Following helium servicing and prior to the first SM RCS engine firings, the regulators maintained lockup of approximately 195 psia. This is approximately 15 psi higher than the specification value for lockup pressure. This is because the regulators are referenced to atmospheric pressure while on the pad as opposed to the vacuum of deep space. At first SM RCS usage, during CSM/S-IVB/LM separation, the manifold pressures decreased to normal regulated pressures and remained constant at 182 ± 7 psia for the duration of the flight. Helium source temperatures and pressures for the four quads during the flight are shown in figures 7 and 8. Preflight checkout data for selected SM helium system components are shown in table VIII.

Propellant Feed System

With the exception of one anomaly, the SM RCS propellant feed system functioned normally throughout the mission, and no indication of propellant leakage was noted. During CSM/S-IVB/LM separation the primary and secondary propellant isolation valves on quad B inadvertently closed. This is discussed later in the "Anomalies" section of this report. The valves were opened by the crew approximately 25 seconds after separation and remained open for the duration of the mission.

Opening of the VW valves in the pressurization line to the secondary propellant tanks was intended to take place when the fuel manifold pressure decreased from 180 psia to 150 psia. However, this did not occur since sufficient propellant was not consumed to deplete the primary fuel tank in either of the four quads. All four VW valves were opened approximately 3 hours prior to CM/SM separation to assure that propellant would be available for the SM jettison maneuver.

Engines

All performance data indicate proper engine performance during the mission. Because of a lack of complete data coverage, it is impossible to determine the exact values for total engine burn time and total number of pulses. However, a rough estimate based on the weight of propellant consumed is 1500 seconds total burn time and 40 000 total pulses. This does not include the SM jettison burn since propellant consumption data are not available after separation.

Thermal Control

The SM RCS thermal control system (TCS) performed satisfactorily throughout the mission. The SC 107 TCS checkout data are shown in table IX.

The spacecraft was launched with the engine package heaters "Off" on all four quads. The primary heater system on each quad was activated at approximately 00:14:00 g.e.t., shortly after orbital insertion. The maximum quad package temperature attained as a result of boost heating was 152° F on quad B, as shown in figure 9. The Apollo 11 launch trajectory is shown in figure 10.

The activation of the primary heaters on quads A and C can be seen in figure 9 as a sudden discontinuity in the temperature-time plot at approximately 00:14:00 g.e.t. The primary heaters of quads B and D did not come on at this time because the primary-heater thermostats on quads B and D are located near the upfiring (-X) engine. The aerodynamic heat input to the engine package from launch is primarily through the upfiring and two roll engines. Therefore, the thermostats on quads B and D were warmer than the temperature indicated on the quad package temperature sensor. The thermostats were evidently warm enough to prevent heater operation when the switches were placed in the "Primary" position. Conversely, the primary thermostats on quads A and C, which are located near the downfiring (-X) engines, were cooler than indicated by the package temperature sensors, and did not reach a temperature at which they would open. The heaters on quads A and C, therefore, came on when the switches were placed in the "Primary" position.

During the mission the TCS operated normally, and except for periods of high engine activity, the heaters cycled normally between 119° and 146° F. A comparison of the primary-thermostat switching limits observed during the flight with preflight checkout data is shown in table X. Because of a lack of complete data coverage, detailed cycling information is not available.

The SM RCS helium tank temperatures are shown in figure 8. The temperatures ranged from 53° to 97° F, primarily depending on vehicle orientation.

Propellant Utilization and Quantity Gaging

The total propellant consumption and the predicted consumption are shown in figure 11(a). During the transposition and docking maneuvers, the actual usage exceeded the predicted usage by approximately 50 pounds. However, at the end of the mission, the predicted usage exceeded the actual usage by approximately 30 pounds. Most of this difference came during the CSM/LM docking period.

The propellant usage for each quad is shown in figure 11(b). The maximum mismatch in propellant expended between the quads was maintained within 40 pounds by selectively varying combinations of one; two-and four-jet roll maneuvers and two-and four-jet translation maneuvers.

The SM RCS propellant quantity was determined by two methods during the flight. The PVT ground computer program utilized pressure, volume, and temperature considerations and was available only on the ground. The P/T sensor, which gives propellant quantity as a function of helium tank pressure and temperature, was displayed in the vehicle in terms of percent full scale of a 0 to 5 voltmeter, as well as being telemetered.

The PVT program was assumed to be the correct value for propellant expended. The quoted accuracy of this program is ± 6 percent due to instrumentation inaccuracies of the inputs to the program, oxidizer-to-fuel (O/F) ratio shift, and the differential between helium tank and propellant ullage temperature. The output of the P/T sensor was designed to read 100 percent when the helium tank pressure was 4150 psia at 70° F and 0 percent when the pressure was 2250 psia at 70° F. The correct theoretical value of helium tank pressure at propellant depletion is 2450 psia at 65° F. To correct the P/T sensor readings for this end-point error as well as for compressibility effects, system temperature variability, and propellant-vapor pressure effects, the nomogram shown in figure 12 was used. Figure 11(b) shows the relation between the propellant expended as derived from the PVT program as well as from the corrected P/T sensor readings.

COMMAND MODULE RCS FLIGHT PERFORMANCE

System Configuration

A schematic of the SC 107 CM RCS is shown in figure 13. This system has not been changed since SC 104 and differs from the SC 101 and SC 103 configurations only in the location of the low-pressure-helium manifold pressure transducer. The location was changed from downstream of the check valves in both the fuel and oxidizer manifolds to upstream of the check valves. This negates the possibility of determining which propellant was depleted first during the depletion burn since the transducer is now in the common manifold between the two tanks and the regulators. A typical CM RCS engine is shown in figure 14.

Instrumentation

The SC 107 CM RCS instrumentation list is shown in table XI. Instrumentation locations are shown in figure 13. No CM RCS instrumentation anomalies occurred during the Apollo 11 mission.

Caution and Warning System

The SC 107 CM RCS caution and warning switch limits are shown in table XII. None of these limits were reached during the mission.

Preflight Activity

The CM RCS fuel (MMH) was loaded on June 18, 1969, and the CM RCS oxidizer (N_2O_4) was loaded on June 22, 1969. A total of 245.9 pounds of propellants was loaded in the two systems. Helium servicing of the CM RCS was accomplished on July 11, 1969. A detailed breakdown of propellant and helium servicing per system is shown in table XIII.

Approximately 9 pounds of oxidizer were off loaded from each CM RCS system to prevent raw oxidizer from contacting the parachutes and risers during the propellant depletion burn operation following entry. No leakage was observed prior to launch.

Flight Time Line

A listing of the times of major CM RCS events and activities of interest during the mission is given in table XIV. Much of the CM time line is not available due to the failure on the onboard recorder used to record CM data during entry.

Propulsion Performance

Table XV lists the measurable SC accelerations for all CM maneuvers for which data are available. Approximately 5 minutes after deactivating system 2, the crew determined that the -yaw thruster was producing near zero thrust in response to automatic coil commands. Proper response was restored, however, when using the direct coils activated by the rotation hand controller. Operation in this mode provided 2-engine control authority although system 2 circuit breakers were open. As discussed in the "Anomalies" section, the valve failure was traced to a faulty terminal board connector in the circuit for the automatic coil of the oxidizer valve. All other data indicate nominal CM RCS performance.

Both manual and automatic control were used during entry. Both systems were active at CM-SM separation; however, system 2 was deactivated approximately 65 seconds later at 194:50:25 g.e.t. The remainder of the entry was made using system 1 only.

Helium Pressurization System

The CM RCS pressurization system functioned normally throughout the flight. The system temperatures and pressures from launch through system activation are shown in figure 15. Throughout this time period the helium manifold pressures remained essentially constant, indicating no system leakage. The system 1 helium manifold pressure ranged from 83 to 88 psia and system 2 from 86 to 88 psia.

The CM RCS was activated at 194:16:23 g.e.t., approximately 33 minutes before CM-SM separation. The helium-isolation squib valves operated normally at system activation. The behavior of both systems at activation is shown in figure 16. The initial helium tank pressure drop at activation for system 1 was approximately 720 psia and for system 2 was 770 psia. After thermal stabilization the pressure decrease for systems 1 and 2 was 580 psia and 610 psia, respectively. Postflight inspection verified that the relief-valve burst disks were not ruptured at activation.

At activation, the fuel and oxidizer tank pressures for both systems locked up at 295 ± 2 psia and the regulators maintained this pressure range through the active firing portion of the entry.

The CM RCS helium source pressures and temperatures from CM-SM separation through the active portion of entry are shown in figure 17. The helium source pressures and manifold pressures during the propellant depletion burn and helium purge operations are not available due to a loss of data associated with the failure of the onboard recorder. No CM RCS helium system leakage was noted following systems activation. Selected preflight checkout data for CM RCS helium pressurization system components are shown in table XVI.

Propellant System

The propellant system functioned normally throughout the flight. No propellant leakage was noted at any period. The propellant isolation valves were opened prior to systems activation.

Engines

All data indicate proper engine performance during the entry. Although data are not available to determine total engine-on time and total number of pulses, an estimate of 120 seconds and 750 pulses was made based on total propellant consumption and previous experience. This is exclusive of the steady-state propellant depletion burn which lasted approximately 60 seconds.

Thermal Control

The CM RCS helium tank temperatures ranged between 56° and 72° F from launch through system activation, as shown in figure 15. The six instrumented CM RCS engine injector temperatures, read by the crew on the onboard meter, remained approximately 50° F (upper limit of the meter) from launch through CM RCS activation. Consequently, the CM RCS valve warmup procedure, which was to be used if any injector fell below 28° F, was not required.

Propellant Utilization

As shown in figure 18, a total of 41 pounds of CM RCS propellant was used prior to the propellant depletion burn. Figure 18 is based on PVT calculations and is not continuous because of a lack of complete data coverage during entry. The occasional negative slope of the propellant expended curve is due to the thermal transients in the system after periods of high usage.

SPACECRAFT DEACTIVATION

On July 26, 1969, the vehicle arrived at Ford Island, Hawaii, at which time deactivation procedures were begun. Although a small amount of helium pressure remained in the oxidizer system, essentially no propellants were found in the CM RCS during deactivation. The postflight examination revealed that the CM RCS relief-valve burst disks were not ruptured and the protective covers were still intact. Also, all engine, helium, fuel, and oxidizer panels appeared to be in good condition with no visible anomalies.

ANOMALIES

Service Module Propellant Isolation Valve Closure

The propellant isolation valves on quad B of the SM RCS closed during command and service module separation from the S-IVB. A similar problem was encountered on the Apollo 9 mission. Tests after Apollo 9 indicated that a valve with normal magnetic latch forces would close at shock levels as low as 87g with an 11-millisecond duration; however, with durations in the expected range of 0.2 to 0.5 millisecond, shock levels as high as 670g would not close the valves. The expected range of shock is 180g to 260g.

Two valves of nominal latching force (7 pounds) were selected for shock testing. It was found that shocks of 80g for 10 milliseconds to shocks of 100g for 1 millisecond would close the valves. The latching forces for the valves were reduced to 5 pounds, and the valves were shock tested again. The shock required to close the valves at this reduced latching force was 54g for 10 milliseconds and 75g for 1 millisecond. After completion of the shock testing the valves were examined and tested, and no degradation was noted.

A review of the checkout procedures indicates that the latching force can be degraded only if the procedures are not properly implemented, such as by the application of reverse current or ac voltage to the circuit. On Apollo 12 a special test has indicated that the valve latching force had not been degraded.

Since there is no valve degradation when the valve is shocked closed and the crew checklist contains precautionary information concerning these valves, no further action is necessary.

Command Module RCS Engine Automatic Coil Failure

The -yaw engine in CM reaction control system 1 produced low and erratic thrust in response to firing commands through the automatic coils of the engine valves. The engine performed normally when fired using the direct coils, as verified by spacecraft rates.

Electrical continuity through at least one of the parallel automatic coils in the engine was evidenced by the fact that the stabilization and control-system driver signals were normal. This, along with the fact that at least some thrust was produced, indicates that one of the two valves was working normally.

During checkout at the launch site, another engine had failed to respond to commands during the valve signature tests. The problem was isolated to a faulty terminal board connector. This terminal board was replaced, and the systems were retested satisfactorily. Because of this incident and because of the previous history of problems with the terminal boards, these connectors were a prime suspect.

Postflight tests showed that two pins in the terminal board (fig. 19) were loose and caused intermittent continuity to the automatic coils of the engine valve. This type failure has been noted previously on terminal boards manufactured prior to November 1967. This board was manufactured in 1966.

The intermittent contact was caused by improper clip position relative to the bus-bar counterbore. This results in loss of some side force, which precludes proper contact pressure against the bus bar. A design change to the base gasket was made to positively ensure that the bus bar is correctly positioned.

The location of pre-November 1967 terminal boards had been determined from installation records and it has been determined that none are in circuits which would jeopardize crew safety. No action will be taken for Apollo 12.

CONCLUSION

It is concluded that the CSM RCS performed satisfactorily in all respects during the Apollo 11 mission.

TABLE I.- SERVICE MODULE RCS CONFIGURATION CHANGE SUMMARY

Parameter	AS 205 CSM 101	AS 503 CSM 103	AS 504 CSM 104	AS 505 CSM 106	AS 506 CSM 107	AS 507 CSM 108
Auxiliary helium-pressurization valve upstream of secondary fuel tank	No	No	Yes	Yes	Yes	Yes
Capability to electrically isolate individual SM RCS engines	No	Yes	Yes	Yes	Yes	Yes
Cabin display of SM RCS helium tank temperature	No	Yes	Yes	Yes	Yes	Yes
Primary tank outlet temperatures measured	Yes	No	No	No	No	No
Secondary heater thermostats range (77° ± 7° F to 104° ± 14° F) switch limits	Yes	Yes	Yes	No	No	No
Secondary heater thermostats range (120° ± 5° F to 129° ± 5° F) switch limits	No	No	No	Yes	Yes	Yes
Panel insulation multilayer aluminized mylar encapsulated with H-film	Yes	No	No	No	No	No
Panel insulation multilayer aluminized H-film	No	Yes	Yes	Yes	Yes	Yes
Look-angle blankets installed	No	Yes	Yes	Yes	Yes	Yes

TABLE II.- SERVICE MODULE RCS INSTRUMENTATION LIST

Measurement number	Parameter	Telemetry (a)	Cabin display	Response, S/S	Data range
SR5001P	Helium tank pressure, quad A	PCM+	Yes	1	0 to 5000 psia
SR5002P	Helium tank pressure, quad B	PCM+	Yes	1	0 to 5000 psia
SR5003P	Helium tank pressure, quad C	PCM+	Yes	1	0 to 5000 psia
SR5004P	Helium tank pressure, quad D	PCM+	Yes	1	0 to 5000 psia
SR5013T	Helium tank temperature, quad A	PCM+	No	10	0 to 100° F
SR5014T	Helium tank temperature, quad B	PCM+	No	10	0 to 100° F
SR5015T	Helium tank temperature, quad C	PCM+	No	10	0 to 100° F
SR5016T	Helium tank temperature, quad D	PCM+	No	10	0 to 100° F
SR5025Q	Propellant quantity, quad A	PCM+	Yes	1	0 to 100 percent
SR5026Q	Propellant quantity, quad B	PCM+	Yes	1	0 to 100 percent
SR5027Q	Propellant quantity, quad C	PCM+	Yes	1	0 to 100 percent
SR5028Q	Propellant quantity, quad D	PCM+	Yes	1	0 to 100 percent
SR5065T	Package temperature, quad A	PCM	Yes	1	0 to 300° F
SR5066T	Package temperature, quad B	PCM	Yes	1	0 to 300° F
SR5067T	Package temperature, quad C	PCM	Yes	1	0 to 300° F
SR5068T	Package temperature, quad D	PCM	Yes	1	0 to 300° F
SR5729P	Helium manifold pressure, quad A	PCM+	Yes	10	0 to 400 psia
SR5776P	Helium manifold pressure, quad B	PCM+	Yes	10	0 to 400 psia
SR5817P	Helium manifold pressure, quad C	PCM+	Yes	10	0 to 400 psia
SR5830P	Helium manifold pressure, quad D	PCM+	Yes	10	0 to 400 psia
SR5737P	Fuel manifold pressure, quad A	PCM+	No	10	0 to 300 psia
SR5784P	Fuel manifold pressure, quad B	PCM+	No	10	0 to 300 psia
SR5822P	Fuel manifold pressure, quad C	PCM+	No	10	0 to 300 psia
SR5823P	Fuel manifold pressure, quad D	PCM+	No	10	0 to 300 psia
SR5733P	Oxidizer manifold pressure, quad A	PCM+	No	10	0 to 300 psia
SR5780P	Oxidizer manifold pressure, quad B	PCM+	No	10	0 to 300 psia
SR5820P	Oxidizer manifold pressure, quad C	PCM+	No	10	0 to 300 psia
SR5821P	Oxidizer manifold pressure, quad D	PCM+	No	10	0 to 300 psia
SR5046X	Sec prop iso[b] valves position, quad A	No	Yes	1	On/off event
SR5047X	Sec prop iso valves position, quad B	No	Yes	1	On/off event
SR5048X	Sec prop iso valves position, quad C	No	Yes	1	On/off event
SR5049X	Sec prop iso valves position, quad D	No	Yes	1	On/off event
SR5050X	Pri prop iso[c] valves position, quad A	No	Yes	1	On/off event
SR5051X	Pri prop iso valves position, quad B	No	Yes	1	On/off event
SR5052X	Pri prop iso valves position, quad C	No	Yes	1	On/off event
SR5053X	Pri prop iso valves position, quad D	No	Yes	1	On/off event

[a]Measurements labeled PCM are available only during periods of high-bit-rate data transmission. Measurements labeled PCM+ are available during periods of high- or low-bit-rate data transmission.

[b]Secondary propellant isolation.

[c]Primary propellant isolation.

TABLE III.- SERVICE MODULE RCS CAUTION AND WARNING SWITCH LIMITS

Measurement number	Parameter	Hi/Lo	Redline	C/W limits	
				Spec	Actual
SR5737P	Fuel manifold pressure, quad A	Hi	220 psia	215 psia	200.3 psia
		Lo	75 psia	145 psia	143.6 psia
SR5784P	Fuel manifold pressure, quad B	Hi	220 psia	215 psia	213.8 psia
		Lo	75 psia	145 psia	157.0 psia
SR5822P	Fuel manifold pressure, quad C	Hi	220 psia	215 psia	209.6 psia
		Lo	75 psia	145 psia	151.8 psia
SR5823P	Fuel manifold pressure, quad D	Hi	220 psia	215 psia	210.8 psia
		Lo	75 psia	145 psia	153.1 psia
SR5065T	Package temperature, quad A	Hi	210° F	205° F	204.7° F
		Lo	65° F	75° F	83.7° F
SR5066T	Package temperature, quad B	Hi	210° F	205° F	203.3° F
		Lo	65° F	75° F	81.7° F
SR5067T	Package temperature, quad C	Hi	210° F	205° F	206.2° F
		Lo	65° F	75° F	84.4° F
SR5068T	Package temperature, quad D	Hi	210° F	205° F	205.0° F
		Lo	65° F	75° F	84.6° F

TABLE IV.- SERVICE MODULE RCS PROPELLANT AND HELIUM SERVICING DATA

Parameter	Quad A	Quad B	Quad C	Quad D
Primary fuel-tank load, lb	70.6	70.1	70.3	69.9
Secondary fuel-tank load, lb	39.6	39.7	40.0	40.0
Total fuel load, lb	110.2	109.8	110.3	109.9
Total oxidizer load, lb	225.3	225.5	225.2	224.7
Loaded O/F ratio	2.05	2.05	2.04	2.05
Total propellant load, lb	335.5	335.3	335.5	334.6
Helium service pressure, psia	4189	4102	4160	4158
Helium tank loading temperature, °F	71	69	70	70

TABLE V.- SERVICE MODULE RCS EVENT TIME LINE

Event	Ground elapsed time, hr:min:sec
Lift-off	00:00:00.6 (13:32:00.6, G.m.t.)
CSM/S-IVB LM separation command	3:17:04.6
CSM/S-IVB LM docking	3:24:03
CSM/LM ejection from S-IVB	4:16:59.3
LOI-2 ullage burn	80:11:18.7
CSM/LM separation maneuver	100:39:52.5
LM jettison	[a]130:09:00
LM separation burn	[a]130:30:01
TEI ullage burn	135:23:26.6
MCC 5	150:29:57.4
CM/SM separation	194:49:19

[a]Times not verified by bilevel data.

TABLE VI.- SERVICE MODULE ΔV PERFORMANCE

Ullage burn	Ground elapsed time, hr:min:sec	Control authority	Burn duration, sec	Spacecraft weight, lb	ΔV on time, ft/sec	ΔV PIPA, ft/sec
LOI-2 ullage	80:11:18.7	2 engine - G&N	20.08	38 305	1.75	2.04
CSM/LM separation	100:39:52.5	4 engine - G&N	5.20	36 575	1.58	1.37
TEI ullage	135:23:26.6	2 engine - G&N	17.70	36 664	2.98	2.73
MCC-5	150:29:57.4	4 engine - G&N	10.00	26 075	4.44	4.25

TABLE VII.- SERVICE MODULE RCS ATTITUDE CONTROL PERFORMANCE

Maneuver	Ground elapsed time, hr:min:sec	Spacecraft weight, lb	Pitch acceleration, deg/sec^2	Yaw acceleration, deg/sec^2	Roll acceleration, deg/sec^2
+X	[a]3:17:05	63450	-0.124	0.346	
	130:10:13	36700	- .227		
	150:29:57		- .336		
-X	[a]3:17:14	63450	.194	- .478	
	100:39:52	36575	.404	- .160	
+Pitch	3:17:56	63450	.940		
	3:18:16	63450	1.011		
	135:26:30	36650	1.684		
+Yaw	[a]3:17:16	63450		.528	
	[a]3:17:18	63450		.467	
	3:17:34	63450		.837	
	3:17:39	63450		.837	
	3:18:16	63450		.804	
	3:18:28	63450		.893	
	194:48:13	26350	.179	1.582	
-Yaw	[a]3:17:09	63450		- .478	
	[a]3:17:11	63450		- .456	
	3:17:43	63450		- .893	
	136:26:28	36650		-1.386	
	194:46:44	26350	- .229	-1.675	
+Roll 2 engine	3:22:17	63450			2.185
	3:22:33	63450			2.365
-Roll 2 engine	3:22:16	63450			-2.284
	3:22:32	63450			-2.337

[a]Maneuvers during time period when quad B isolation valves were closed.

TABLE VIII.- SELECTED PREFLIGHT CHECKOUT DATA,

SM RCS HELIUM PRESSURIZATION SYSTEM

(a) Helium pressure regulators

Parameter	Specification value	Quad A		Quad B		Quad C		Quad D	
		Assy 1	Assy 2	Assy 1	Assy 2	Assy 1	Assy 2	Assy 1	Assy 2
Primary regulation, psia	181 ± 4	179	178	180	179.5	178.5	181	180.5	179.5
Primary lockup, psia	183 ± 5	182	181.5	182	182.5	181	184	181	180
Secondary regulation, psia	185 ± 4	183	181	181.5	183	182	182	183	182.5
Secondary lockup, psia	187 ± 5	186	183.5	183	185	185	185.5	185	184.5

(b) Relief valves

Parameter	Specification value	Quad A		Quad B		Quad C		Quad D	
		Fuel	Oxid	Fuel	Oxid	Fuel	Oxid	Fuel	Oxid
Cracking pressure, psia	225 to 248	236	239	239	237	237	245	235	241
Reseat pressure, psia	>220	224	224	232	233	229	236	227	233

TABLE IX.- COMPARISON OF NR-DOWNEY AND KSC

SM RCS TCS CHECKOUT DATA

Quad	Secondary switch limits, °F				Primary switch limits, °F			
	On		Off		On		Off	
	NR	KSC	NR	KSC	NR	KSC	NR	KSC
A	125	123	146	142	123	122	147	142
B	125	125	145	142	123	121	148	145
C	122	121	144	140	122	121	145	141
D	122	121	140	137	118	123	143	137

TABLE X.- COMPARISON OF SM RCS TCS PRIMARY THERMOSTAT SWITCHING LIMITS DURING FLIGHT WITH PREFLIGHT CHECKOUT DATA

Quad	On, °F			Off, °F		
	NR	KSC	Flight	NR	KSC	Flight
A	123	122	120	147	142	142
B	123	121	121	148	145	142
C	122	121	119	145	141	146
D	118	123	121	143	137	138

TABLE XI.- COMMAND MODULE RCS INSTRUMENTATION LIST

Measurement number	Parameter	Telemetry[a]	Cabin display	Response, S/S	Data range
CR0001P	Helium tank pressure, system 1	PCM+	Yes	1	0 to 5000 psia
CR0002P	Helium tank pressure, system 2	PCM+	Yes	1	0 to 5000 psia
CR0003T	Helium tank temperature, system 1	PCM	Yes	1	0 to 300° F
CR0004T	Helium tank temperature, system 2	PCM	Yes	1	0 to 300° F
CR0035P	Helium manifold pressure, system 1	PCM+	No	10	0 to 400 psia
CR0036P	Helium manifold pressure, system 2	PCM+	No	10	0 to 400 psia
CR0037P	Helium manifold pressure, system 1	No	Yes	10	0 to 400 psia
CR0038P	Helium manifold pressure, system 2	No	Yes	10	0 to 400 psia
CR2100T	Injector temperature, -P, system 1	No	Yes	-	-50 to +50° F
CR2103T	Injector temperature, -Y, system 1	No	Yes	-	-50 to +50° F
CR2110T	Injector temperature, -P, system 2	No	Yes	-	-50 to 50° F
CR2114T	Injector temperature, CCW, system 1	No	Yes	-	-50 to +50° F
CR2116T	Injector temperature, +Y, system 2	No	Yes	-	-50 to +50° F
CR2119T	Injector temperature, CW, system 2	No	Yes	-	-50 to +50° F
CR1020X	Prop iso[b] valve position, system 1	No	Yes	1	On/off event
CR1021X	Prop iso valve position, system 2	No	Yes	1	On/off event

[a]Measurements labeled PCM are available only during periods of high-bit-rate data transmission. Measurements labeled PCM+ are available during periods of high- or low-bit-rate data transmission.

[b]Propellant isolation.

TABLE XII.- COMMAND MODULE RCS CAUTION AND WARNING SWITCH LIMITS

Measurement number	Parameter	Hi/Lo	Redline	C/W limits	
				Spec	Actual
CR0035P	Helium manifold pressure, system 1	Hi Lo	332 psia None	330 psia 260 psia	320.3 psia 266.7 psia
CR0036P	Helium manifold pressure, system 2	Hi Lo	332 psia None	330 psia 260 psia	317.7 psia 264.0 psia
[a]CR0037P	Helium manifold pressure, system 1	Hi Lo	332 psia None	No PCM	No PCM
[a]CR0038P	Helium manifold pressure, system 2	Hi Lo	332 psia None	No PCM	No PCM

[a]Onboard display measurement.

TABLE XIII.- COMMAND MODULE RCS PROPELLANT AND HELIUM SERVICING DATA

Parameter	System 1	System 2
Fuel tank load, lb	44.8	44.4
Fuel loading temperature, °F	70	70
Oxidizer tank load, lb	78.4	78.3
Oxidizer loading temperature, °F	70	70
Loaded O/F ratio	1.75	1.76
Total propellant load, lb	123.2	122.7
Helium service pressure, psia	4205	4130
Helium tank loading temperature, °F	73	65

TABLE XIV.- COMMAND MODULE RCS EVENT TIME LINE

Event	Start time, hr:min:sec
CM RCS system activation	194:16:23
CM-SM separation	194:49:19
CM RCS system 2 deactivated	194:50:25
CM RCS disabled	N.A.[a]
CM RCS depletion burn	N.A.
Helium purge	N.A.
Propellant isolation valves closed	N.A.

[a]N.A. - Data not available.

TABLE XV.- COMMAND MODULE RCS ATTITUDE CONTROL PERFORMANCE

Maneuver	Ground elapsed time, hr:min:sec	Control authority	Measured acceleration, °/sec²
+Yaw	194:54:58	1 engine	5.02
	194:58:50.5	2 engine	[a]8.20
	194:58:51	1 engine	4.39
-Yaw	194:55:20	1 engine	[b]-.06
	194:58:50	2 engine	[a]-10.31
	194:58:57	1 engine	[b]-.06

[a]Direct coil firing.

[b]Fuel cold flow.

TABLE XVI.- SELECTED PREFLIGHT CHECKOUT DATA, CM RCS HELIUM PRESSURIZATION SYSTEM

(a) Helium pressure regulators

Parameter	Specification value	System 1		System 2	
		Assy 1	Assy 2	Assy 1	Assy 2
Primary regulation, psia	291 ± 6	290	291	287.5	288
Primary lockup, psia	285 to 302	290.5	291.5	290	290
Secondary regulation, psia	285 to 302	291	290	293.5	290
Secondary lockup, psia	285 to 308	293	291.5	296	292

(b) Relief valves

Parameter	Specification value	System 1		System 2	
		Fuel	Oxid	Fuel	Oxid
Cracking pressure, psia	346 ± 14	347	346	344	349.5
Reseat pressure, psia	>327	331.5	333	333	333.5

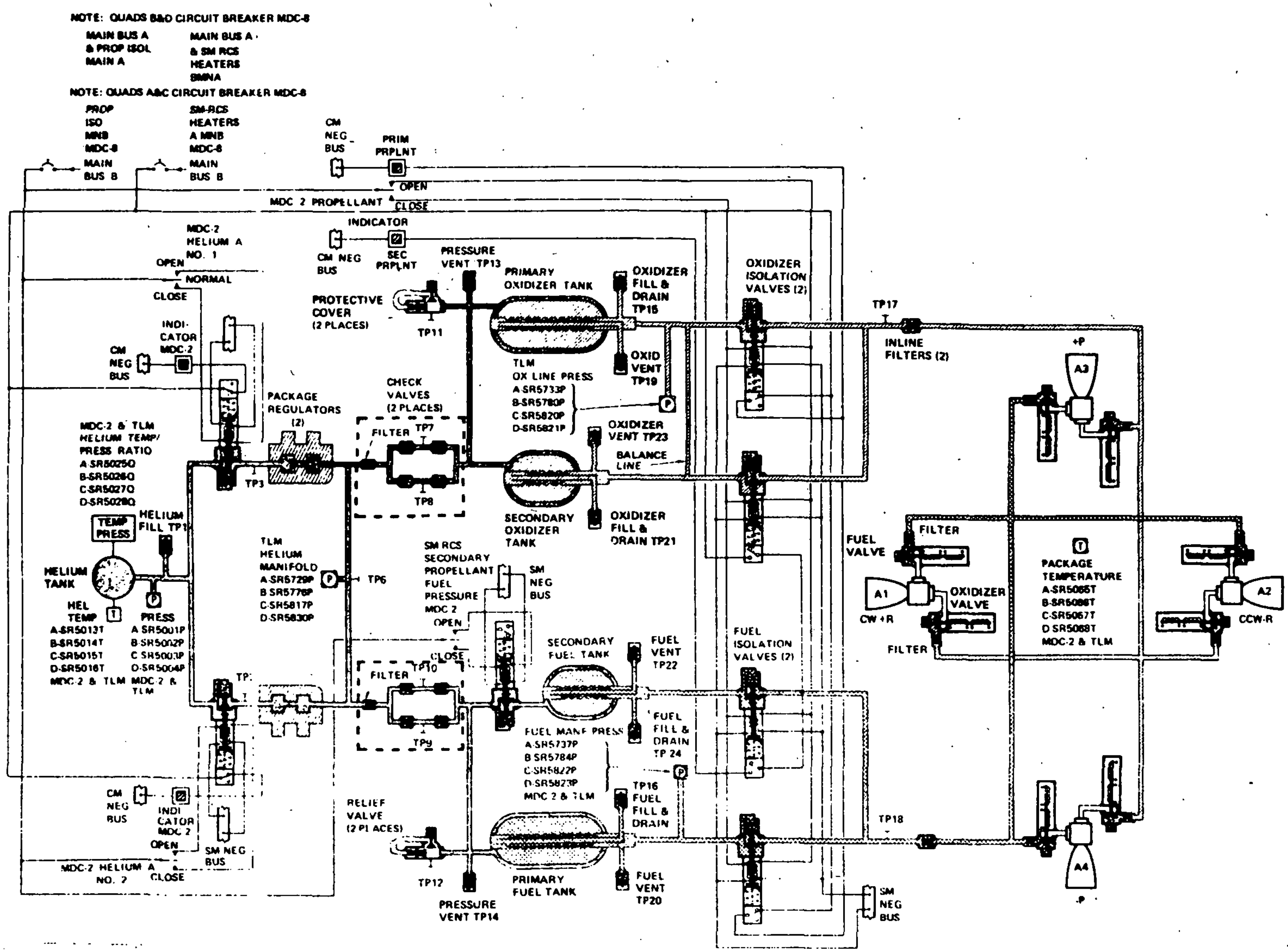


Figure 1.- Service module RCS schematic.

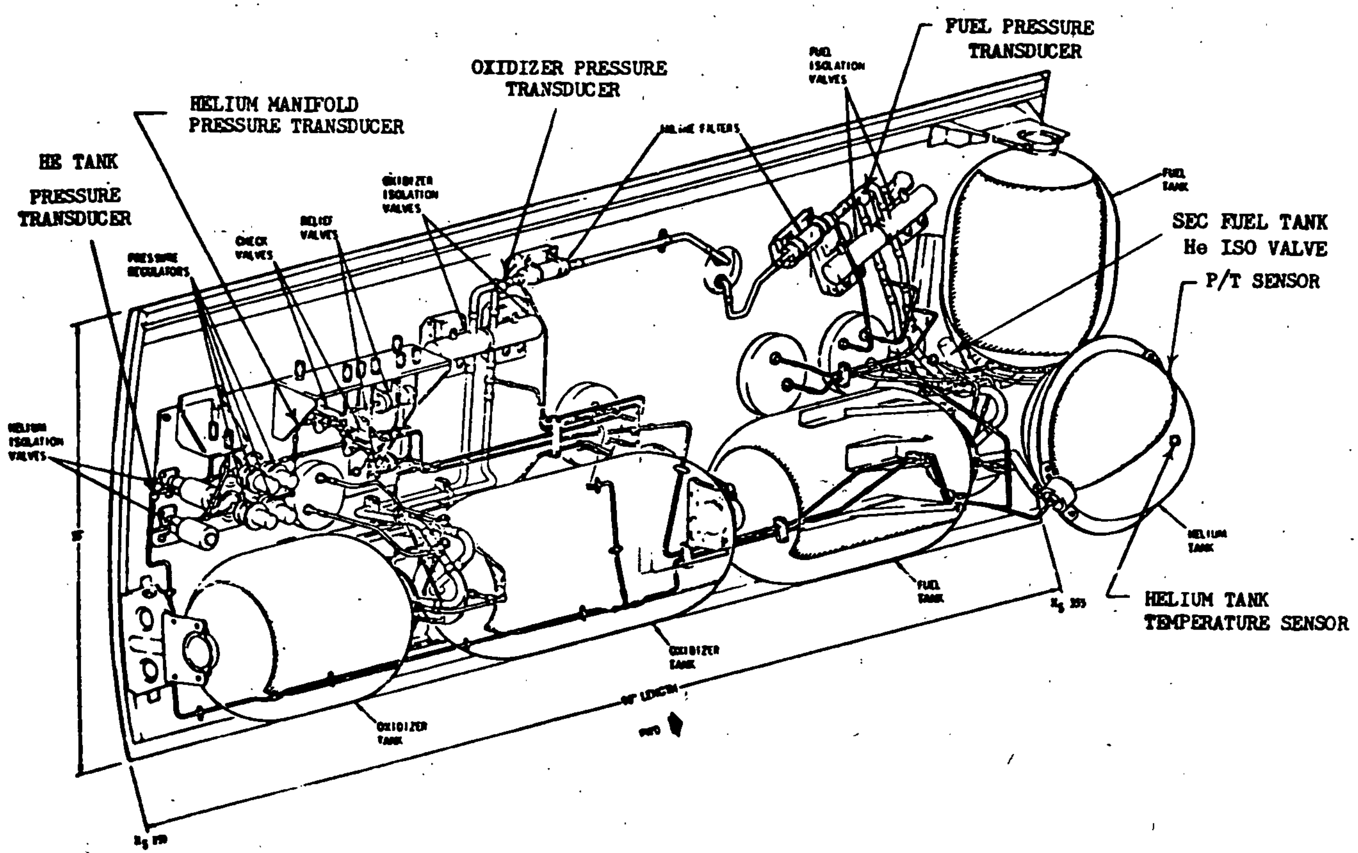
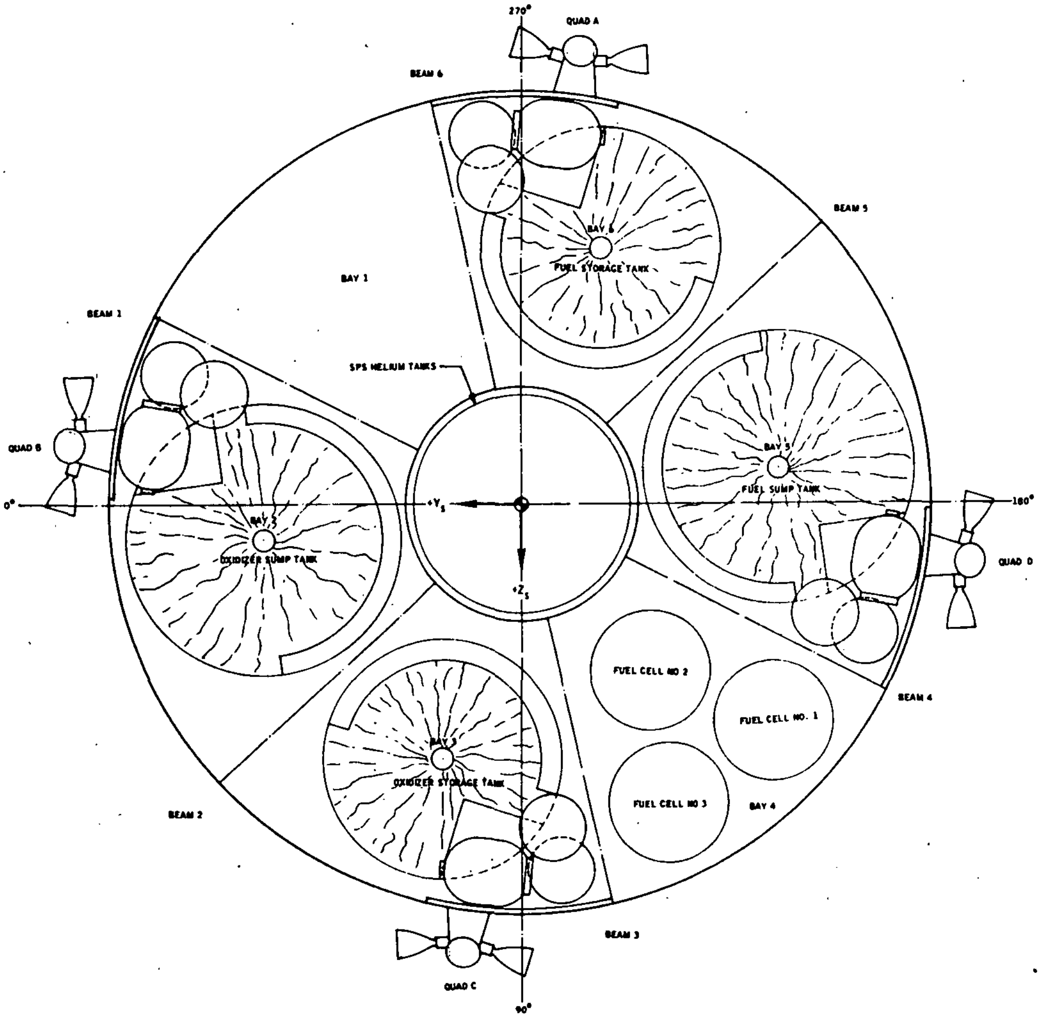
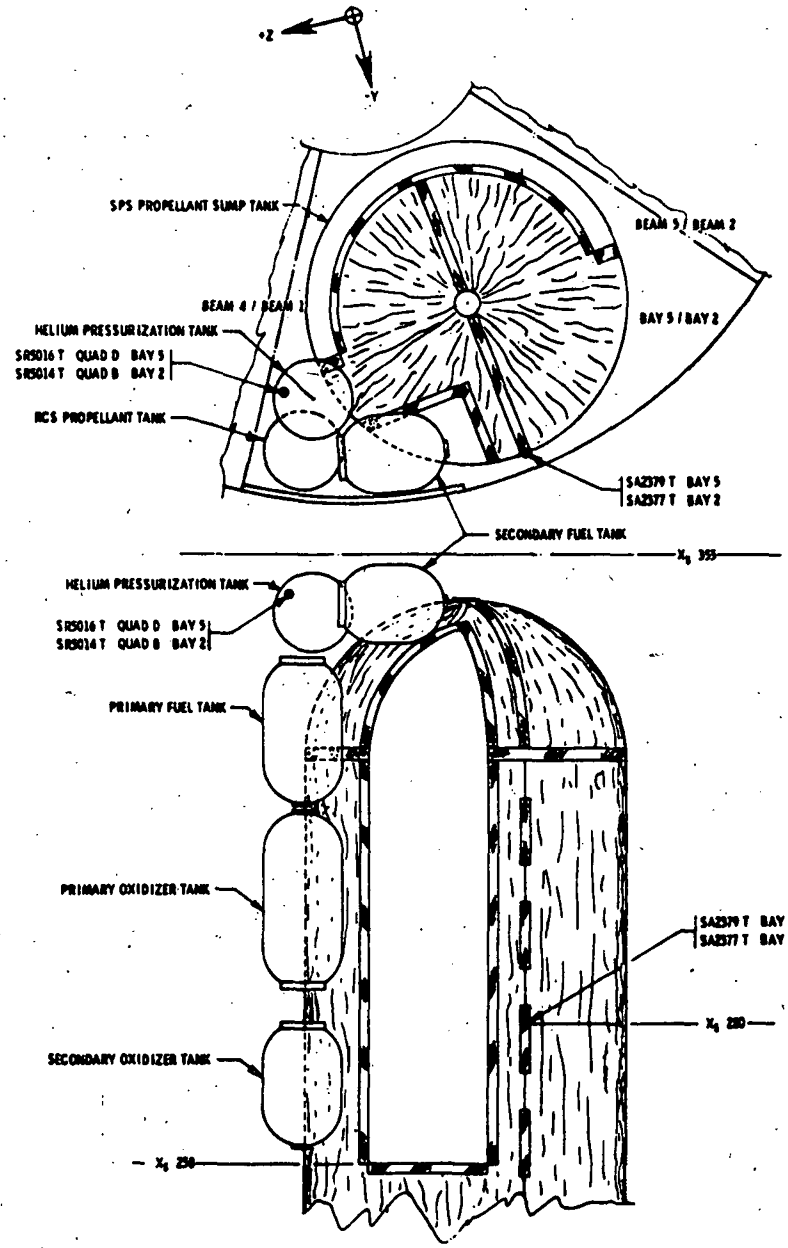


Figure 2.- Service module RCS panel assembly, quads B and D.



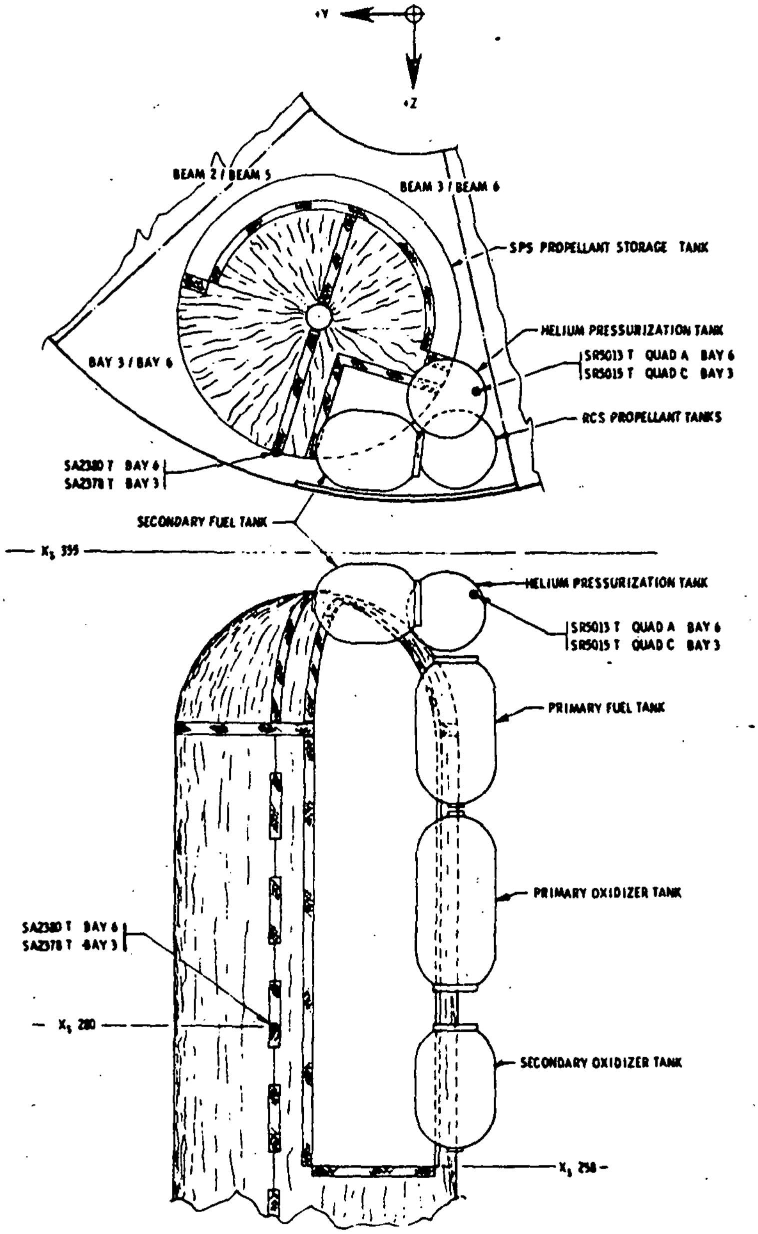
(a) View looking aft.

Figure 3.- Location of SM RCS components within the SM.



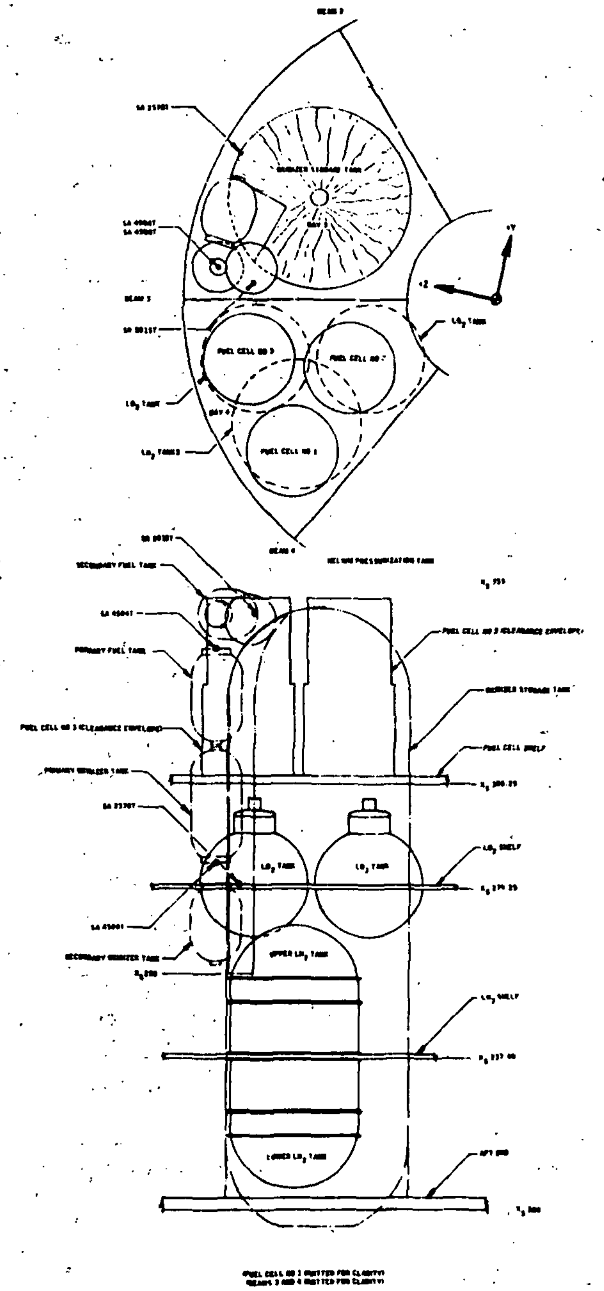
(b) View looking inboard, bay 5 (bay 2 similar).

Figure 3.- Continued.



(c) View looking inboard, bay 3 (bay 6 similar).

Figure 3.- Continued.



(d) View looking normal to beam 3.

Figure 3.- Concluded.

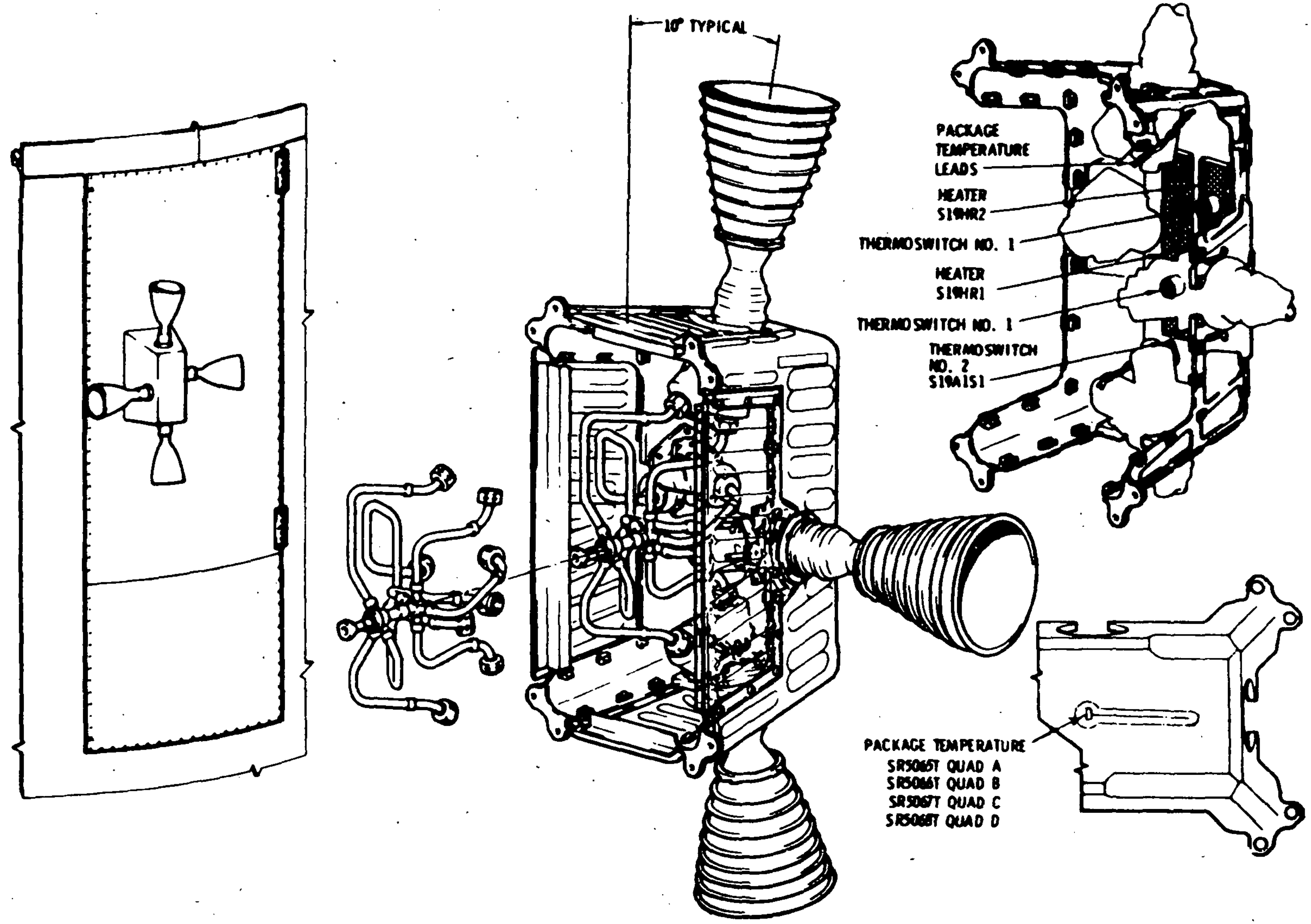


Figure 4.- Service module RCS quad engine housing.

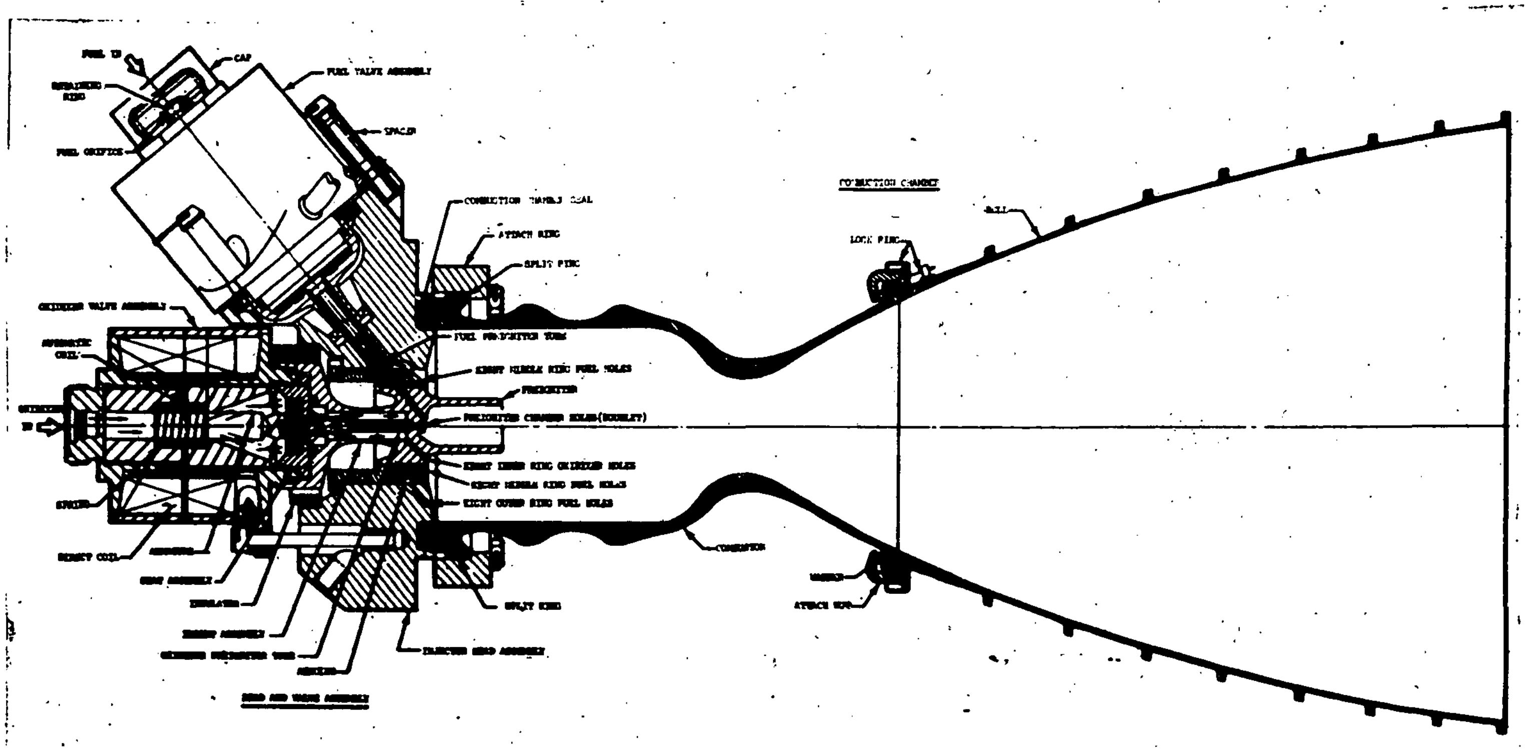


Figure 5.- Service module RCS engine.

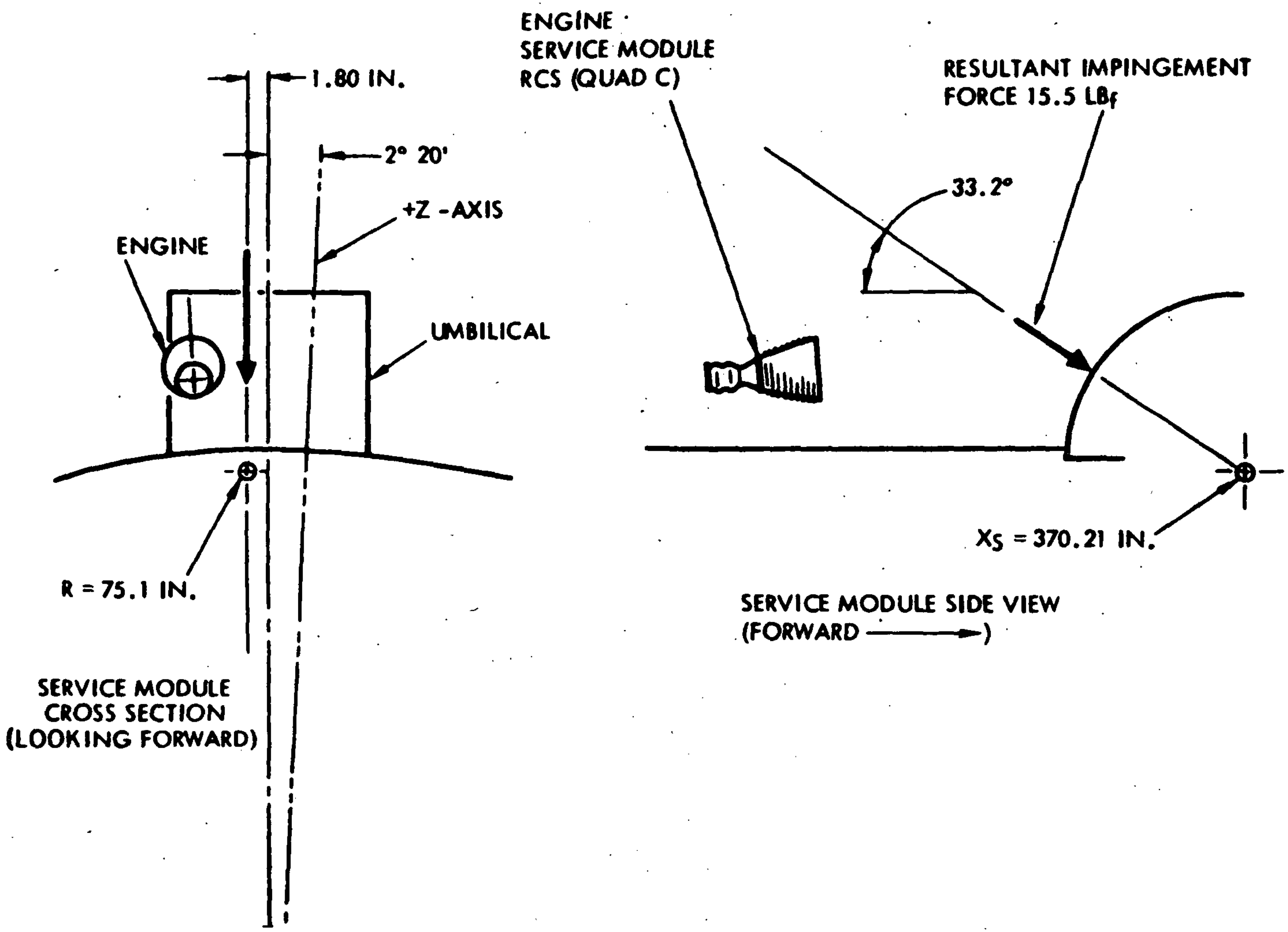


Figure 6.- Location of CSM umbilical relative to the forward firing (-X/-P) engine of SM RCS quad C.

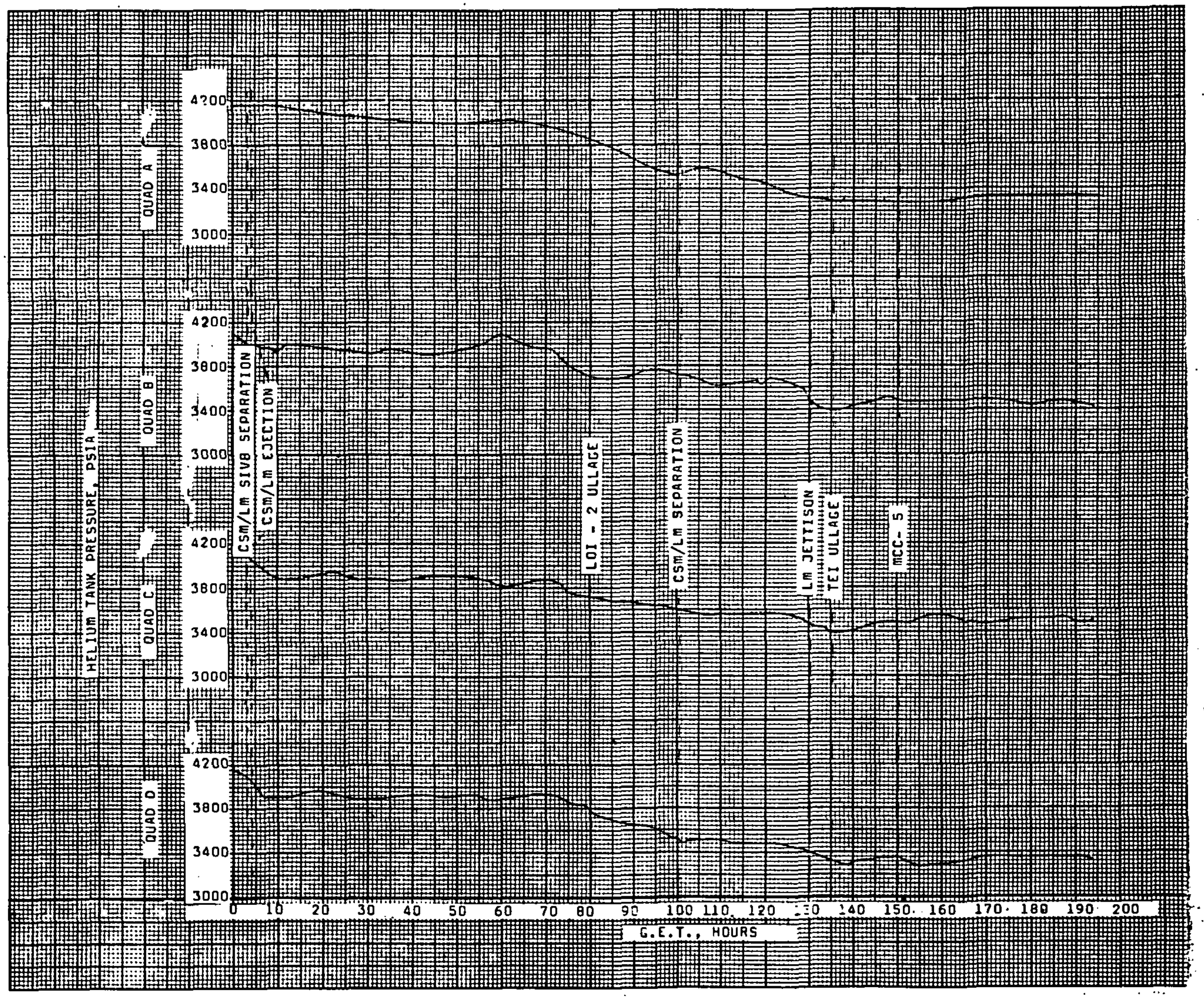


Figure 7.- Service module helium tank pressure as a function of time.

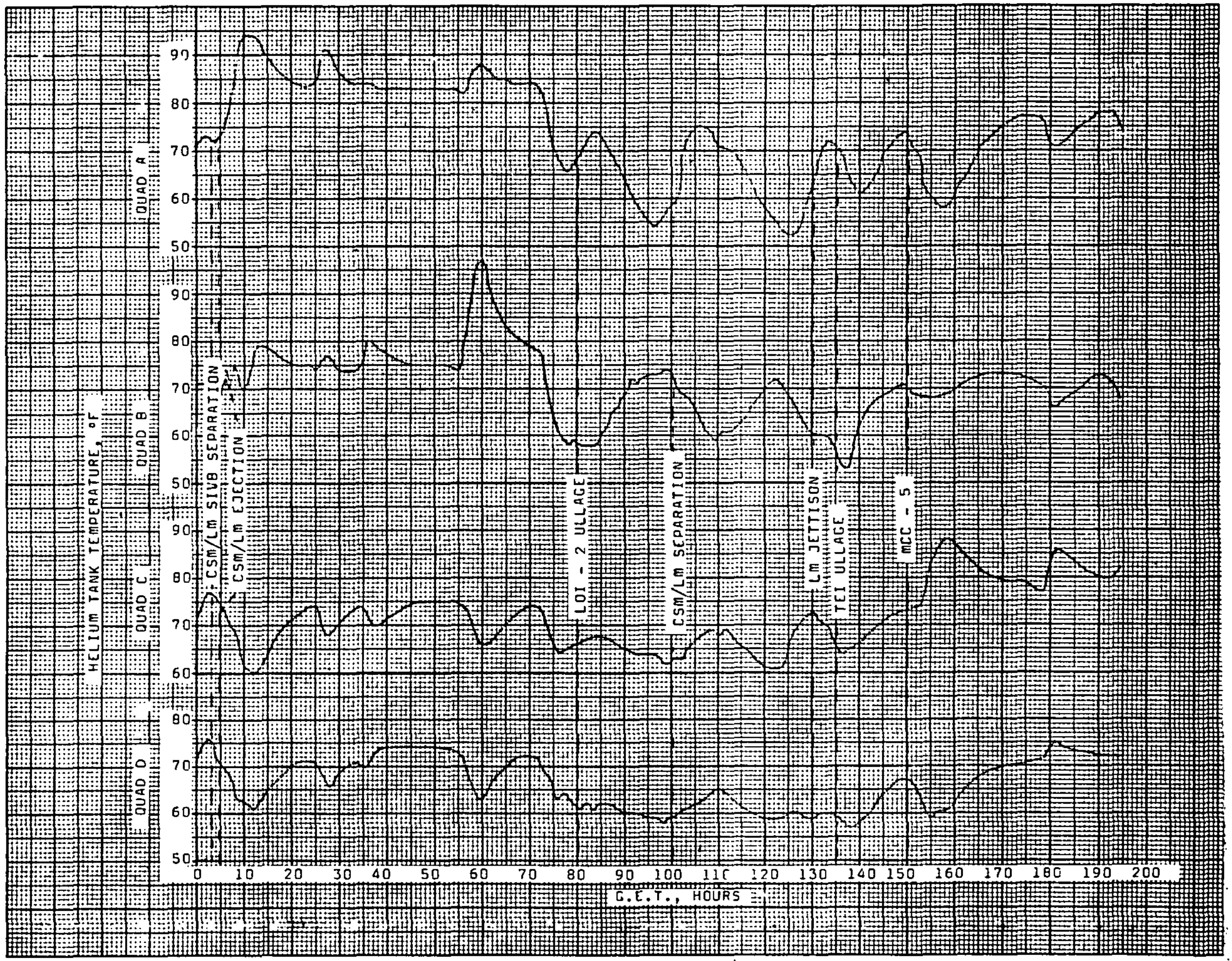


Figure 8.- Service module helium tank temperature as a function of time.

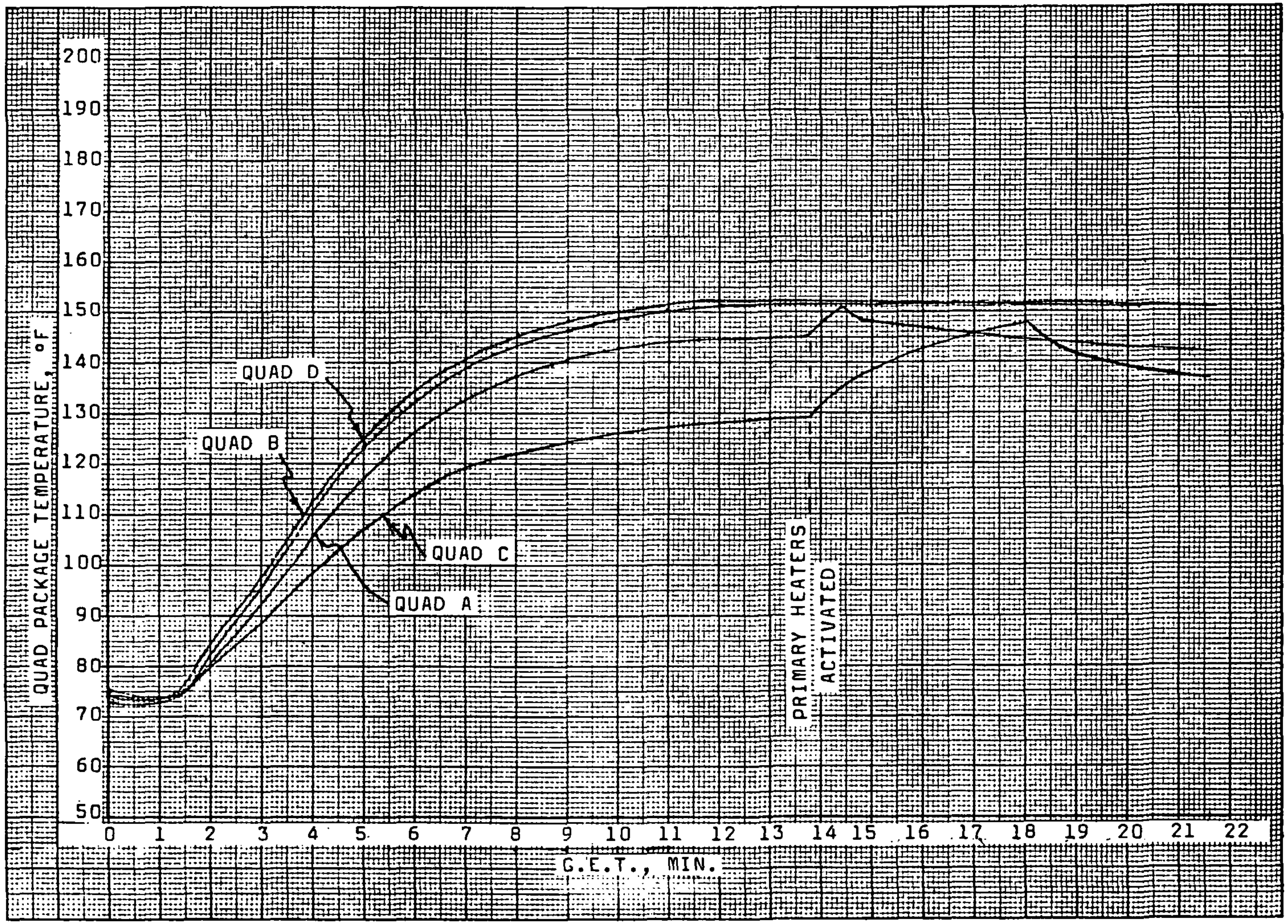


Figure 9.- Quad package temperatures during launch.

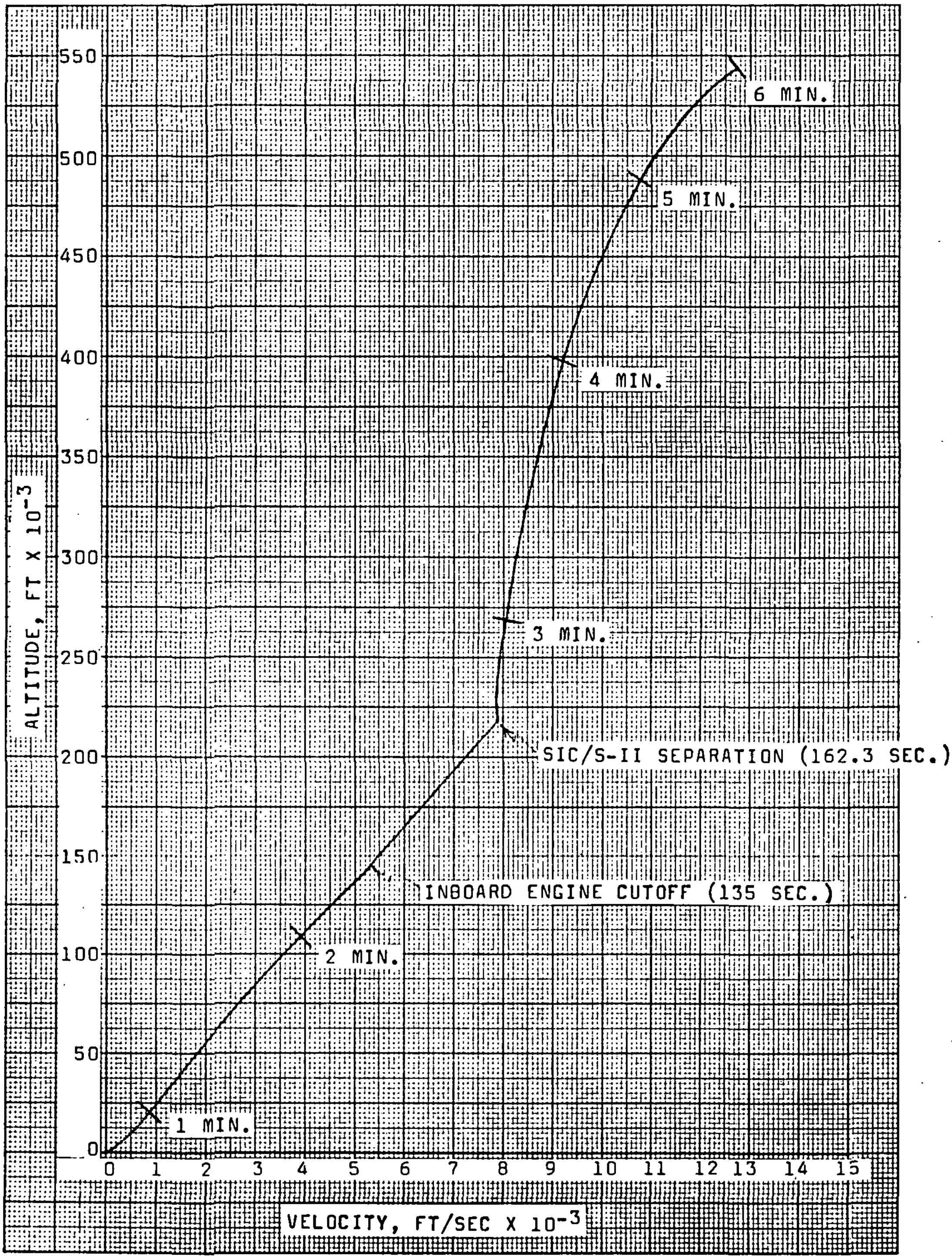
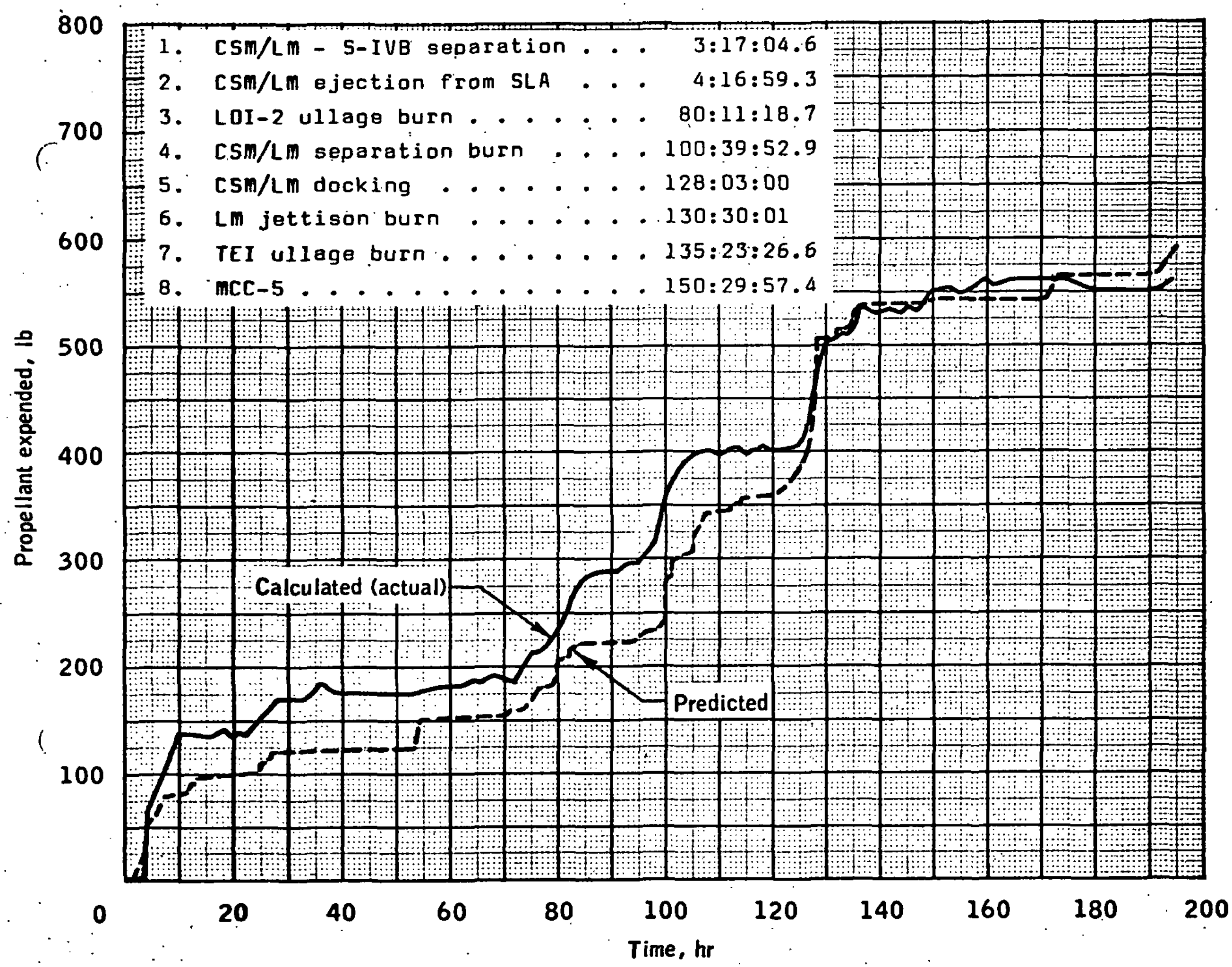
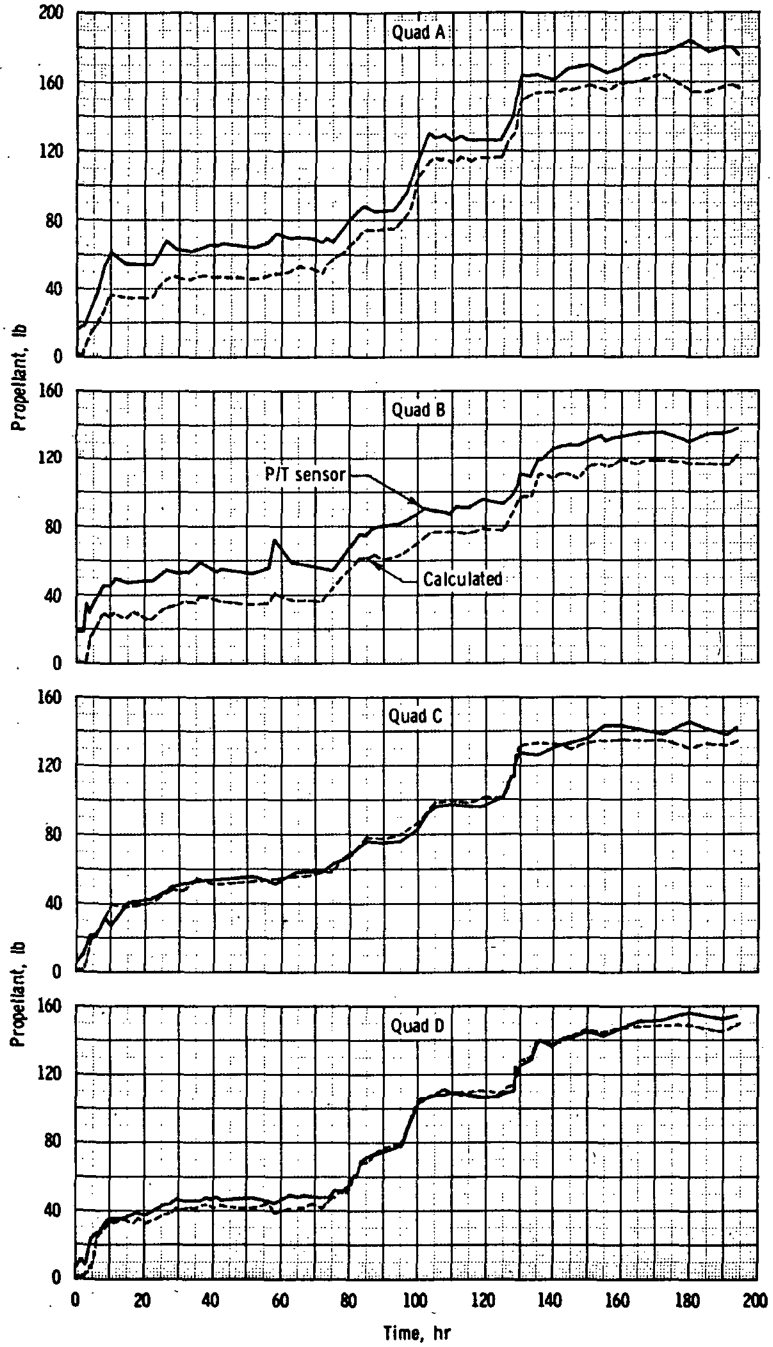


Figure 10.- Apollo 11 launch trajectory.



(a) Comparison of actual and predicted propellant consumption.

Figure 11.- Service module RCS propellant consumption profiles.



(b) Individual quad propellant consumption

Figure 11.- Concluded.

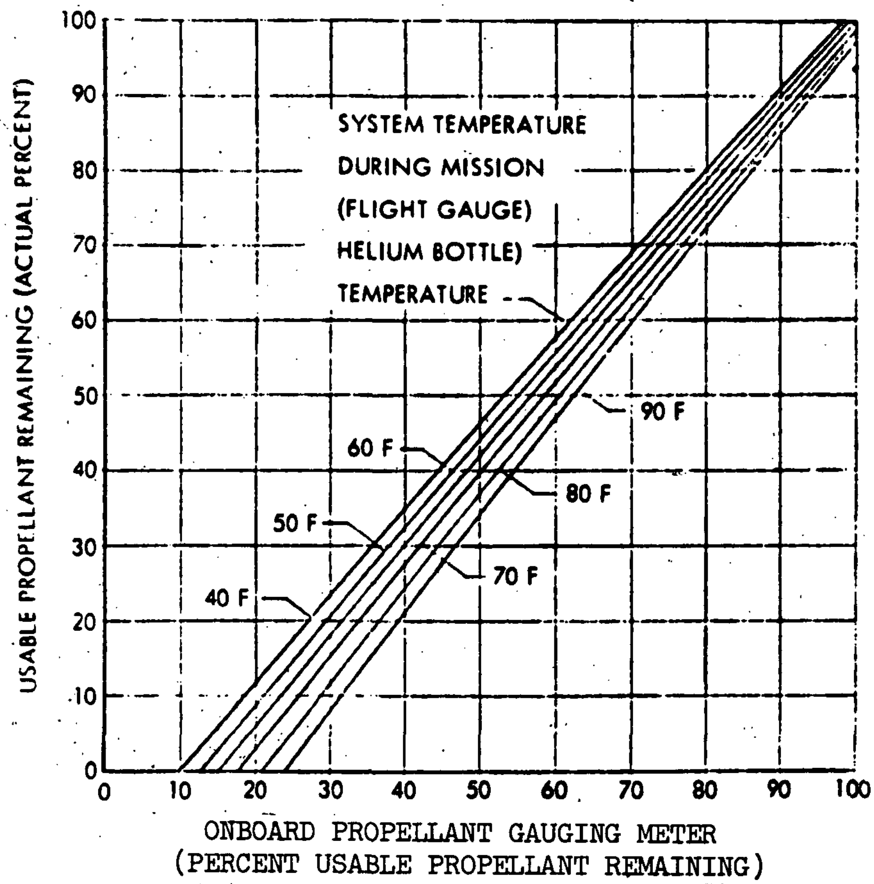


Figure 12.- Minus two-sigma SM RCS onboard propellant gaging meter correction nomogram.

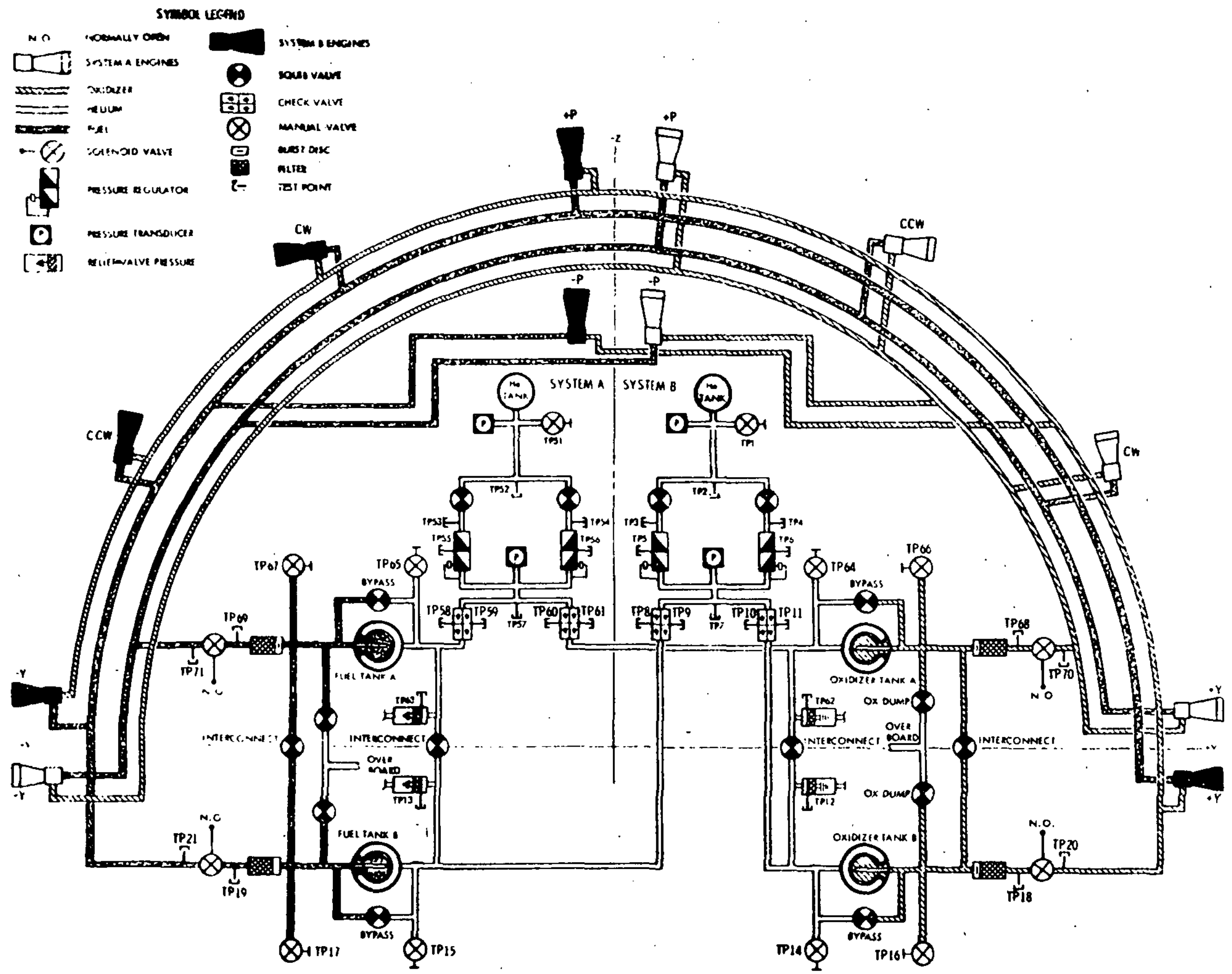


Figure 13.- Command module RCS flow schematic.

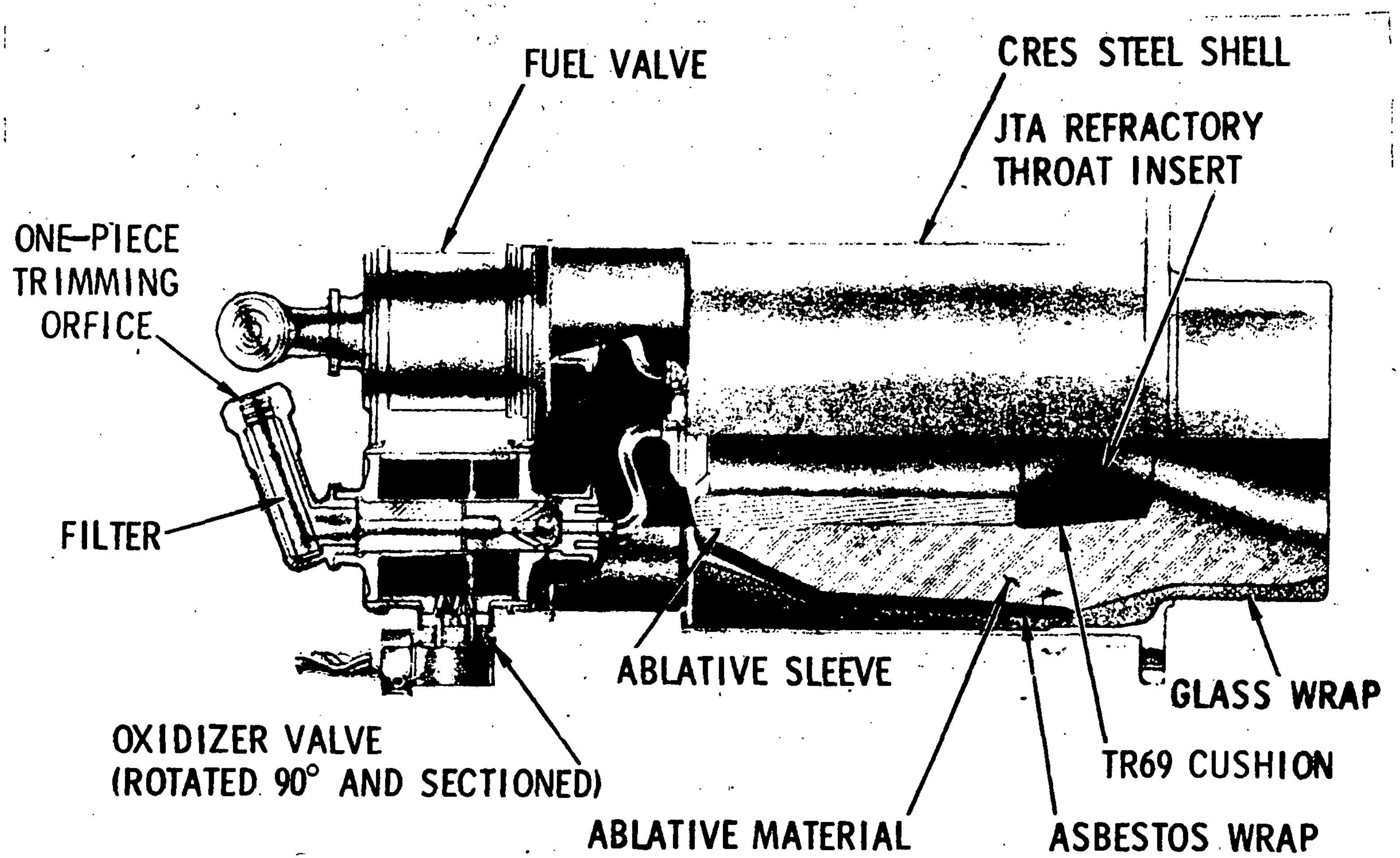


Figure 14.- Typical CM RCS engine.

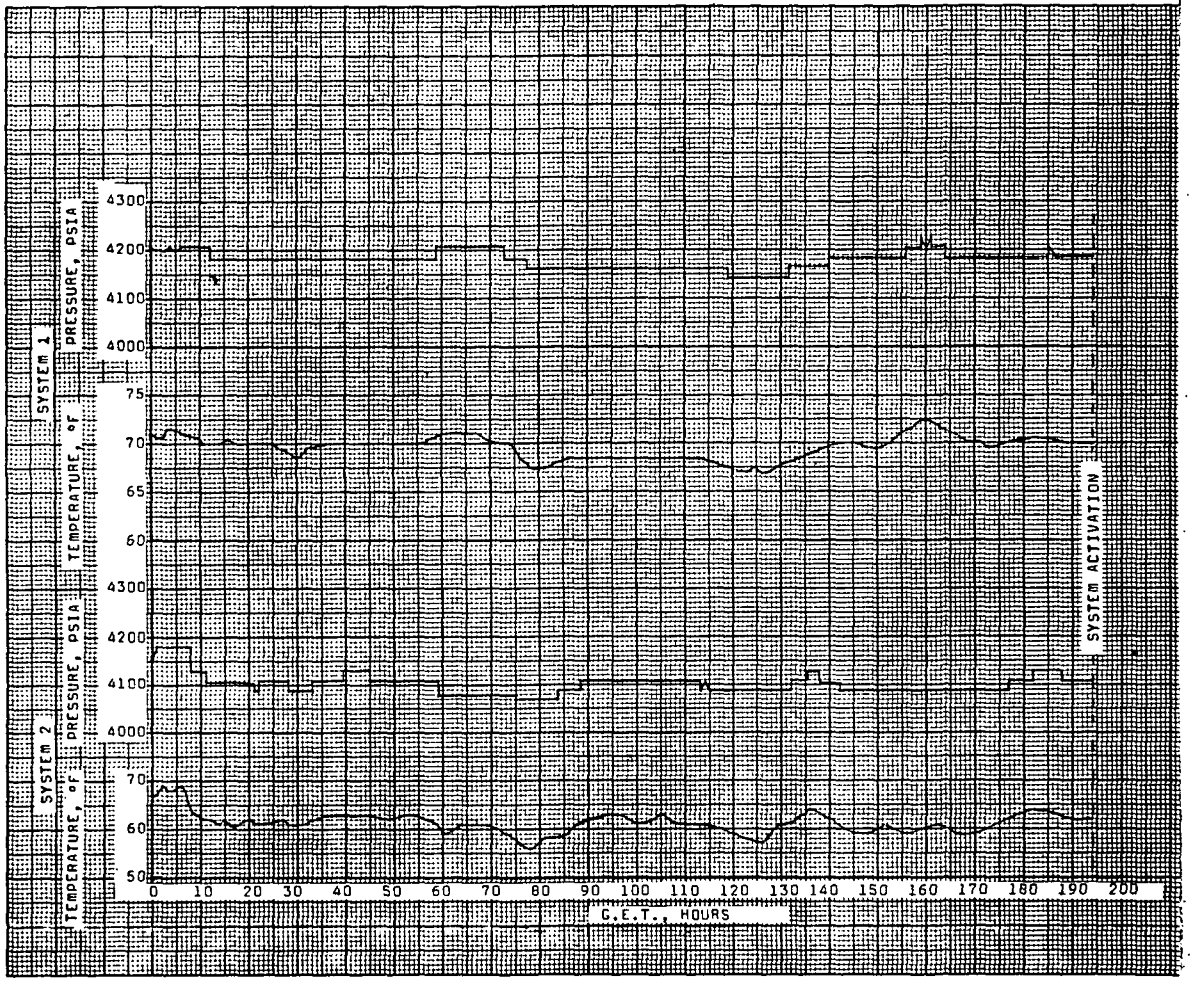


Figure 15.- Command Module RCS helium tank pressure and temperature from launch to system activation.

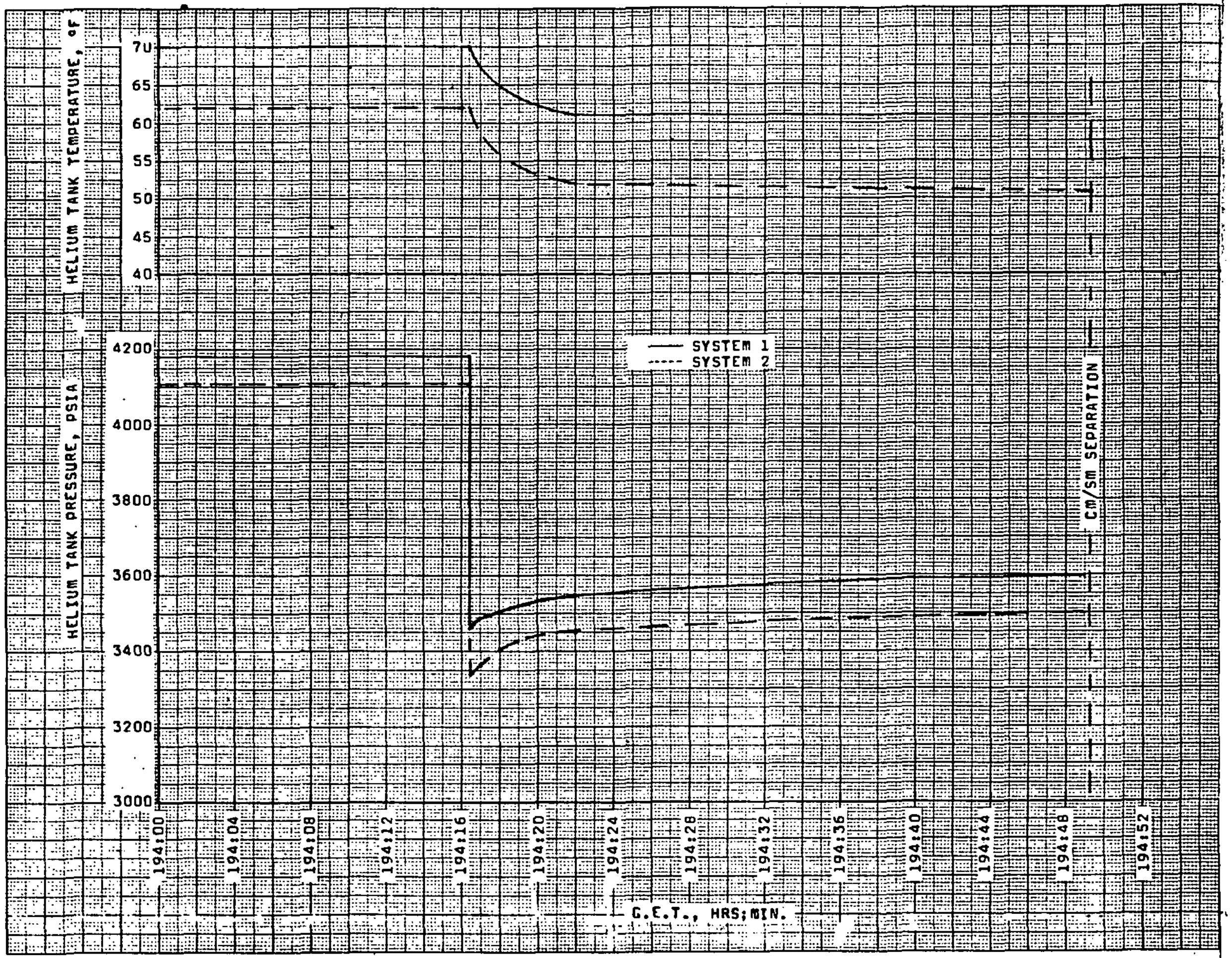


Figure 16.- Command module RCS helium tank pressure and temperature from system activation to CM/SM separation.

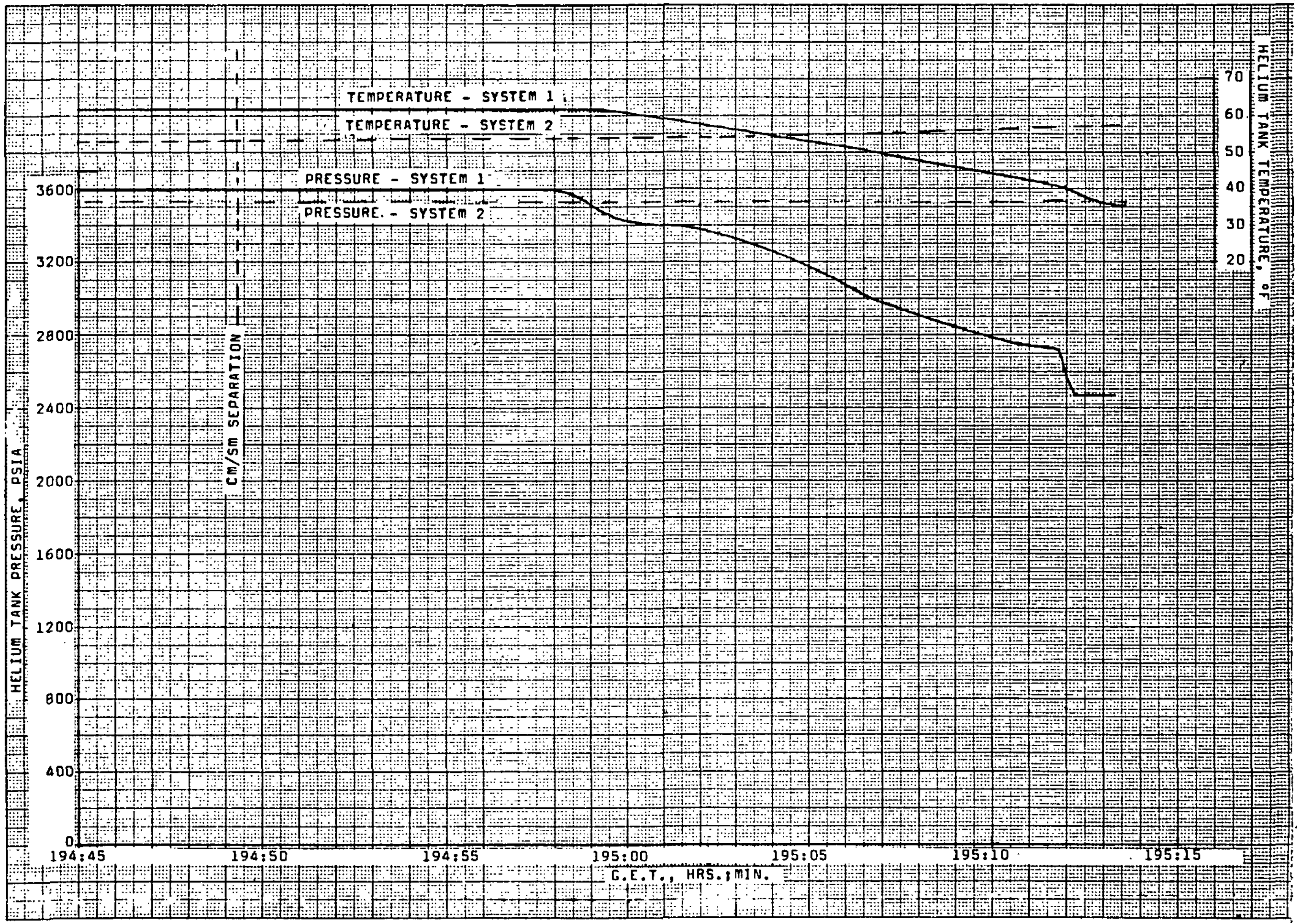


Figure 17.- Command Module RCS helium tank pressure and temperature during entry.

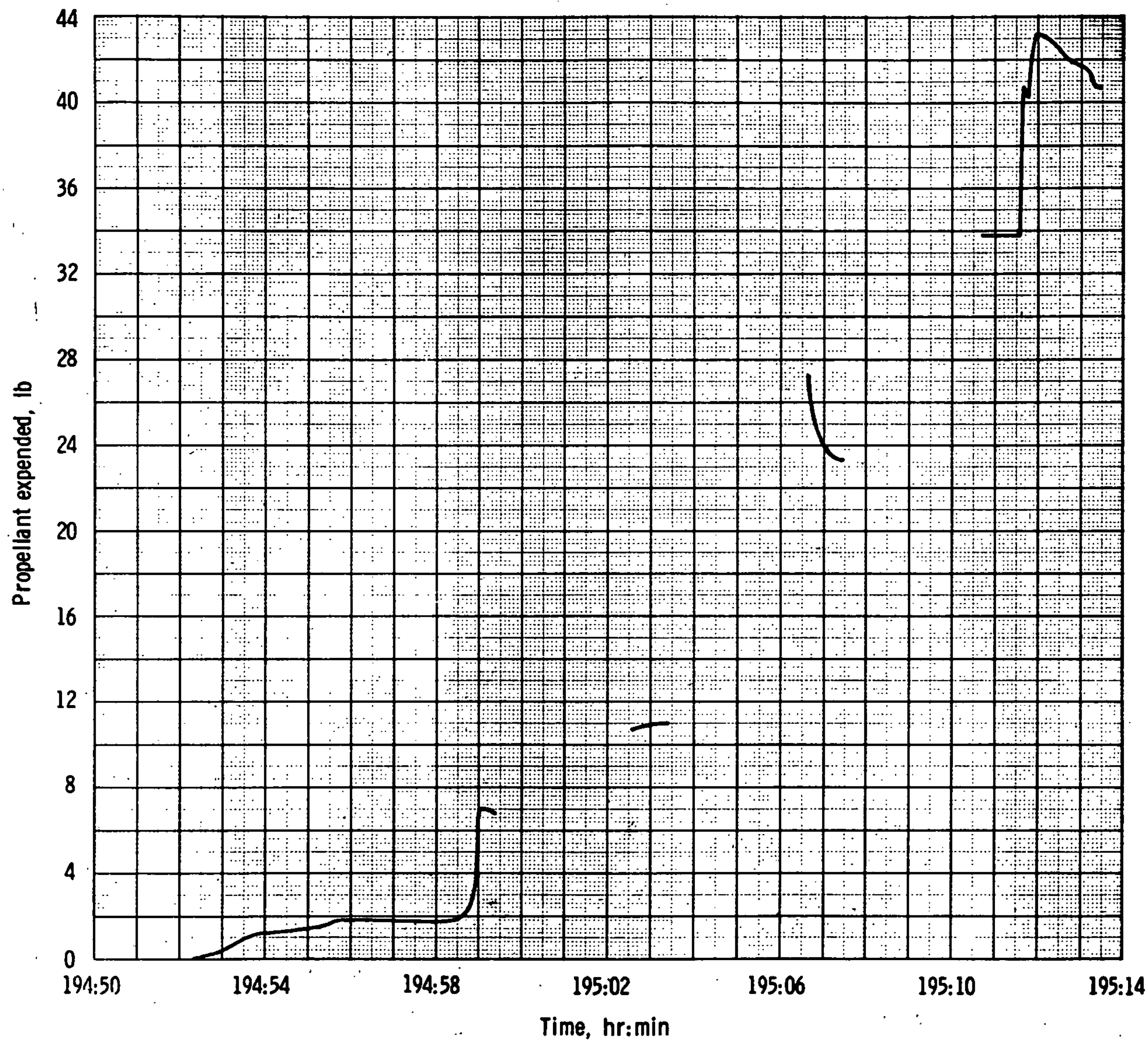


Figure 18.- Propellant expended from CM RCS.

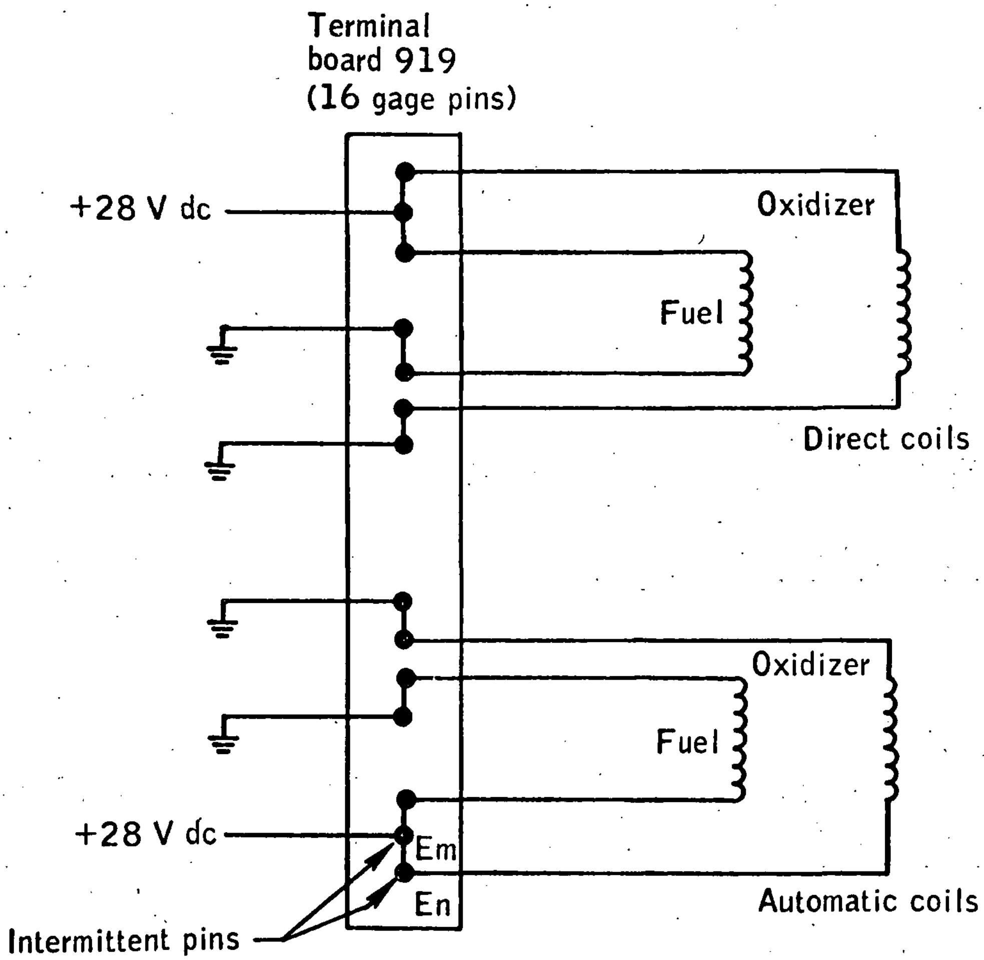


Figure 19.- Terminal board schematic for -yaw engine, system 1.