SD 68-654-2

ENGINEERING COURSE FOR SATURN S-II STAGE SYSTEMS FOR NASA AND HEROICRELICS.ORG

VOLUME 2

S-II STAGE PROPULSION AND MECHANICAL SYSTEMS

November 1968

Approved by

R R Dow

for B. Botfeld
Manager, Mechanical Systems Analysis
and Requirements
S-II Engineering

SPACE DIVISION
NORTH AMERICAN ROCKWELL CORPORATION

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FOREWORD

This volume is one of four volumes comprised by the Engineering Course on Saturn S-II Systems for NASA (SD 67-654) and is to be used only in conjunction with the classroom presentation. The course is being presented in accordance with Change Order 1085 to Contract NAS7-200.

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CONTENTS

ILLUSTRATIONS

SECTION I. S-II PROPULSION SYSTEM

ENGINE SYSTEMS

FUNCTION

The J-2 engines provide thrust for the second stage of the Saturn V launch vehicle, raising the vehicle altitude from approximately 200,600 to 602,000 feet and increasing the velocity from approximately 5200 to 14,500 mph. The total thrust is provided by a cluster of five J-2 engines, each having a nominal thrust rating of 225,000 pounds and burning for approximately 365 seconds.

ENGINE SYSTEM FEATURES

This section is divided into three subsections:

1. The arrangement subsection deals with the physical location of the engine system, arrangement of its main components, and a brief physical description.

2. The engine-system operating features subsection is concerned with the actual output of the engine.

3. The engine-system support features subsection deals with the supply of propellants and with control from stage to engine systems.

ARRANGEMENT

The engine system is composed of five J-2 engines. This cluster, located at the aft end of the S-II stage, is attached directly to the thrust structure. (See Figure 1.) Each engine consists of a basic bell-shaped thrust cone from which the burning gases are emitted. The four outboard engines are attached to a gimbal block at the stage interface. From this interface the flight control system can direct the engine thrust vector, achieving stage directional changes or stabilization. On the outboard side of each outboard engine, the stage fuel supply system interfaces with the engine, while the LOX supply interfaces 180 degrees from the fuel supply (i. e., on the inboard side). The other main components of each engine are shown in Figure 2.

Figure 1. J-2 Engine System Arrangement

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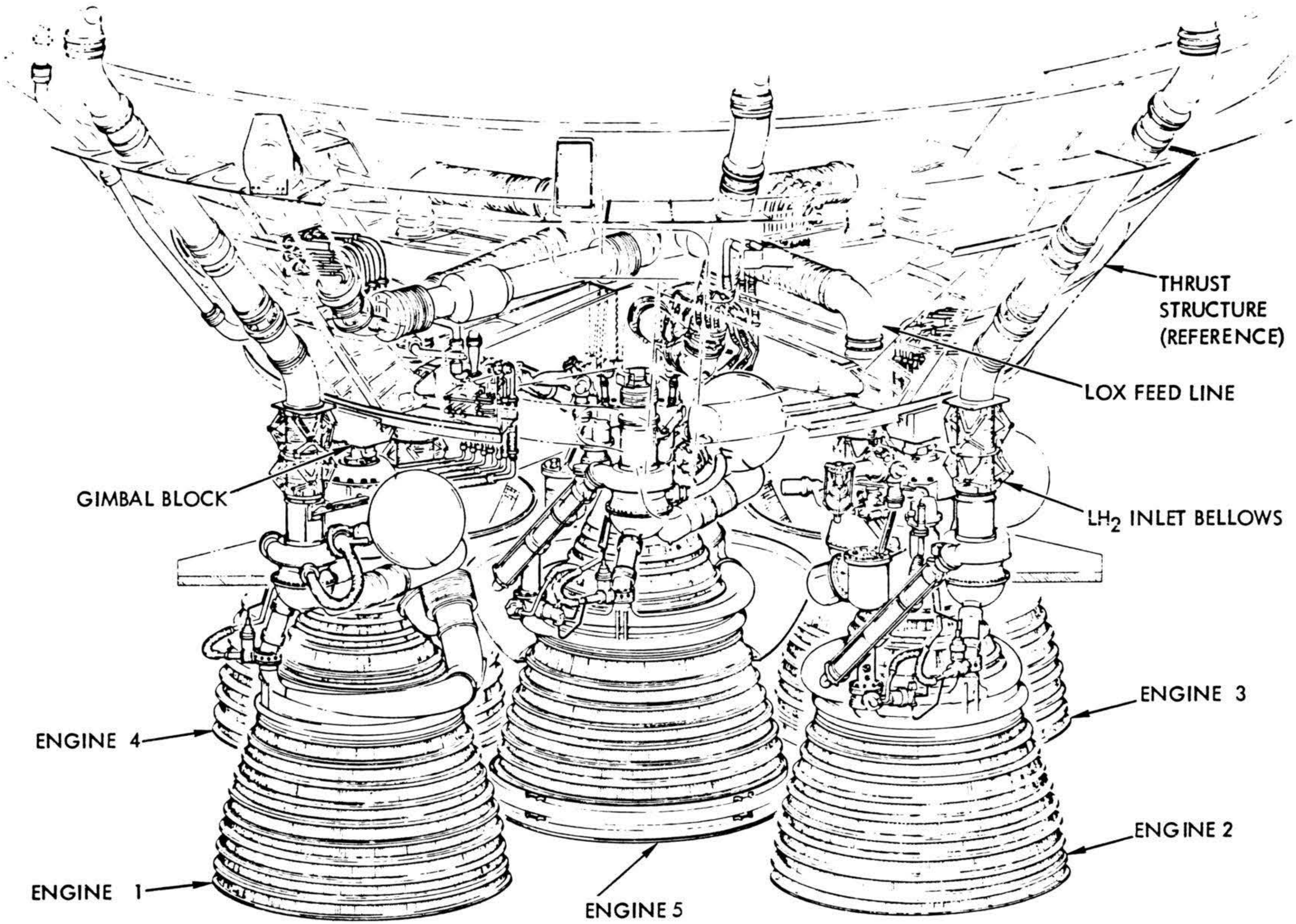

Figure 2. J-2 Engine Component Location

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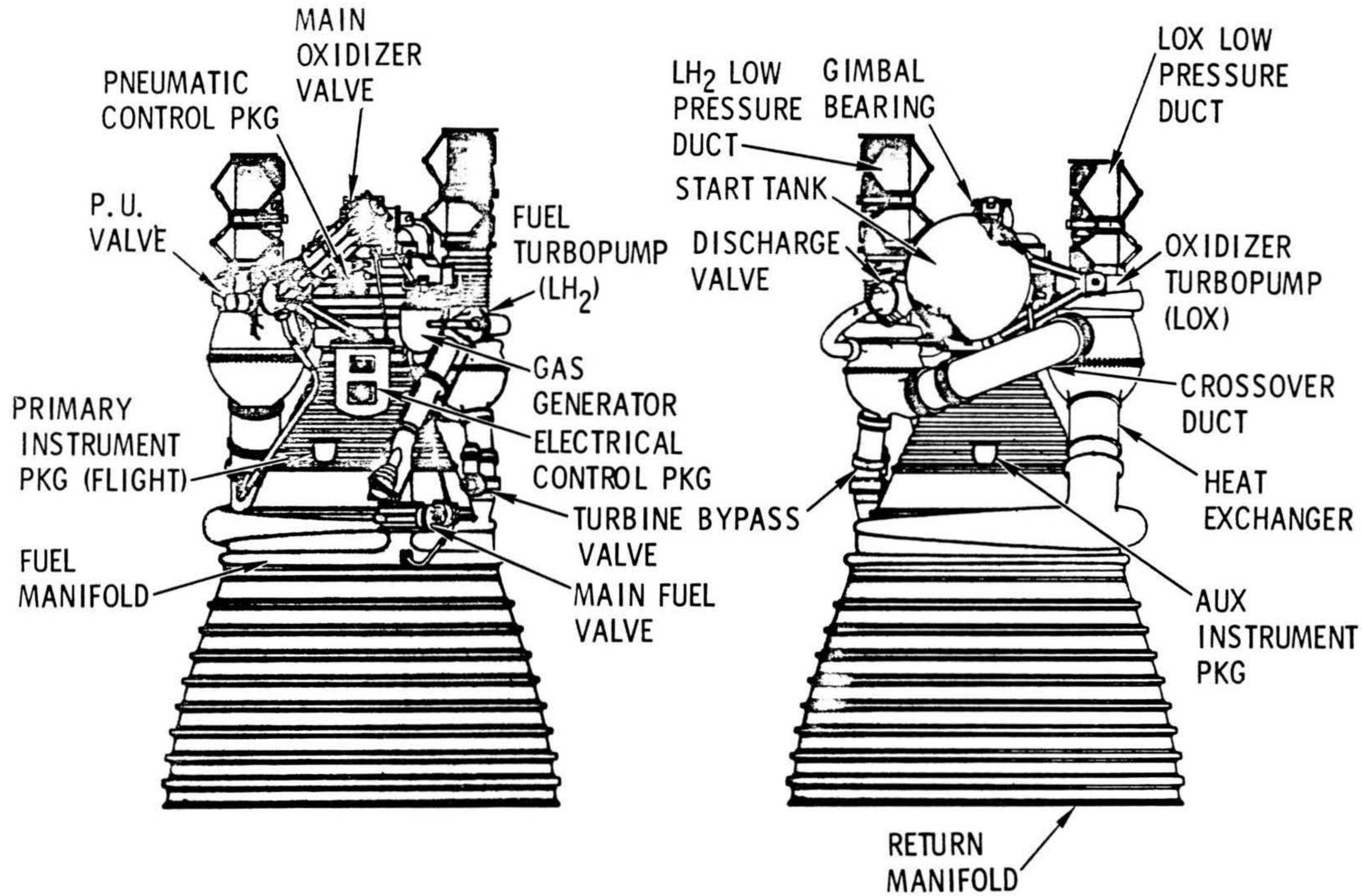


ENGINE SYSTEM OPERATING FEATURES

The J-2 rocket engine (Figure 3) is a high-performance engine that utilizes liquid oxygen and liquid hydrogen as propellants. The only substances used in the engine are the propellants and helium gas. The extremely low operating temperature of the engine prohibits the use of lubricants or other fluids. The engine features a single, tubular-walled, bell-shaped thrust chamber and two independently driven, direct-drive turbopumps for liquid oxygen and liquid hydrogen. Both turbopumps are powered in series by a single gas generator, which utilizes the same propellants as the thrust chamber. Propellant utilization is accomplished by bypassing liquid oxygen from the discharge side of the oxidizer turbopump to the inlet side through a valve driven by a servomotor.

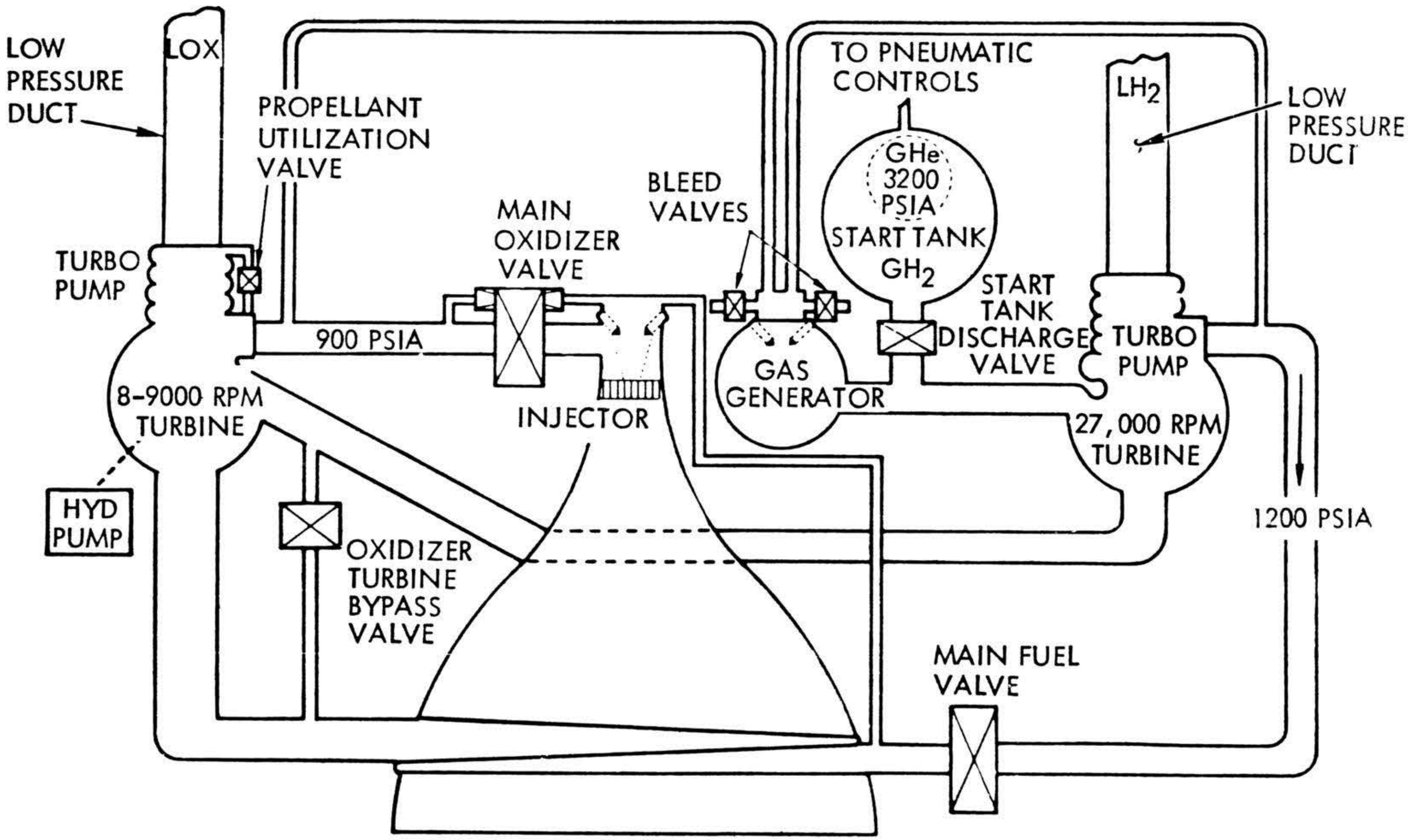
The exhaust gases from the gas generator are directed to the inlet of the fuel turbopump turbine, and the exhaust gases of the fuel turbopump turbine are routed to the inlet of the oxidizer turbopump turbine, thus creating a power series that allows each turbopump to operate at its most favorable speed. An engine-mounted, hydrogen gas start tank provides the energy source for engine start.

A pneumatic control system is used for engine valve operation and obtains its energy from a regulated gaseous helium system supplied by an engine-mounted tank. An electrical control system, which contains solid-state logic elements, is used to sequence the start and shutdown operations of the engine. Electrical power is stage-supplied.

Engine Ready

The engine-ready circuit monitors the conditions and events that are significant to engine start and provides a signal when all prestart electrical requirements have been met. The significant conditions monitored by the engine-ready circuit are as follows:

1. Oxidizer turbine bypass valve open
2. Connectors installed indication
3. Helium control valve deenergized
4. Ignition phase control valve deenergized
5. Start tank discharge valve control valve deenergized


LOW PRESSURE DUCT
LOX
PROPELLANT UTILIZATION VALVE
MAIN OXIDIZER VALVE
BLEED VALVES
TO PNEUMATIC CONTROLS
GHe 3200 PSIA
START TANK
GH_2
LH_2
LOW PRESSURE DUCT
TURBO PUMP
900 PSIA
8-9000 RPM TURBINE
INJECTOR
GAS GENERATOR
START TANK DISCHARGE VALVE
TURBO PUMP
27,000 RPM TURBINE
HYD PUMP
OXIDIZER TURBINE BYPASS VALVE
1200 PSIA
MAIN FUEL VALVE

6. Mainstage control valve deenergized

7. Augmented spark igniter spark system deenergized

8. Gas generator spark system deenergized

9. Mainstage OK deenergized

10. Ignition bus energized

11. Control power on

12. Mainstage OK No. 1 and No. 2 pressure switches open

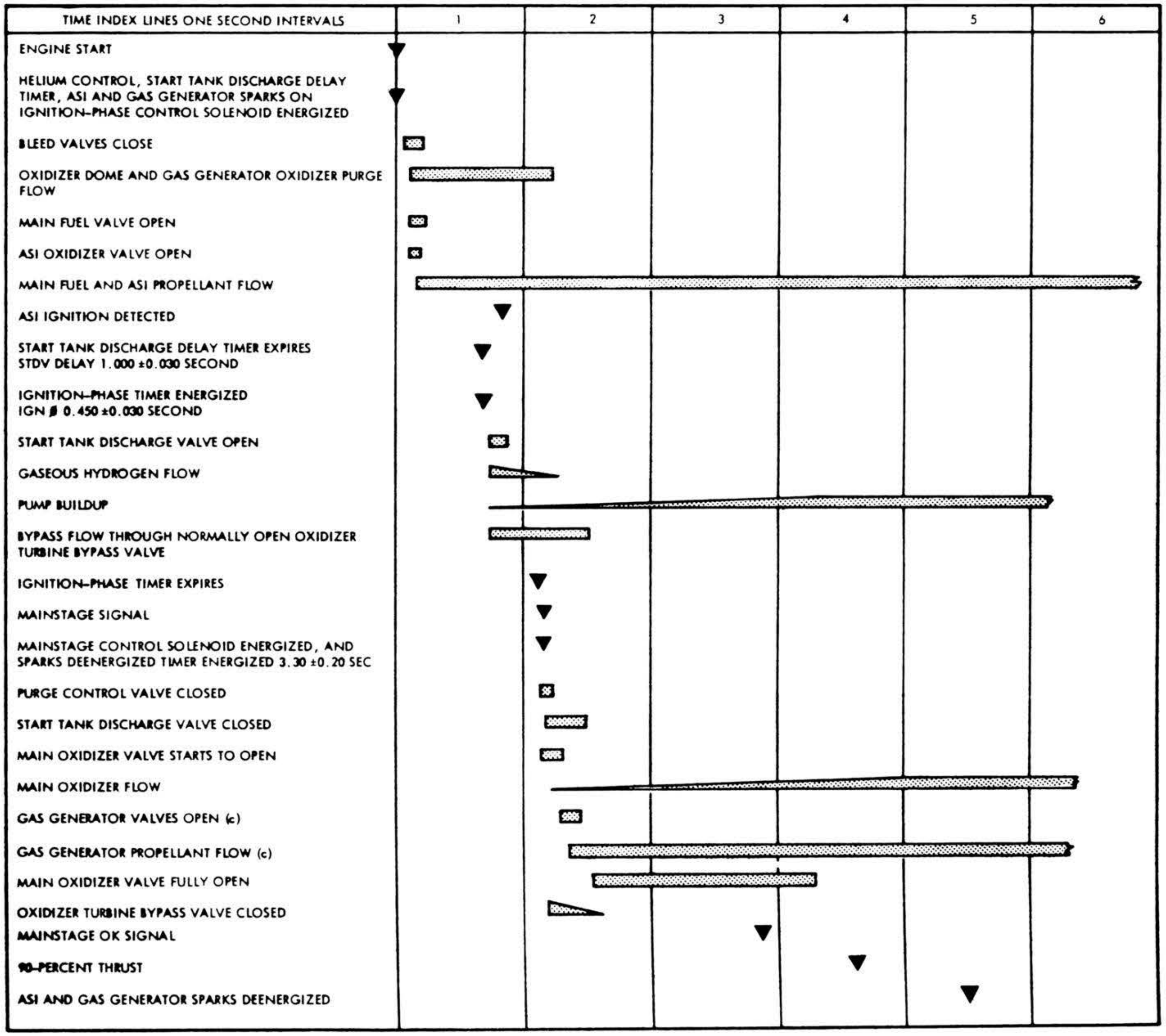
13. Absence of engine start signal

Start Sequence

When engine start is initiated (Figure 4), the spark exciters in the sequence controller are energized and provide energy for the gas generator and augmented spark igniter spark plugs. The helium control and ignition phase control valves are simultaneously energized, allowing helium from the helium tank to flow through the pneumatic regulator to the pneumatic control system. The propellant bleed valves are closed, and the oxidizer dome and gas generator oxidizer injector manifold are purged. A continuous purge is made of the oxidizer turbopump intermediate seal cavity. Opening control pressure is supplied to the oxidizer turbine bypass valve. The augmented spark igniter oxidizer bypass valve and the main fuel valve are opened. Fuel is tapped from downstream of the main fuel valve for ignition in the augmented spark igniter chamber. Fuel is now flowing under tank pressure through the stationary turbopump. Simultaneous with engine start, the start tank discharge valve (STDV) delay timer in the sequence controller is energized. Upon expiration of the timer the control valve and the ignition phase-timer in the sequence controller are energized.

As the STDV control valve energizes and the discharge valve opens, gaseous hydrogen, stored under pressure in the start tank, flows through the series turbine drive system, accelerating both turbopumps to the proper operating levels to allow subsequent ignition and power buildup of the gas generator. The relationship of fuel turbopump to oxidizer turbopump speed buildup is controlled by an orifice in the oxidizer turbine bypass duct. The normally open oxidizer turbine bypass valve permits a percentage of the gas to bypass the oxidizer turbine.

	Figure 4. J-2 Engine Start Sequence	DATE ______ SPEAKER ______ CONTROL NO. ______



At expiration of the ignition phase timer, the mainstage control valve is energized. Simultaneously, the start tank discharge valve is closed. Helium pressure is vented from the MOV closing actuator and from the opening port of the purge control valve. MOV first stage actuation is accomplished. The purge control valve closes, terminating the oxidizer dome and gas generator oxidizer injector manifold purges. Application of opening pressure, together with controlled venting of the main oxidizer valve closing pressure, provides a controlled ramp opening of the MOV. The sequence valve, located within the main oxidizer valve assembly, supplies pneumatic pressure to the opening control port of the gas generator control valve and through an orifice to the closing control port of the oxidizer turbine bypass valve.

The propellants flowing into the gas generator are ignited by spark plugs; hot-gas products of combustion pass through the exhaust duct to drive the turbines; main duct propellant flows increase; and the propellants, now flowing under pump pressure, are ignited in the thrust chamber.

Transition into mainstage occurs as the turbopumps accelerate to steady-state speeds. As oxidizer injection pressure increases toward the steady-state level, a mainstage OK signal is generated by the oxidizer injection pressure switches. There are two pressure switches; actuation of either switch will generate the mainstage OK signal. (Cutoff occurs if there is no signal before expiration of the sparks-deenergized timer.) The augmented spark igniter and gas generator spark exciters are deenergized by expiration of the sparks-deenergized timer. Cutoff will occur if both pressure-switch-activated signals (mainstage OK) are lost during mainstage operation.

Mainstage Operation

Engine chamber pressure (D013) buildup actuates the mainstage OK pressure switches within 4 seconds after S-II engine start. Chamber pressure continues to increase following the actuation of the propellant utilization system to the high EMR position. The stable level is reached within 15 seconds. Figure 14 is a composite of the thrust chamber pressure profiles as experienced on the AS-501 flight. Operation at high EMR continues until the PM system initiates modulation of the PU valve.

Engine operation continues until propellant depletion, dropout of both mainstage OK pressure switches, or instrument units (IU) command.

Cutoff Sequence

The cutoff signal is received by the sequence controller (Figure 5), which simultaneously deenergizes the mainstage control and ignition phase control valves and energizes the helium-control deenergize timer. Opening control pressure is vented from both the first- and second-stage main oxidizer valve-opening actuators, from the augmented spark igniter oxidizer valve, and from the main fuel valve.

Both the oxidizer dome purge and the gas generator oxidizer purge will flow when thrust chamber and gas generator chamber pressures decay below the level of control system pressure. The augmented spark igniter oxidizer valve, the main fuel valve, and the fast-shutdown valve actuate to allow the gas generator control valve opening control pressure to vent rapidly. All valves, except the augmented spark igniter oxidizer valve and the oxidizer turbine bypass valve, are spring-loaded to the closed position and start to close as soon as opening pressure is vented. Combustion pressure in the gas generator assists the spring in closing of the gas generator control valve. The oxidizer turbine bypass valve starts to open as closing pressure is vented.

Expiration of the helium-control deenergize timer causes the helium venting control system pressure to vent through the oxidizer dome and gas generator oxidizer purges. As the control system pressure is vented to the actuation pressure of the normally closed purge control valve, the valve actuates closed and the purges stop. Pressure is now locked up, holding the bleed valves closed. The pressure in this system is bled off through an accumulator bleed orifice. As this pressure decays, the propellant bleed valves open by spring pressure, and the cutoff sequence is complete.

ENGINE SYSTEM SUPPORT FEATURES

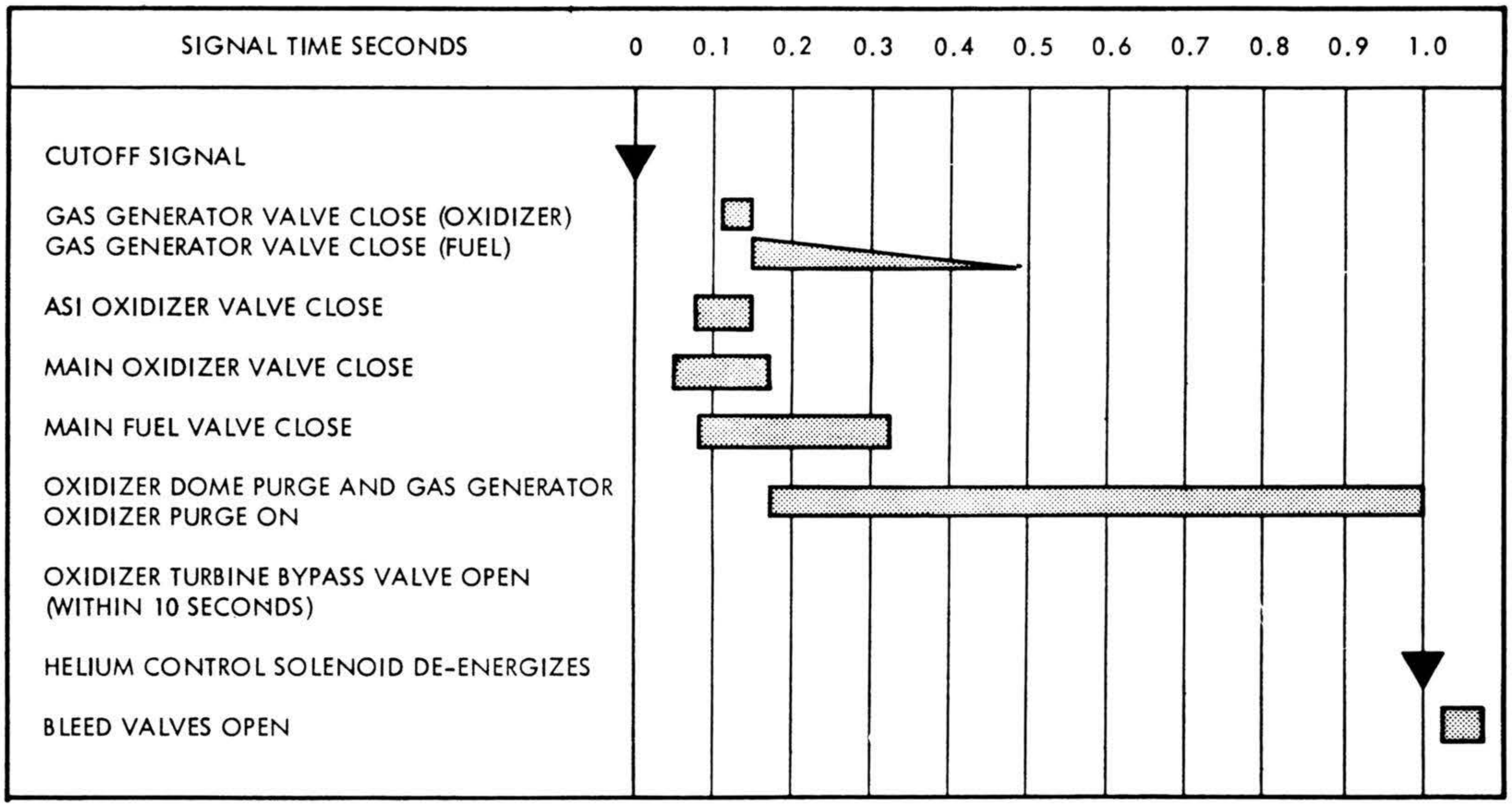
The engine system provides power and gases for functions other than pure thrust for stage operation. One of these, flight control power, is an independent function. Engine supporting stage functions are propellant tank pressurization, recirculation, and propellant utilization. Each of these major support functions are described in separate sections; the only discussion in this section will be the actual requirements of the engine system to support these functions.

Propellant Utilization

Propellant utilization capability is provided by bypassing oxidizer from the oxidizer turbopump outlet back to the inlet. The propellant utilization valve is positioned by electrical input from a vehicle propellant-tanks level-sensing device. The engine mixture ratio may be varied 1.0 mixture ratio unit.

Figure 5. J-2 Engine Cutoff Sequence

DATE ____________
SPEAKER ____________
CONTROL NO. ____________



Pressurization

This function is self supporting, since the engine requires a minimum net positive suction head (NPSH) at each of the propellant inlets of 178 feet of LH_2 and 42.7 feet of LOX. To meet these requirements, propellant gases are supplied to the stage pressurization system. GOX is furnished by passing LOX through the heat exchanger in each engine, where it is heated to a gaseous state before being supplied to the stage pressurization system. GH_2 is bled directly from the four outboard thrust chambers and supplied to the stage LH_2 tank pressurization system.

Recirculation

Recirculation takes place prior to engine start and does not require engine operation, except that propellant flows through the oxidizer and fuel pumps. The LOX, after passing through the oxidizer pump, is circulated through the LOX bleed line and ultimately back to the LOX tank. LH_2 is routed through the fuel pump and back to the LH_2 tank through the fuel bleedline.

Flight Control

Thrust vector control is achieved by gimbaling the entire engine. Flexible inlet bellows are provided to allow the engine to be gimbaled. A gimbal is installed at the center of the thrust chamber dome, and gimbal actuator attach points are provided on the thrust chamber body. Gimbal actuators are not furnished as part of the engine. Hydraulic pressure for gimbal actuation is provided by the vehicle-installed hydraulic system which receives pressure from an engine-mounted hydraulic pump.

ENGINE SYSTEM CONDITION AT LIFTOFF

Figure 6 lists the engine system conditions and requirements at liftoff.

MSC CONSOLE DISPLAY

Figure 7 indicates those measurements on display at MSC. Numerous other measurements also give indirect indications of engine operation.

ENGINE SYSTEM FLIGHT SEQUENCE

The engine system flight sequence is shown in Figure 8.

Figure 6. Engine System Conditioning Requirements

DATE ____________
SPEAKER ____________
CONTROL NO. ____________

	LIFT OFF	ENGINE START
• ENGINE HYDROGEN START TANK TEMPERATURE	-146 TO -303F	-140 TO -300F
• ENGINE HYDROGEN START TANK PRESSURIZED TO:	1180 - 1360 PSIA	1200-1400 PSIA
• ENGINE HELIUM START PRECHARGE TO	2800 TO 3450 PSIA	—
• ENGINE THRUST CHAMBER JACKET CHILLDOWN TO:	-200°F MAX	-150F MAX
• ENGINE LOX NPSH: NULL PU		31.9 FT
• ENGINE LH_2 NPSH: NULL PU		164 FT

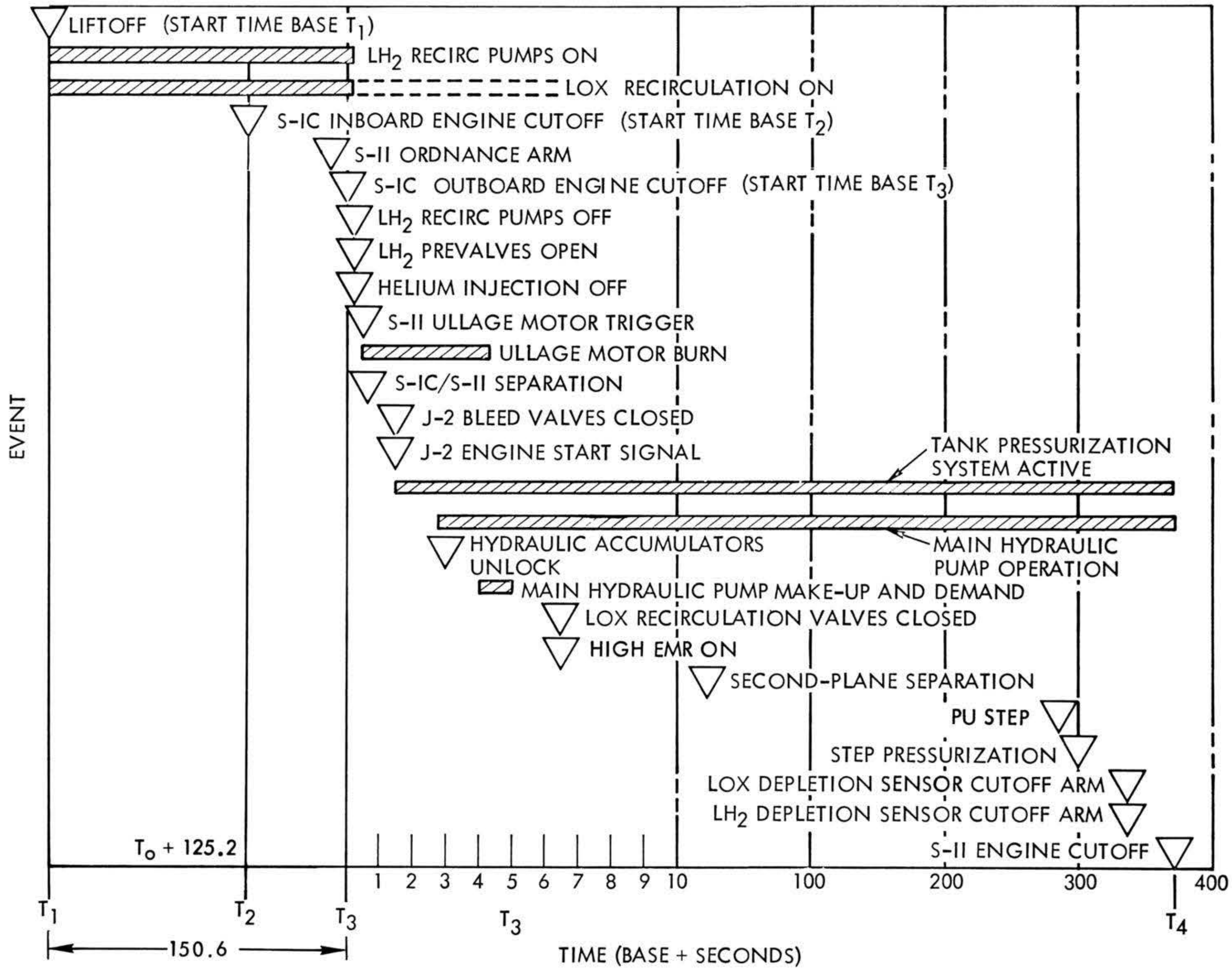
	Figure 7. MSC Console Display	DATE ______ SPEAKER ______ CONTROL NO. ______

MSC CONSOLE DISPLAY

- THRUST CHAMBER PRESSURE (ALL ENGINES) DO13 - 201/205
- THRUST NOT OK (ALL ENGINES)
  K442/446 - 207 THRUST OK NO. 1
  K447/451 - 207 THRUST OK NO. 2
- LOX PUMP INLET PRESSURE (ALL ENGINES) DO91-201/205
- LH_2 PUMP INLET PRESSURE (ALL ENGINES) DO92-201/205
- ENGINE HELIUM TANK PRESSURE (ALL ENGINES) DO15-201/205
- START TANK PRESSURE (ALL ENGINES) DO16 - 201/205

Figure 8. S-II Mechanical Systems Flight Sequence

DATE
SPEAKER
CONTROL NO.



MAJOR ENGINE VARIATION

The only major operational change to the engine system is the increase in thrust from 1,125,000 pounds on the S-II-1, S-II-2, and S-II-3 and 150,000 pounds on S-II-4 and subsequent stages. This increase does not require any significant hardware changes on the engine, but is basically a reorificing of the engine. Other changes required are an increase in the thrust chamber pressure from 762 psi to 779.2 psi and an increasd gas-generator pressure. These changes obtain a thrust increase of 5000 pounds per engine.

ENGINE SYSTEM PERFORMANCE AND REQUIREMENTS

The engine system performance requirements are shown in Figures 9 through 19. Also included on these charts are AS-501 actual performance curves on data points.

AS-501 Performance Summary

The S-II-1 propulsion system operation during the AS-501 flight was entirely satisfactory. No serious anomalies were observed. The S-II stage performance was lower than predicted by very small percentages. Stage thrust at 60 seconds of mainstage operation was 1.4 percent below the AS-501 flight prediction value (March 1967). At the same time period, the total vehicle flowrate is 1.7 percent below prediction, while the specific impulse exceeds the predicted level by 0.23 percent.

The lower performance is attributable to Engines 2, 3, and 5 (serial numbers J-2043, J-2030, and J-2028). These engines required replacement of LOX turbopump assemblies after stage acceptance. The effects of these changes were not incorporated into the flight prediction nor were they completely known prior to flight. Performance of Engines 1 and 4 (no turbopump changes) was very close to predicted.

Engine standardized performance repeatability was within stage acceptance allowable range. Engine thrust, mixture ratio, and specific impulse were within 1 percent for all engines except Engine 3, which deviated by -2.6 percent on thrust and -1.5 percent on mixture ratio. The stage acceptance allowable repeatability ranges are 3, 2, and 2 percent for thrust, EMR, and I_{sp}.

At liftoff and S-II ESC, engine start tank, helium tank, and thrust chamber jacket conditions were within the required limit.

S-II burn time was approximately 5 seconds longer than predicted because of low propellant flowrates and a lower-than-predicted reference mixture ratio (RMR) setting.

Figure 9. Pressure Comparison of AS-501 Engine 1
(Engine LH_2 Inlet Static Press)

DATE
SPEAKER
CONTROL NO.

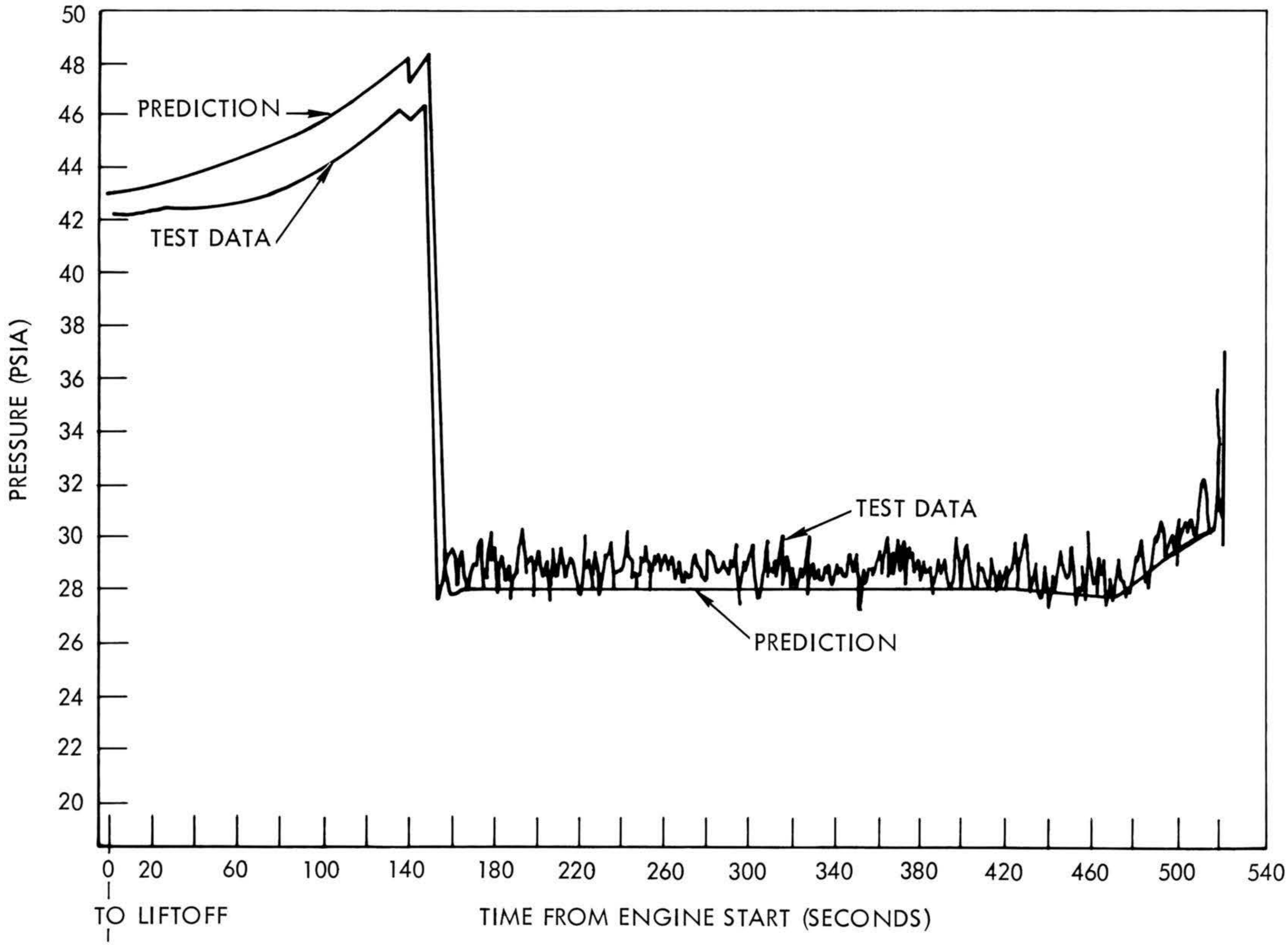


Figure 10. Comparison of AS-501 Engine 5 LH_2 Inlet Total Pressure

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CONTROL NO. ____________

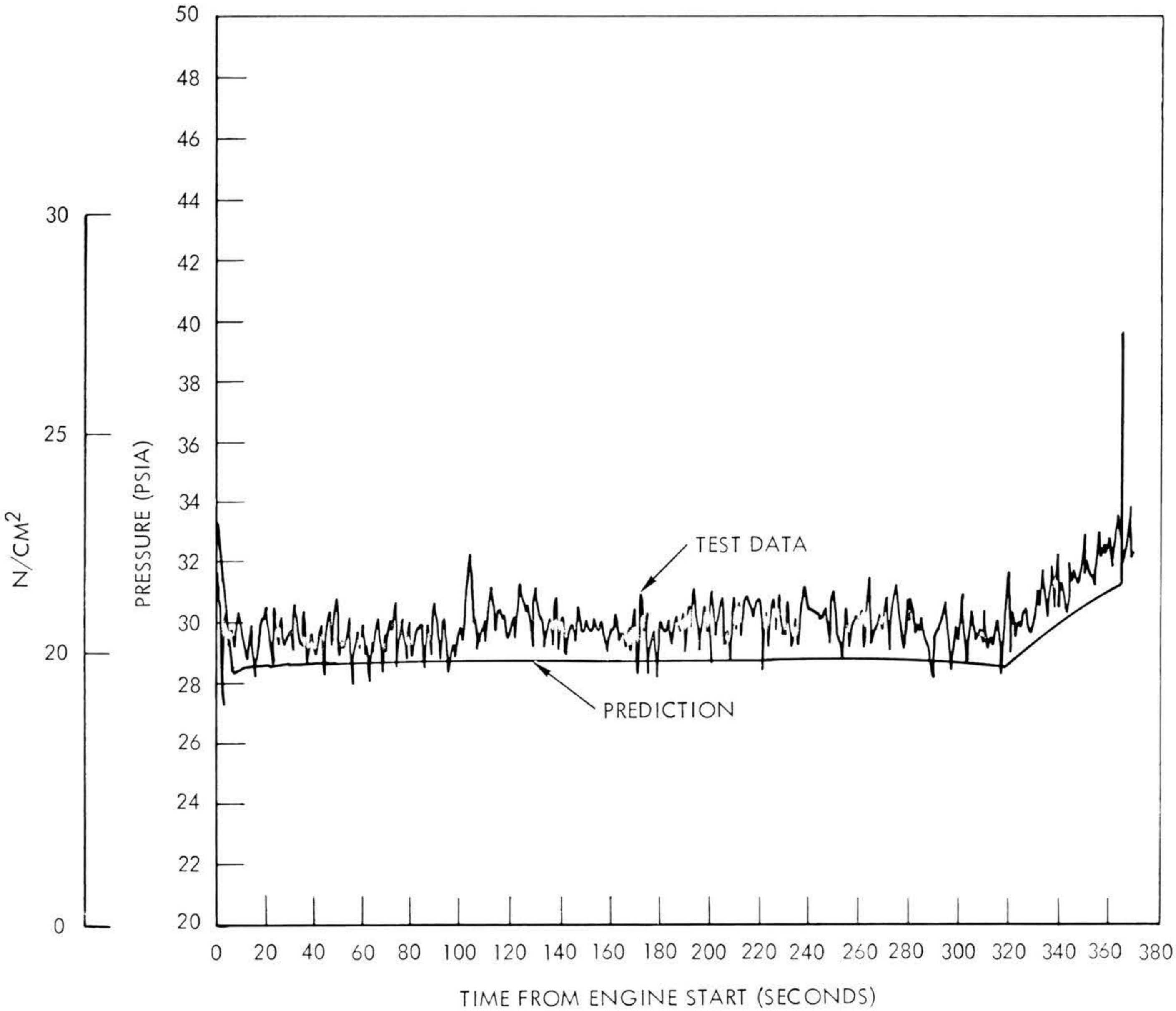

Figure 11. Comparison of AS-501 Engine 1 LOX Inlet Static Pressure

DATE
SPEAKER
CONTROL NO.

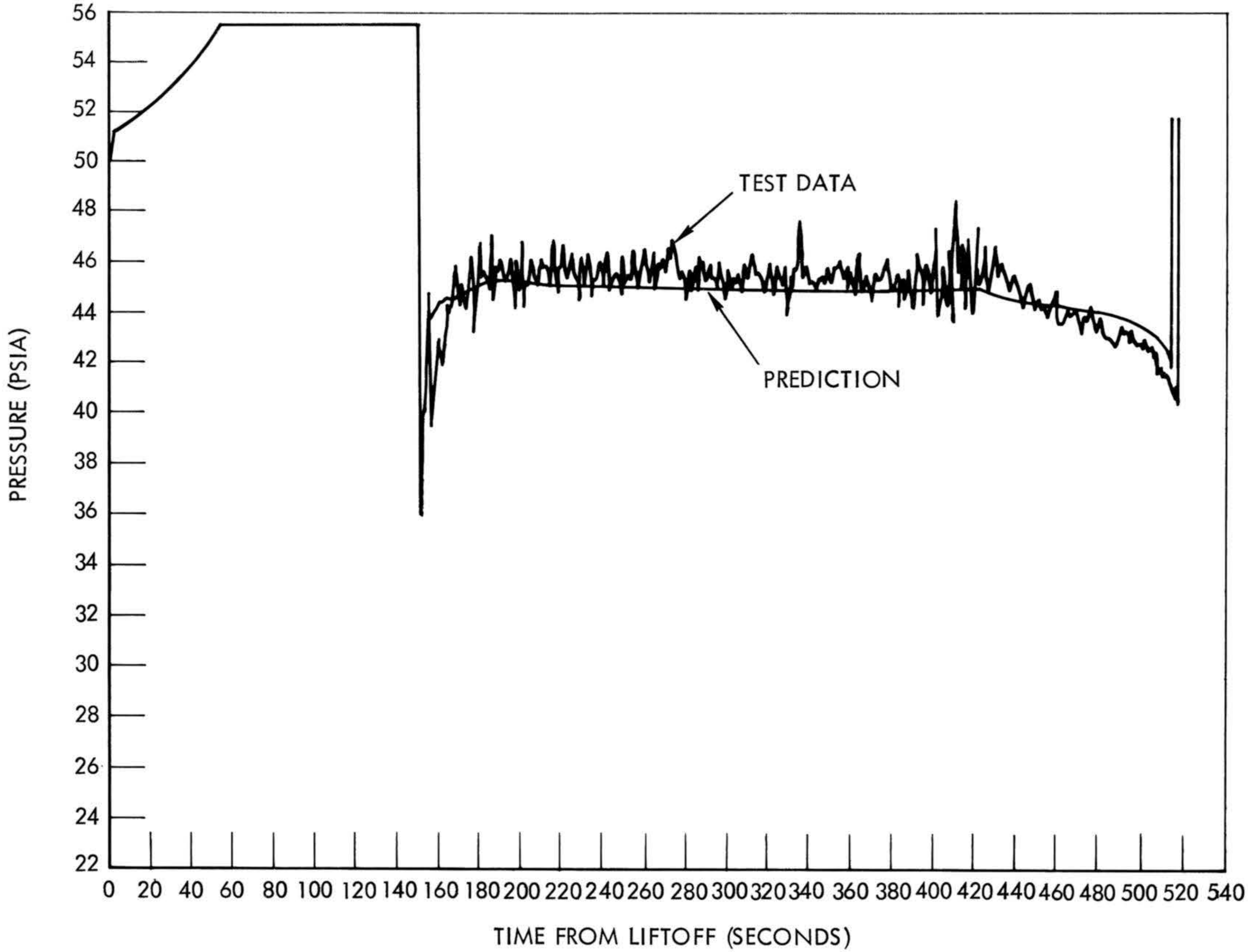

Figure 12. Comparison of AS-501 Engine 5 LOX Inlet Total Pressure

DATE ____________
SPEAKER ____________
CONTROL NO. ____________

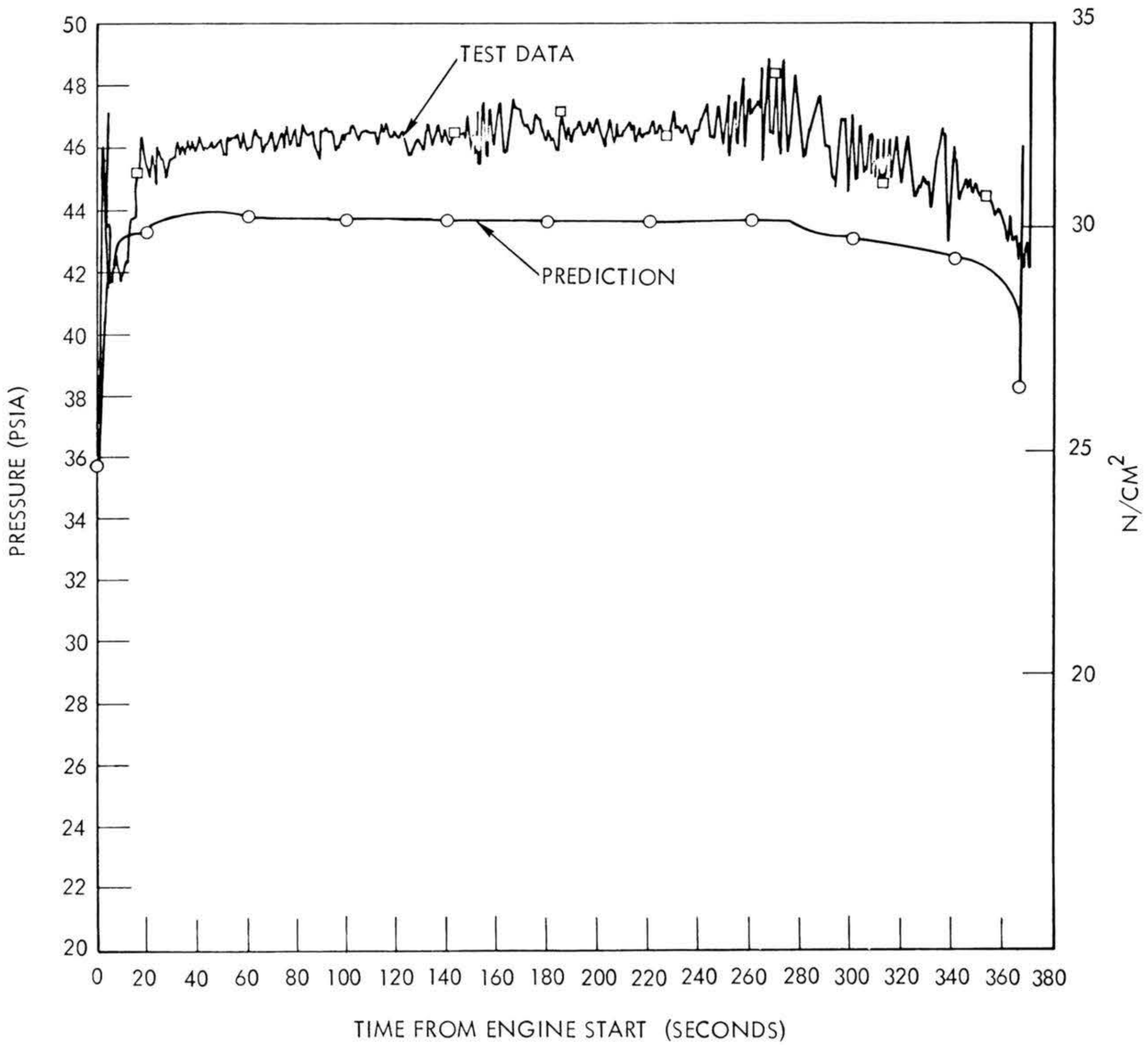

Figure 13. Thrust Chamber Chill Temperature —AS-501

DATE ____________
SPEAKER ____________
CONTROL NO. ____________

ENGINE NO.	AUTO SEQUENCE PERMISSIVE (DEGREES)	LIFTOFF MINUS 20 SECONDS (REDLINE)	LIFT OFF	S-II ENGINE START
	161K (-170F) MAXIMUM	144.3K (-200 F) MAXIMUM		161 K (-170 F)
FLIGHT MEASUREMENTS ACTUALS				
201	119.1 K (-245 F)	102.6 K (-275 F)	104.2 K (-272 F)	130.1 K (-224 F)
202	125.2 K (-234 F)	100.8 K (-278 F)	101.3 K (-277 F)	125.7 K (-233 F)
*203	145.4 K (-198 F)	115.9 K (-251 F)	115.9 K (-351 F)	138.6 K (-210 F)
204	130.1 K (-224 F)	108.8 K (-264 F)	111.3 K (-259 F)	141.5 K (-206 F)
205	124.0 K (-236 F)	103.0 K (-274 F)	105.4 K (-270 F)	136.8 K (-213 F)
RECOMMENDED MAXIMUM TEMPERATURE REQUIREMENTS				
	150 K (-190 F)	127.5 K (-230 F)		
*SLOW RESPONSE TRANSDUCER				

	Figure 14. Thrust Chamber Pressure (Injection) Versus Time for Test 501	DATE ______ SPEAKER ______ CONTROL NO. ______

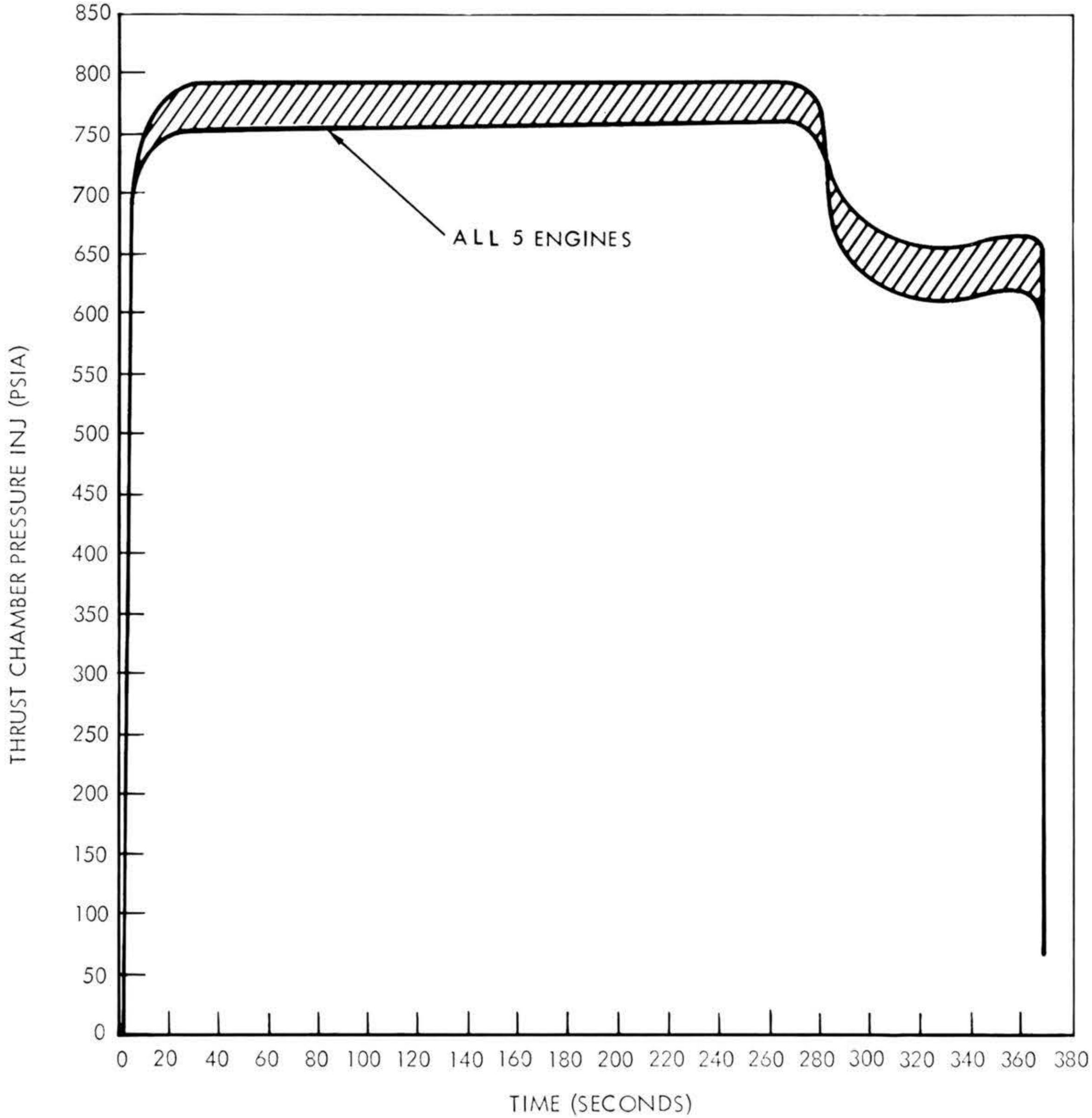

	Figure 15. Start Tank Pressure	DATE ______ SPEAKER ______ CONTROL NO. ______

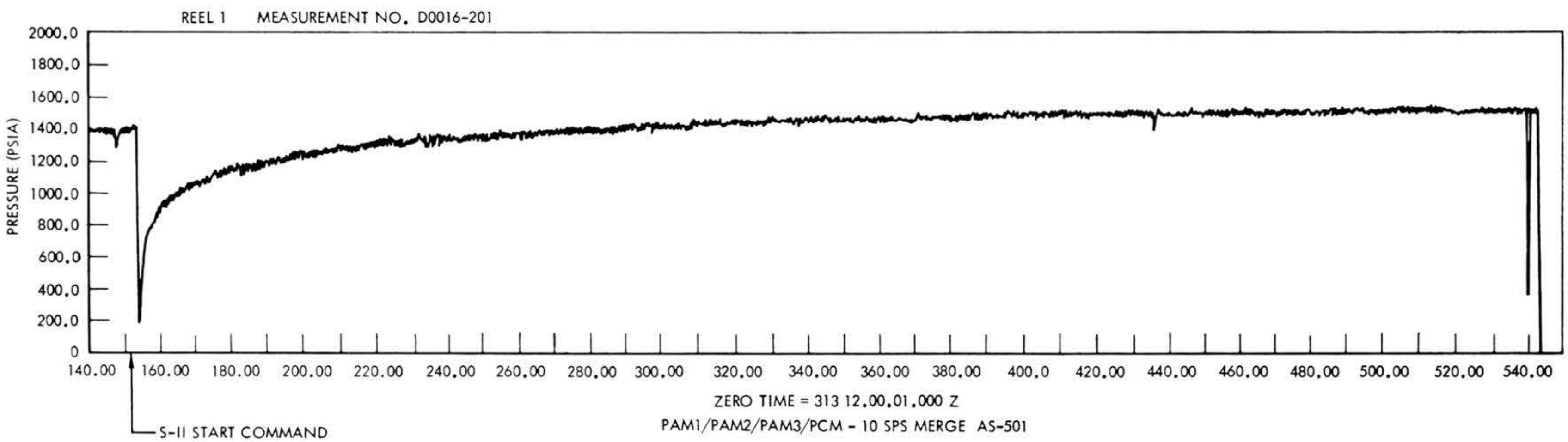

Figure 16. Helium Tank Pressure

DATE ____________
SPEAKER ____________
CONTROL NO. ____________

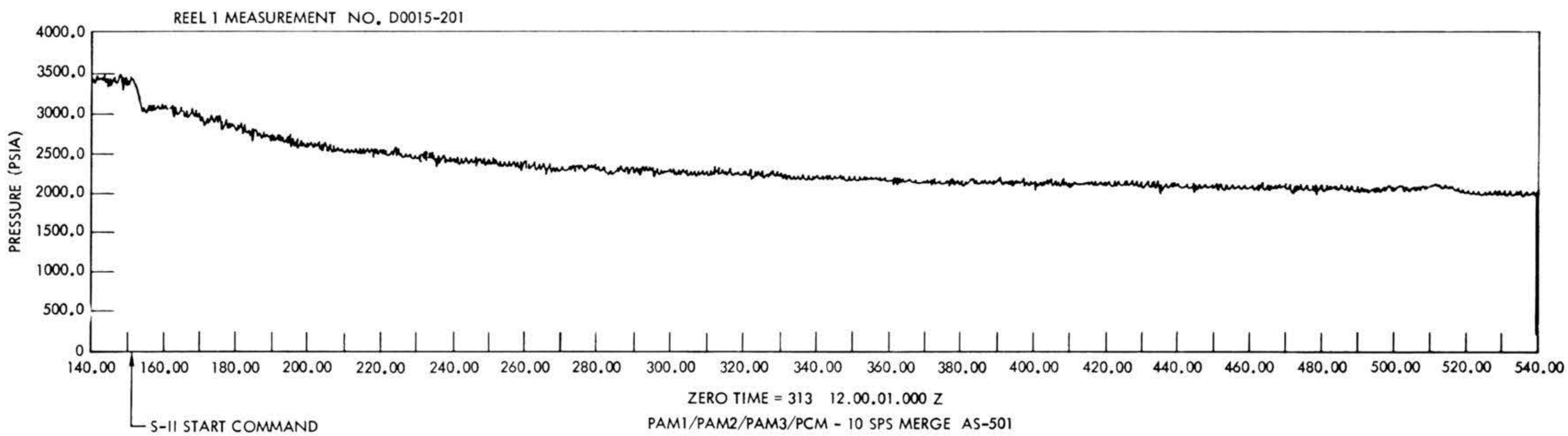

Figure 17. S-II Engine Thrust Buildup, AS-501 Flight

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CONTROL NO. ____

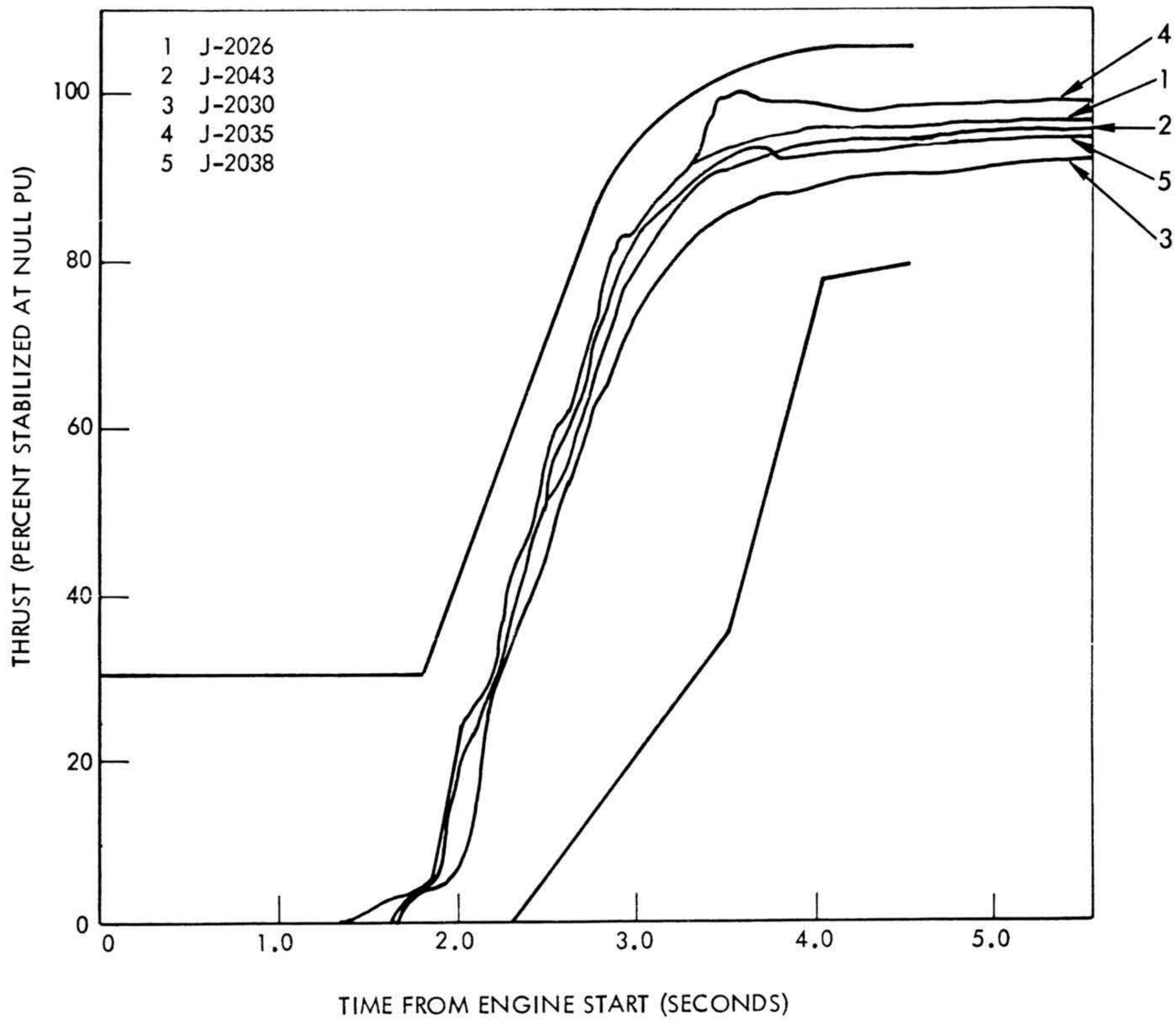


Figure 18. S-II Mainstage Thrust Profile, AS-501 Flight

DATE ____________
SPEAKER ____________
CONTROL NO. ____________

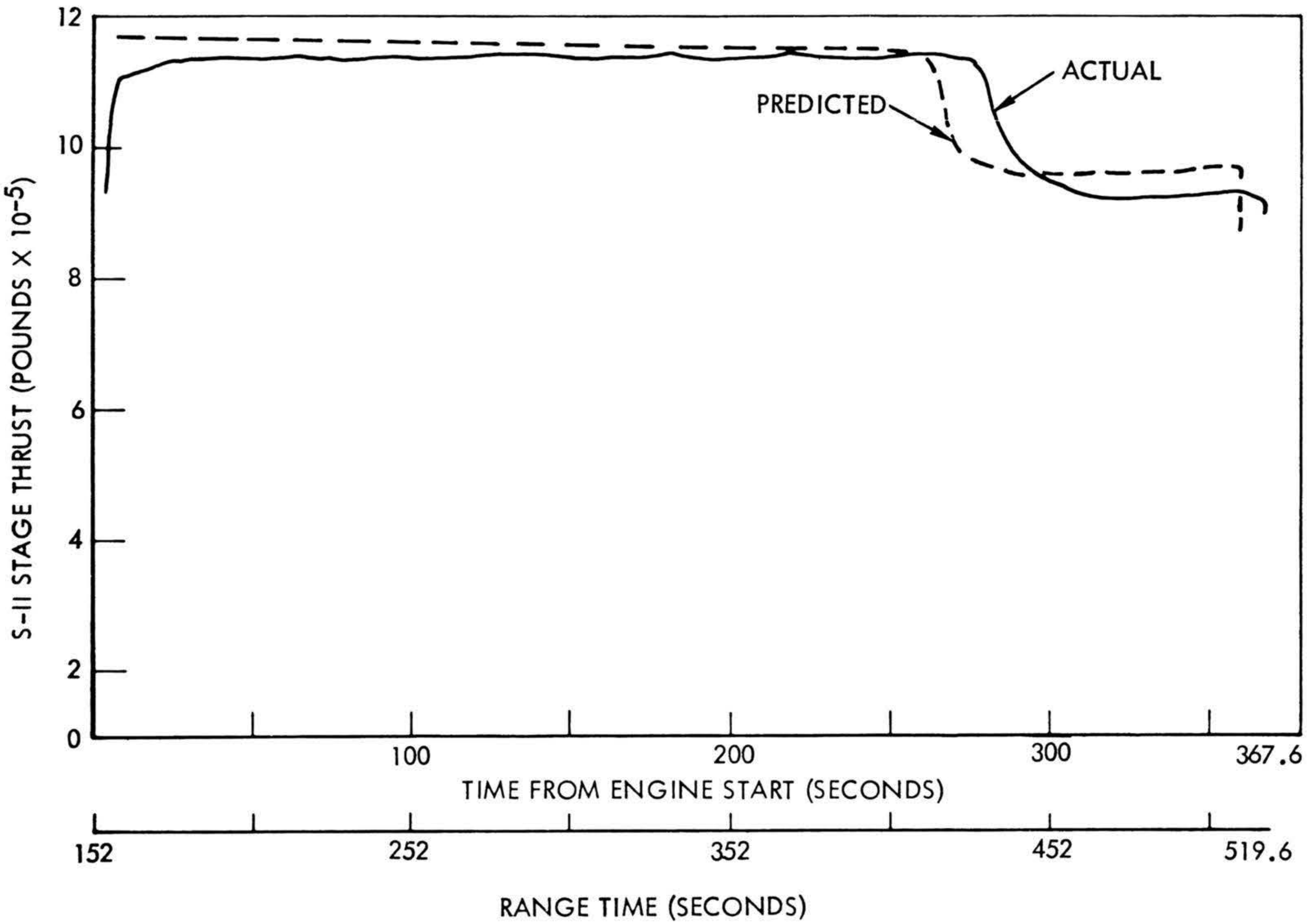
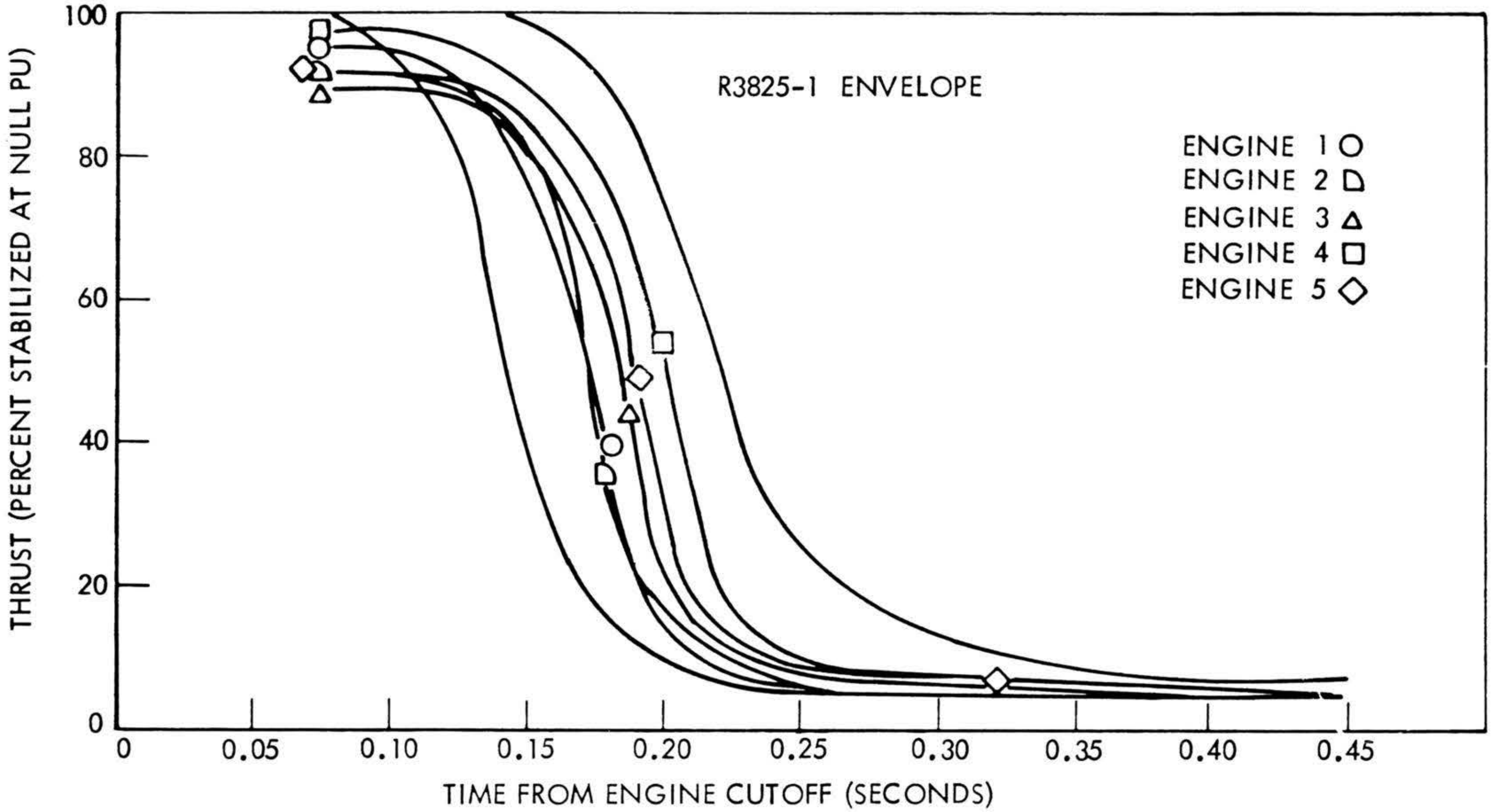


Figure 19. J-2 Engine Thrust Decay Rates	DATE ________ SPEAKER ________ CONTROL NO. ________



J-2 ENGINE THRUST DECAY RATES

The LH_2 pressurization system functioned as required, supplying more than adequate NPSH to the engines at start and throughout mainstage. (See Figures 9 and 10.)

The LOX pressurization system functioned as required, supplying more than adequate NPSH to the engines at start and throughout mainstage. (See Figures 11 and 12.)

The LOX and the LH_2 recirculation systems functioned satisfactorily. Propellant conditions were within established requirements at the engine inlets and at the LOX pump discharge for engine start.

Thrust Chamber Chill

The thrust chamber jacket temperatures at liftoff were satisfactory, although they were on the low side of the predicted range. The prelaunch redline maximum allowable was 144.3 K (-200 F). Engine 3, which had a slow responding transducer, was highest at 115.9 K (-251 F); the other four engines ranged between 108.8 K and 102.6 K (-264 and -275 F). The auto-sequence permissive temperature maximum allowable was 161 K (-170 F). Engine 3 was high at 145.4 K (-198 F); the other four engines ranged between 130.1 K and 119 K (-224 and -245 F). Flight test data are shown in Figures 13 and 14.

Warm-up rates exceeded those predicted—22.8 K to 33.9 K (41 F to 61 F) as compared to a predicted 16.7 K (30 F) rise. The high warm-up rates, coupled with the low chill, resulted in nominal conditions at engine start. Engine start maximum allowable was 172 K (-170 F, -150 F for S-II-2 and subs); actuals were between 141.5 K and 125.7 K (-206 and -233 F).

The high warm-up rates are concluded to be the result of transient conditions (of temperatures still reducing) at the termination of chill. The resulting post-chill temperature stabilization yielded warm-up rates in excess of those predicted.

Thrust Chamber Heat-Up Rates

S-IC boost rates were 9.78 to 11.15 N/ cm^2/min (14.2 to 16.3 psi/ minute) for Engines 1, 3, and 5. Engines 2 and 4 rates were 6.55 to 7.31 N/ cm^2/min (9.5 to 10.6 psi/minute); it is concluded that relief valve cracking was occurring on these two engines.

Engine Helium Tank (Figures 15 and 16)

Chilldown. Lower temperatures were experienced during launch chilldown than the countdown demonstration test (CDDT)—109.3 K versus 112 K (-263 F vs -258 F) as a result of the extended start tank chilldown. The extended chilldown resulted in helium tank temperatures of 109.3 K to 116.3 K (-263 to -250 F).

Heat-Up Rates. Rates from prelaunch verification to engine start were 21.7 to 30.7 N/ cm^2/min (32 to 45 psi/minute).

Start Tank Versus Helium Tank Temperature Differentials. At prelaunch verification, the temperature differential was 2.8 K to 4.4 K (5 to 8F). At engine start, the temperature differential was 0.55 K to 3.33 K (1 to 6 F). The start tank is always the coldest.

Engine Thrust Buildup

Individual J-2 engine thrust buildups were completely satisfactory. Figure 15 shows that each engine lies entirely within the required envelope. The slowest thrust buildup is exhibited by engine J-2030, which is a repeat of its performance during stage acceptance. The most rapid buildup occurs on engine J-2035. As expected, all buildup rates are faster and more uniform than measured during stage acceptance at sea level.

The small disturbance apparent in the buildup of J-2035 approximately 3 seconds after S-II engine start is attributed to the action of the main LOX valve. Main thrust chamber pressure and main LOX valve position are shown on a common time axis in Figure 17. The initial second-position ramp-rate for the valve is quite slow, resulting in a more rapid than normal engine buildup. After the excess hydraulic forces on the valve gate are relieved, the valve ramps rapidly to the full open position, and the system returns to its normal operating level.

Similar operating characteristics were observed during stage acceptance testing of S-II-3 at MTF and have occurred many times during engine acceptance. The engine manufacturer does not consider this characteristic to be detrimental to engine reliability. No problems resulted in mainstage operation as a result of this item.

No other abnormalities were observed during the engine buildup transition period.

Propulsion System Performance - Main Stage (Figure 18)

As a total stage, the S-II-1 performance was slightly below the official predicted level for the AS-501 flight.

On an individual engine basis, it is apparent that the deviations from predicted performance are concentrated in the three J-2 engines that were subject to replacement of LOX turbopump assemblies prior to launch. These are Engine Positions 202, 203, and 205. In addition, engine J-2043 (202) was reorificed prior to flight. Table 6.3-2 presents a comparison of actual and predicted performance parameters for each J-2 engine. Excellent agreement is indicated between predicted and actual thrust for Positions 201 and 204. The maximum deviation is less than +2500 Newtons (560 pounds). For Engine 203, however, the deviation is -26,305 Newtons (-6614 pounds). Official flight predictions for AS-501 were not adjusted for the hardware changes in the J-2 engines prior to launch.

No significant anomalies were observed during S-II mainstage operation.

Stage performance determined from flight instrumentation is in good agreement with the simulated performance based upon trajectory data.

Stage Thrust Decay (Figure 19)

The engine cutoff signal was received 367.624 seconds after S-II start. At this time, the total stage thrust was 4,084,883 Newtons (918,364 pounds), and the average EMR was 4.52. The stage thrust decayed to 5 percent of this level in approximately 410 milliseconds.

Thrust decay was computed using the engine manufacturer's suggested relationship between actual thrust (as measured by a load cell) and thrust computed from the measured chamber pressure. Use of this relationship is required due to the design of the chamber pressure sensing port, which creates a significant time lag during pressure decay periods. In addition, the 10.34 Newtons/cm^2 (15 psi) bias associated with the instrumentation tap design during mainstage was not used for computing thrust decay.

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ULLAGE MOTOR SYSTEM

FUNCTION

To ensure stable flow of propellants into the J-2 engine during engine start, a small amount of forward acceleration is required to settle the propellants in their tanks. This acceleration is provided by ullage motors.

DESIGN REQUIREMENTS AND FEATURES

It has been determined that before and during engine start, 0.067 g acceleration for 3.25 seconds is necessary to meet these requirements. The acceleration and duration are provided by utilizing solid propellant rocket motors.

The four ME901-0089, 23,000-pound thrust ullage motors are evenly spaced around the aft end of the S-IC/S-II interstage. Mounted within fairings, the motors are parallel to the vehicle centerline. The motor nozzles are just above the first separation plane and are canted outward 10 degrees to reduce exhaust plume impingement. With any one ullage motor out, the remaining motors are capable of maintaining a minimum vehicle acceleration of 0.067 g during the S-IC/S-II separation sequence.

SYSTEM DESCRIPTION

The S-II ullage motor system (Figure 20) consists of two exploding bridgewire (EBW) firing units, two EBW detonators, two confined detonating fuse (CDF) manifolds, 17 CDF assemblies, 8 CDF initiators (two per motor), and four solid propellant ullage motors. The EBW firing units, EBW detonators, and CDF manifolds are installed on a panel in the S-IC/S-II interstage. The CDF assemblies connect the CDF manifolds with the two initiators on each ullage motor. The cross section of a typical motor is shown in Figure 21.

SEQUENCE OF OPERATIONS

The S-II ullage motor firing sequence begins in the EBW firing units. These units are armed by a signal from the instrument unit (IU) at S-IC inboard engine cutoff by the application of 28-vdc power to the charging circuits, in which the storage capacitors are charged to 2300 volts. At S-IC outboard engine shutdown, the IU sends a command through the S-II switch selector and the S-II separation controller, which triggers the EBW firing unit

Figure 20. Ullage Motor System (Block Diagram and Location)

DATE ____________
SPEAKER ____________
CONTROL NO. ____________

NOTE:
REDUCED TO
4 MOTORS FOR
S-II-2 & SUBS

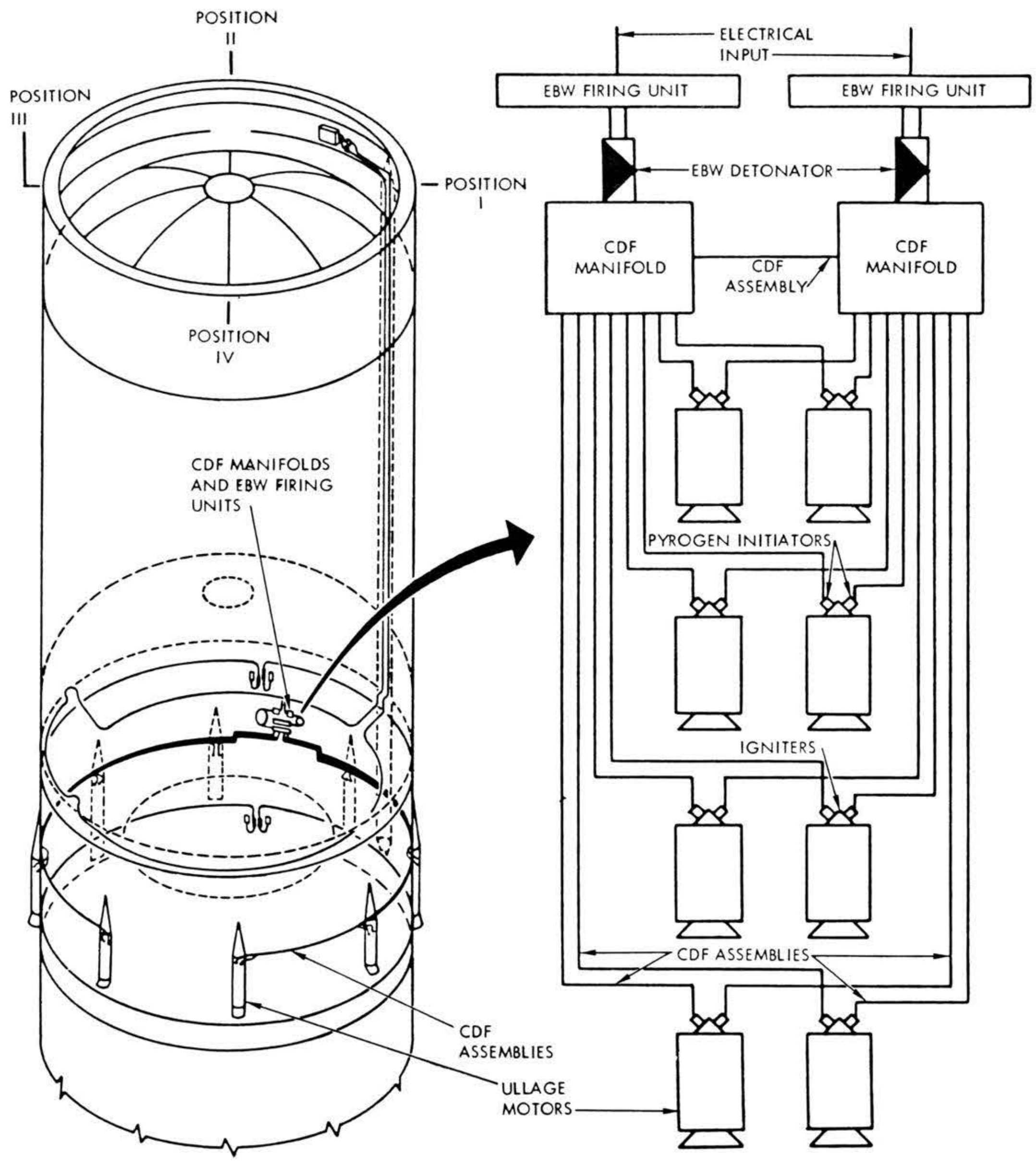

Figure 21. Ullage Motor

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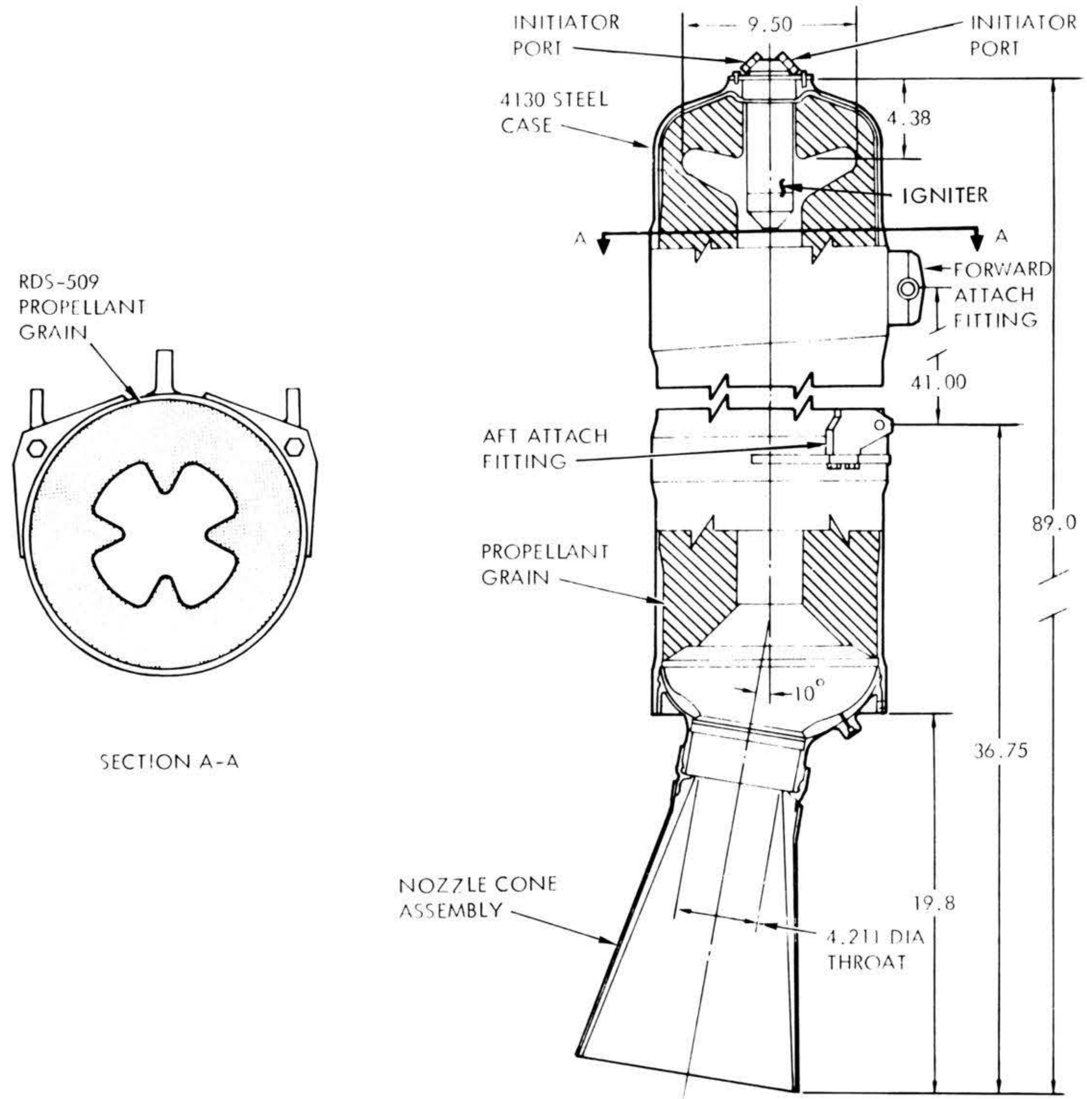
CONTROL NO. ____________



in each of the two parallel ordnance trains (Figure 1) and explodes the bridgewire in the EBW detonators. The resulting detonation propagates through the CDF manifolds, CDF assemblies, and CDF initiators to the ullage motors. Either initiator will start the igniter, which is an integral part of the motor. A crossover CDF assembly between CDF manifolds provides added system reliability. An additional reliability feature is a complete redundant signal system from the IU (S-II-3 and subsequent stages).

FLIGHT PERFORMANCE

Performance data obtained from the AS-501 (S-II-1) flight are presented in Figure 22 and Table 1.

DATE ____________
SPEAKER ____________
CONTROL NO. ____________

Figure 22. S-II Ullage Motors, Composite Curve, Motors 1 Through 8

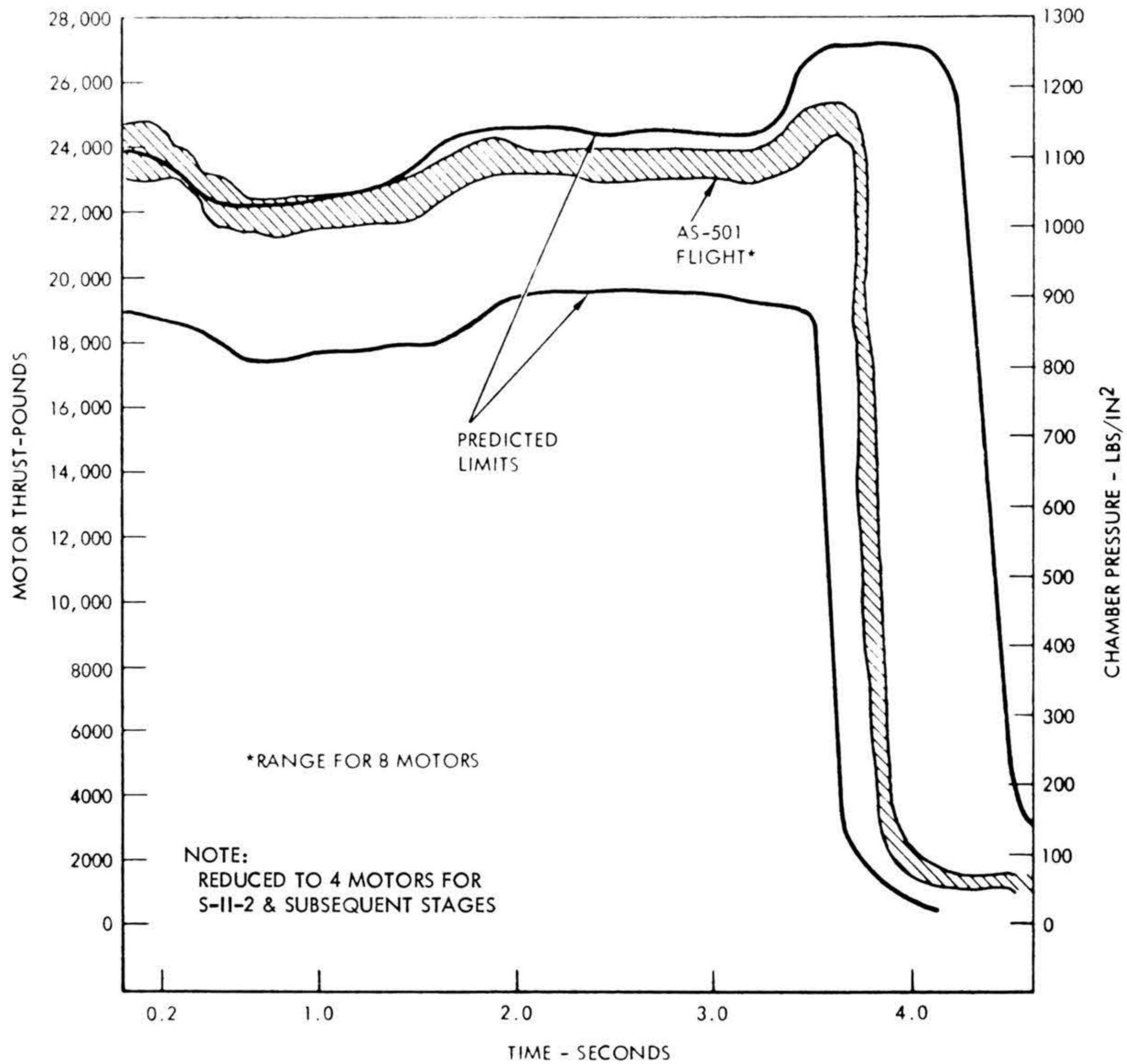


	Table 1. AS-501 Flight Analysis, S-II Ullage Motor	DATE ____ SPEAKER ____ CONTROL NO. ____

MOTOR	1	2	3	4	5	6	7	8
BURN TIME (SECONDS)	3.79	3.71	3.74	3.74	3.77	3.70	3.72	3.77
MAXIMUM THRUST (POUNDS)	25,100	27,200	24,800	24,800	25,000	26,200	25,400	—
AVERAGE BURN TIME CHAMBER PRESSURE (PSIA)	1018	1038	1010	1010	1020	1015	1020	1030
AVERAGE BURN TIME THRUST (POUNDS)	—	23,796	23,188	23,101	23,433	23,347	23,433	23,688

SECTION II. S-II STAGE PROPELLANT MANAGEMENT SYSTEM

FUNCTION

The flight propellant management (PM) system is comprised of a propellant utilization (PU) subsystem and an engine cutoff (ECO) subsystem. The basic function of the PU system (Figure 23) is to control the engine mixture ratio during S-II flight to achieve optimum performance and simultaneous depletion of LOX and LH_2. Significant Apollo payload gain is the end result. The PU subsystem also performs the function of loading and mass indication. (See block diagram Figure 24.)

The function of the ECO subsystem is to detect and provide a signal when propellants in LOX or LH_2 tanks have depleted to the minimum level that will allow safe engine shutdown.

SYSTEM FEATURES

The PU subsystem is of the continuous capacitance-type and provides the capability for programmed mixture ratio control and simultaneous depletion of propellants which provides significant payload gains. The capacitance-type PU system also provides a broad adjustability of full propellant load and a continuous mass indication regardless of propellant density. (Location of probes is shown on Figure 25.) The ECO subsystem is of the point-sensor type and provides the capability for LOX and LH_2 depletion cutoff.

SYSTEM DESCRIPTION

Propellant Utilization (PU)

The PU subsystem provides a signal for controlling the J-2 engine propellant utilization valves, which bypass LOX around the engine pumps for control of the engine mixture ratio (EMR).

In closed-loop operation, this signal represents the deviation of the ratio of propellants remaining in the tanks from that selected to achieve simultaneous tank depletion and is generated by the PU computer. The PU subsystem starts closed-loop operation upon receipt of a signal from the S-IVB interface. The PU subsystem controls the engine PU valves to a reference mixture ratio (RMR). Proper selection of the actual tanked

Figure 23. Propellant Utilization System

DATE ____________
SPEAKER ____________
CONTROL NO. ____________

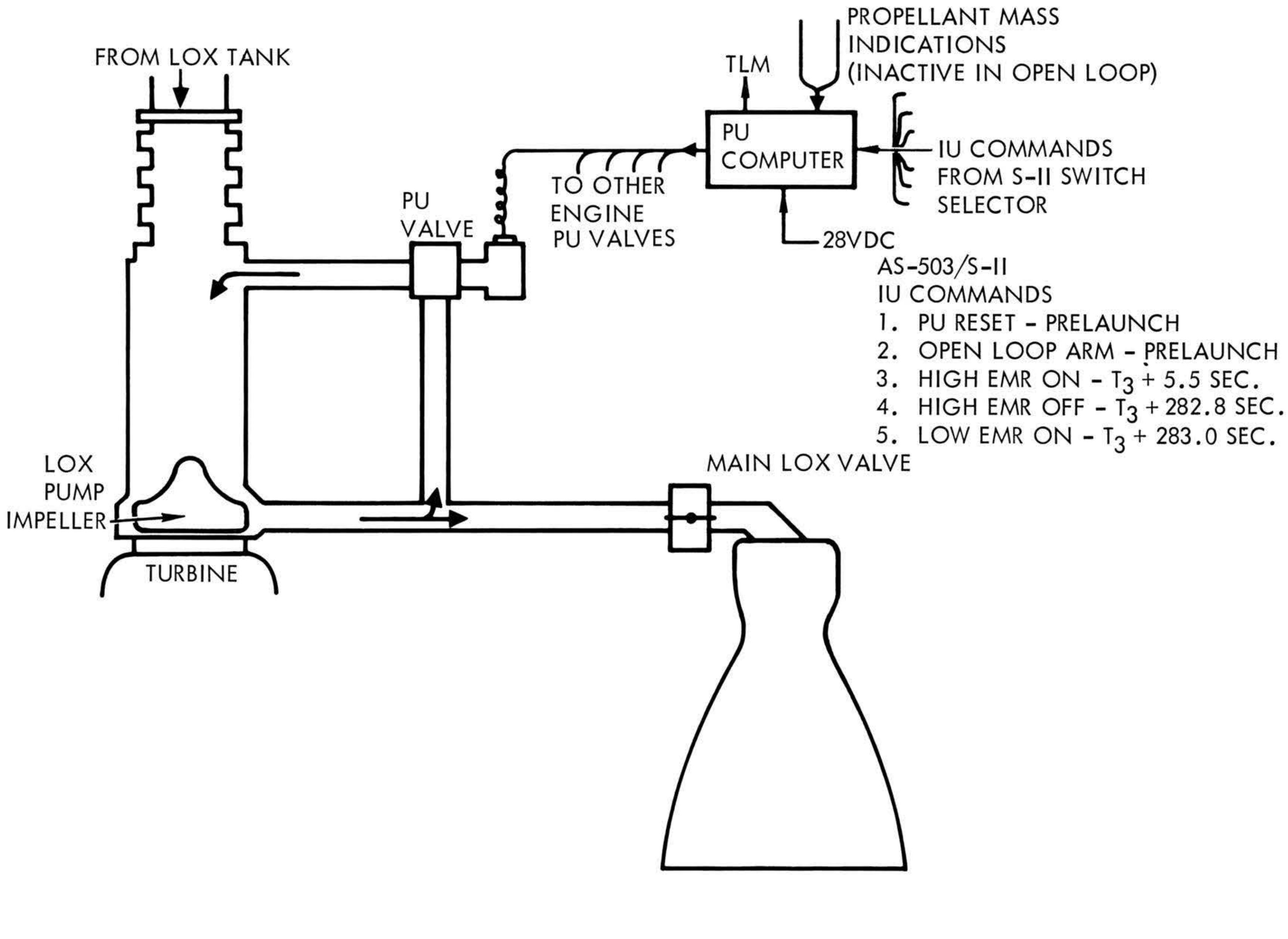


Figure 24. Propellant Utilization System Block Diagram

DATE ______
SPEAKER ______
CONTROL NO. ______

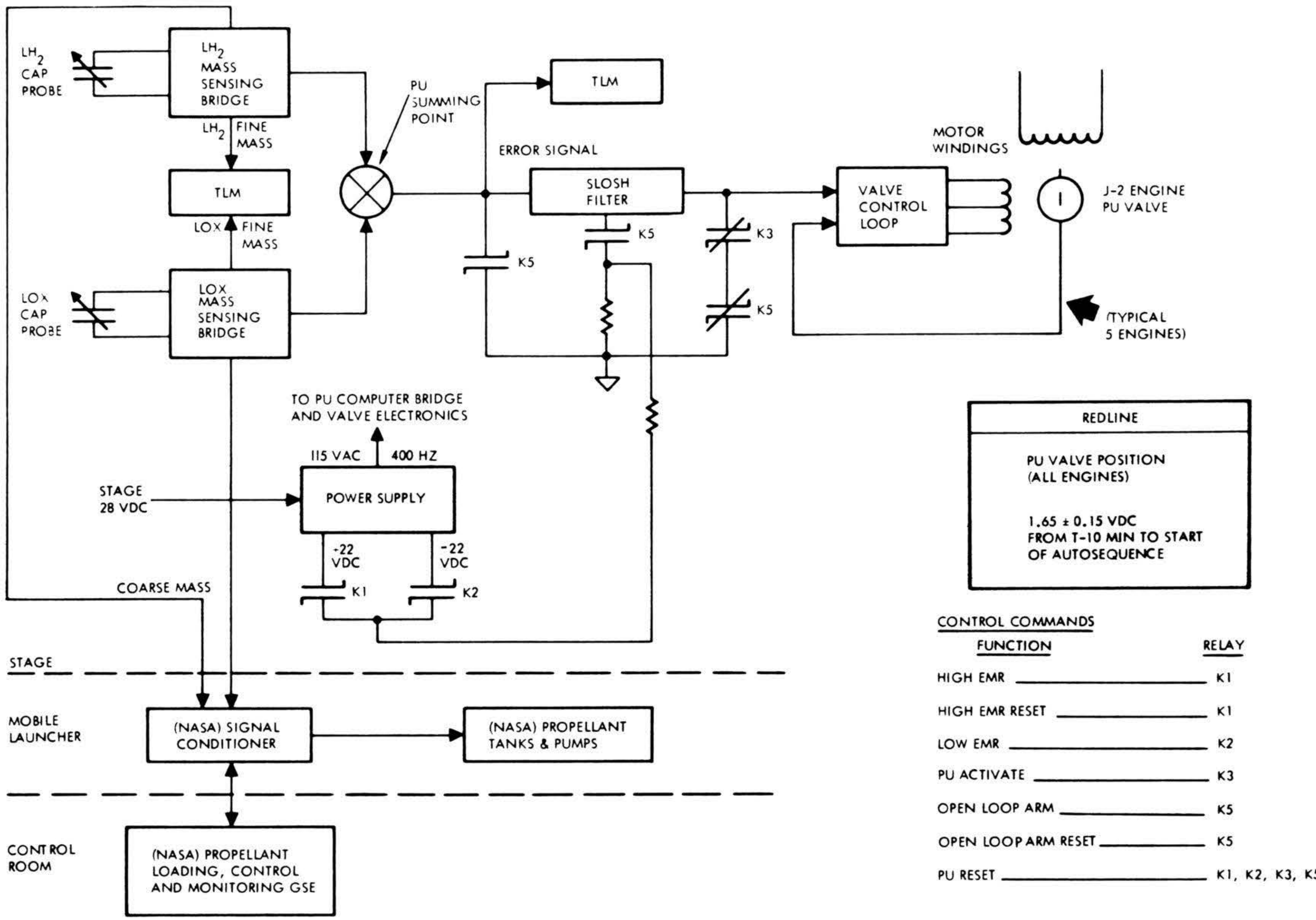
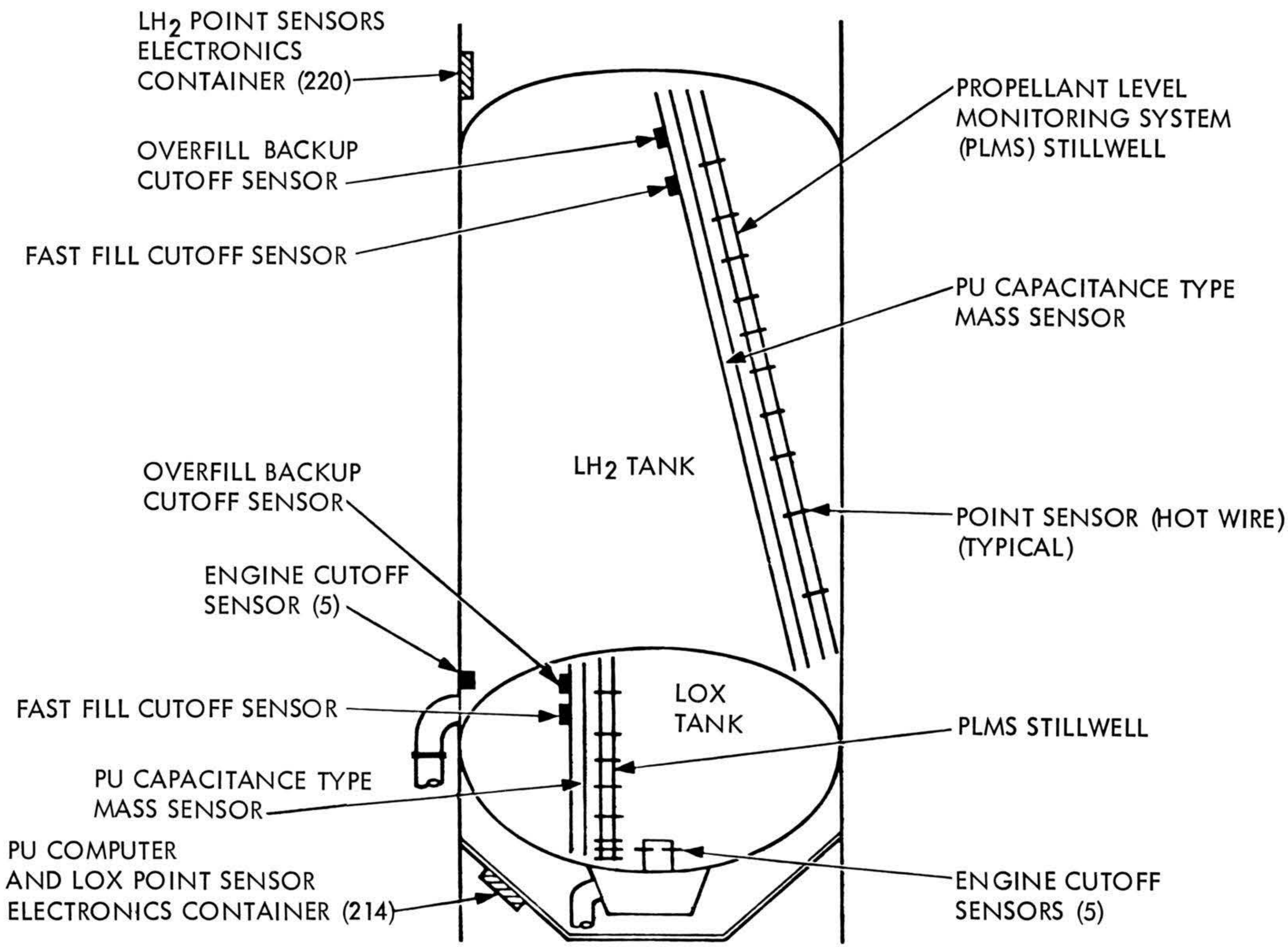


	Figure 25. Propellant Management System	DATE ____ SPEAKER ____ CONTROL NO. ____



mixture ratio allows selective programming of a high-MR/low-MR flight profile for programmed mixture ratio (PMR).

For the S-II-3 stage, the PU system has been modified to permit open-loop operation in which the PU valves are controlled by fixed command signals received from the IU. This differs from closed-loop operation in that feedback information from the tank mass sensors is not used for controlling the PU valves. For engine start, the PU valves will be held in the null position (5.0 nominal EMR) until ESC +5.5 seconds, at which time a High EMR ON command from the IU will drive the valves to the maximum EMR position (5.5 nominal EMR). At ESC +283 seconds, the PU valves will be commanded to the low mixture ratio position (4.4 EMR nominal) for the remainder of the S-II burn.

Engine Cutoff (ECO)

The engine cutoff subsystem is independent of the PU system. The ECO system consists of five point sensors in each propellant tank plus associated electronics equipment. All sensors are of the hot-wire type and are removable externally. The five LH_2 ECO point sensor transducers are mounted individually near each of the LH_2 feedline outlets. The five LOX ECO point sensor transducers are grouped at the entrance to the tank sump on a pedestal that extends upward from the bottom center of the sump.

The ECO subsystem provides a depletion signal through a voting circuit when two out of five sensors from the same tank indicate a dry condition. The depletion signal is given at a propellant level determined by the adjustable time delay (0.0 seconds for the S-II-3) at the output of each ECO sensor controller (signal conditioner). The signal output from the sensor controller is 28 ± 4 vdc when a sensor is dry and zero volts when the sensor is immersed in liquid. The depletion signal is transmitted from the voting circuit to the engine controller which shuts down the engine. (See Figures 26 and 27.)

SEQUENCE OF OPERATION

The important events occurring during the operation of the propellant management system are shown in Figure 28, resulting in the EMC history shown in Figure 29. Figure 30 presents the closed-loop operation occurring on AS-501 flight for comparison.

CONDITIONS AT LIFTOFF

The system is set to provide an engine mixture ratio of 5.0.

Figure 26. AS-501 S-II LH_2 Cutoff Resuduals

DATE ____________
SPEAKER ____________
CONTROL NO. ____________

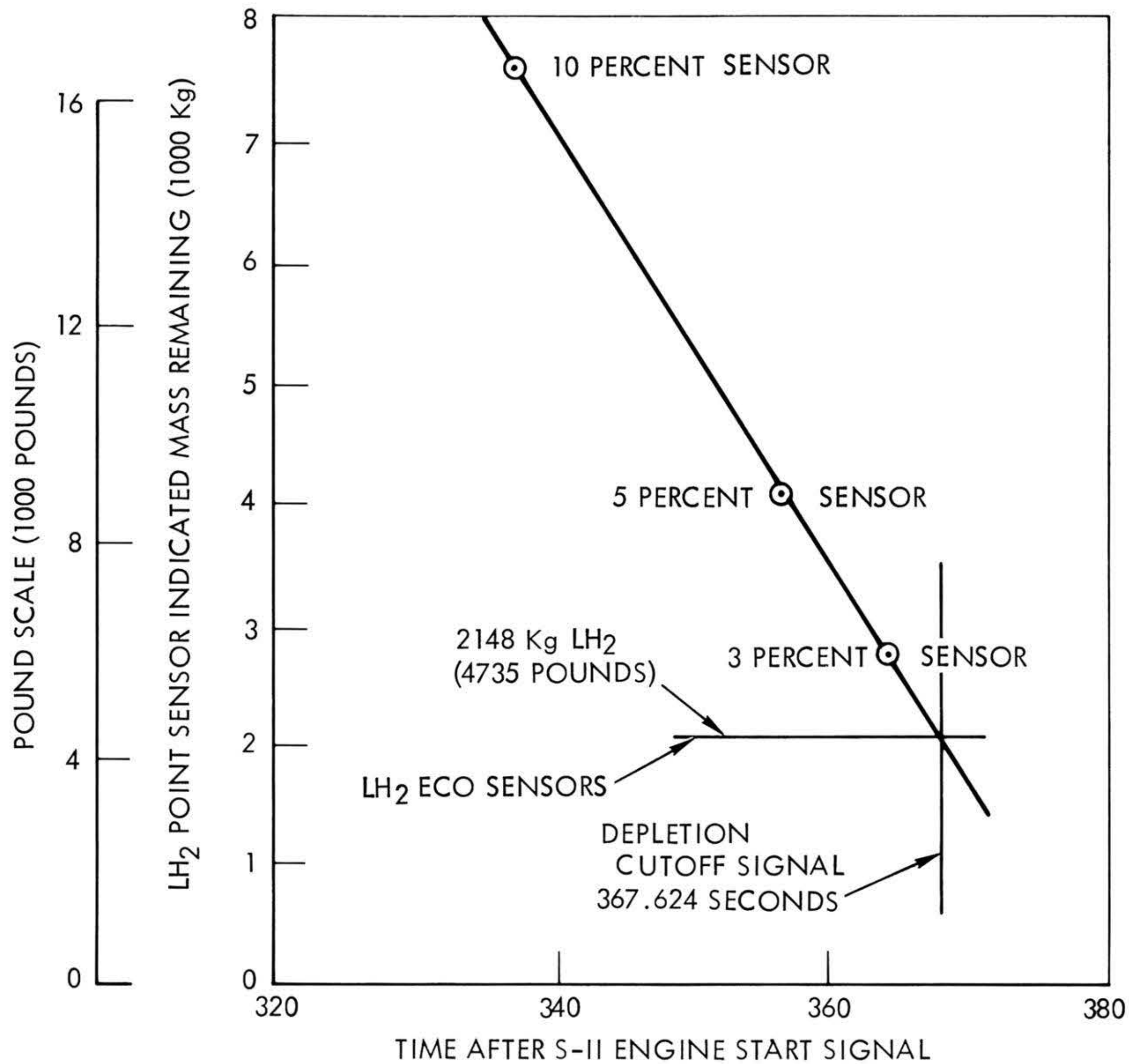


Figure 27. AS-501 S-II LOX Cutoff Residuals

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SPEAKER ____________
CONTROL NO. ____________

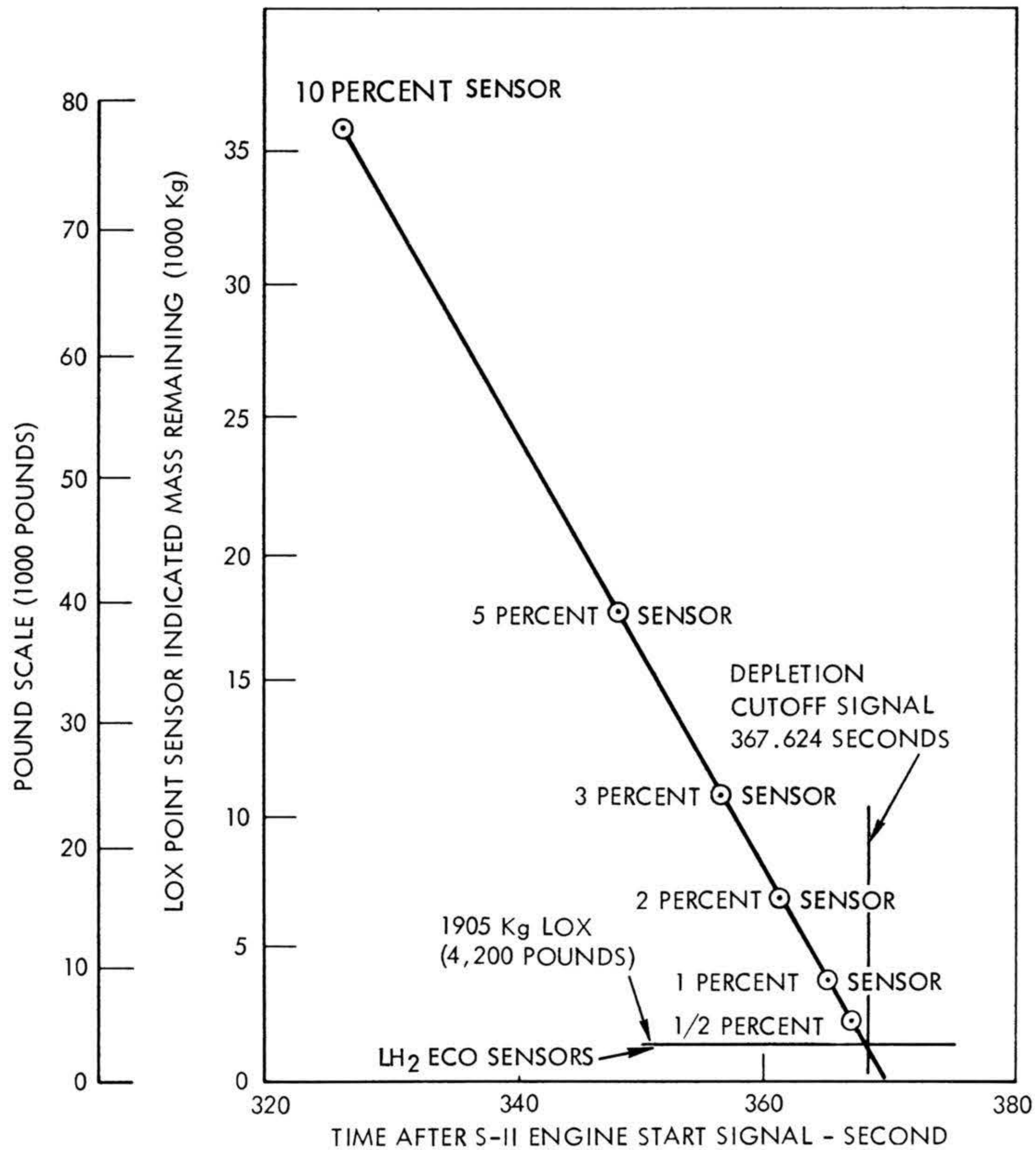

Figure 35. Sequence of Operations	DATE ________ SPEAKER ________ CONTROL NO. ________

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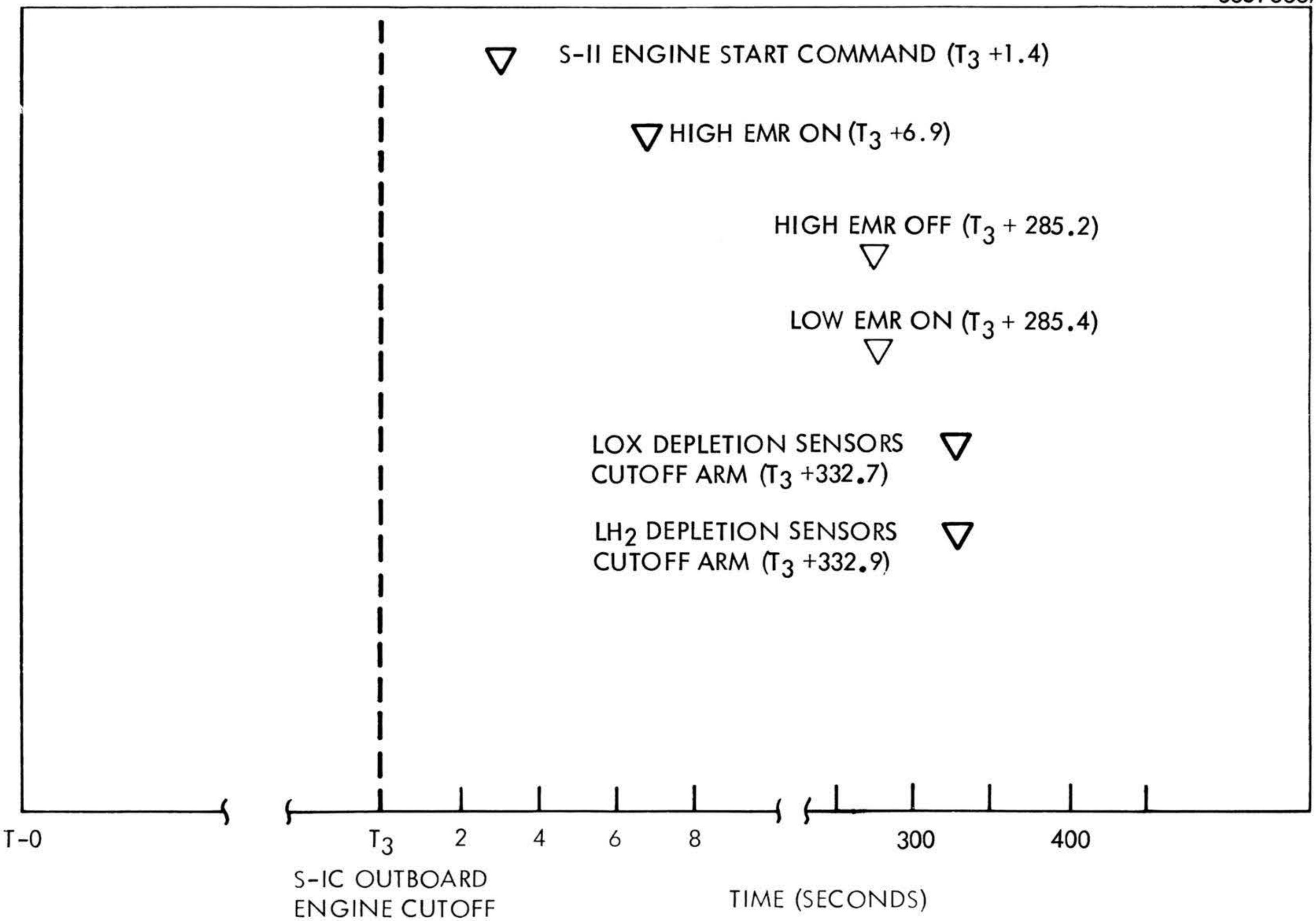


Figure 29. AS-501 EMR History S-II-1

DATE

SPEAKER

CONTROL NO.

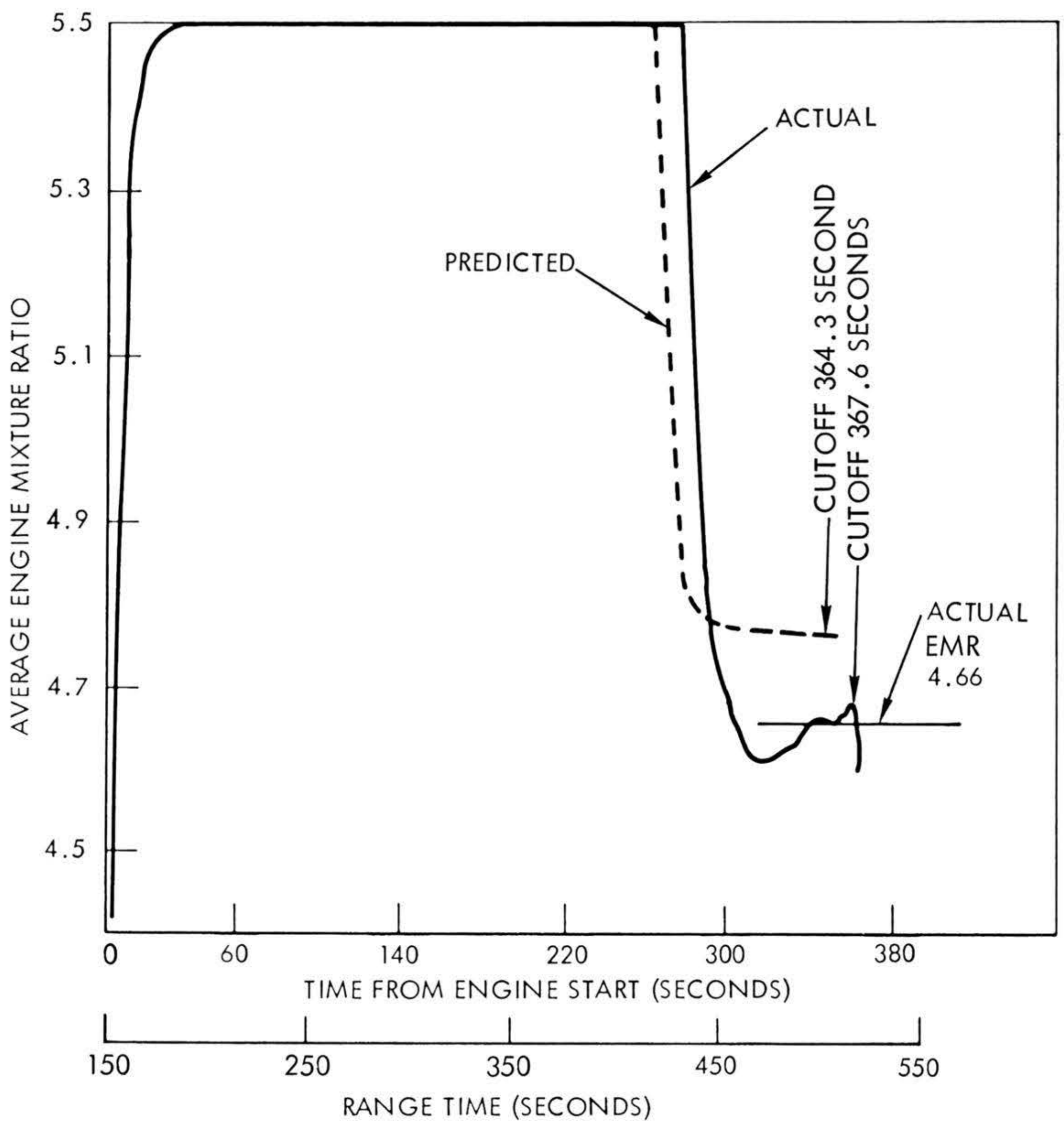
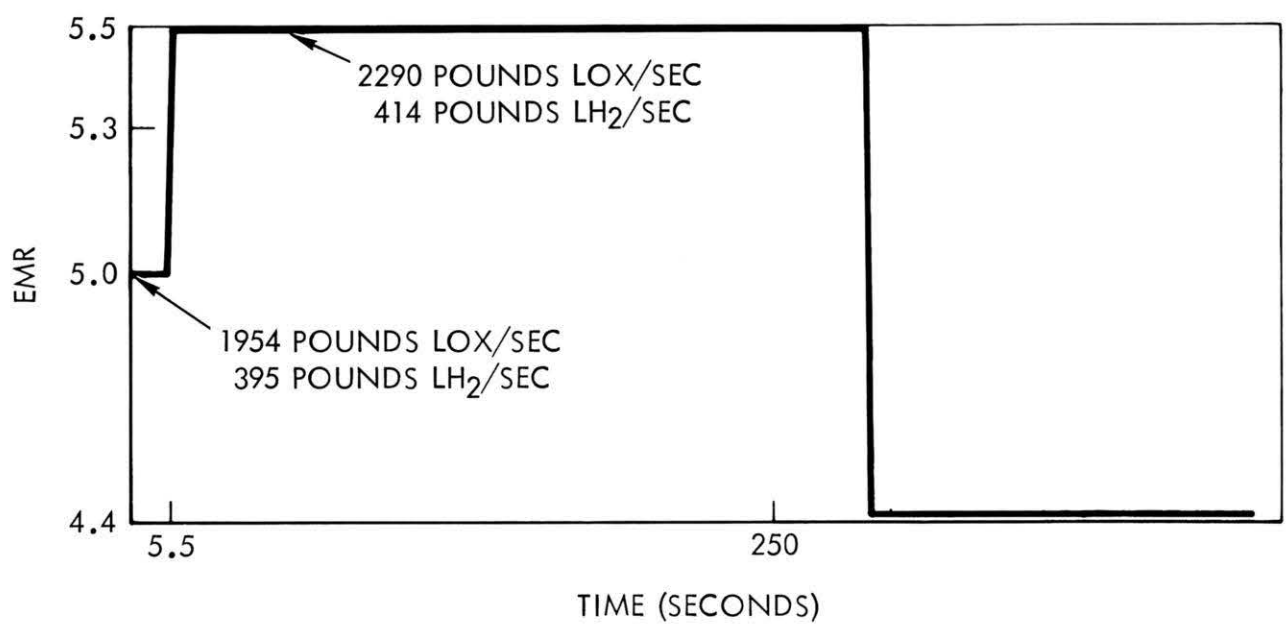


Figure 30. Propellant Management System Features, S-II-3

DATE
SPEAKER
CONTROL NO.

PROPELLANT MANAGEMENT SYSTEM FEATURES

- OPEN-LOOP PU CONTROL
- PROGRAM MIXTURE RATIO CONTROL
- CONTINUOUS CAPACITANCE SENSING METHOD
- LOX DEPLETION FOR MINIMUM RESIDUALS



MSC CONSOLE DISPLAY

There are no displays at MSC to directly indicate the performance of the propellant management system. However, data shown in Figures 29 and 30 taken from the recorded data show system performance during flight.

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SECTION III. S-II STAGE FLIGHT CONTROL SYSTEM

FUNCTION

The flight control subsystem is designed to provide and maintain vehicle directional control during flight.

SYSTEM FEATURES

The flight control subsystem has been designed to provide and maintain directional control during flight by gimbaling the four outboard engines in conjunction with control signals transmitted from the instrumentation unit (IU). The flight control system gimbals each outboard J-2 engine for pitch, yaw, and roll control by an independent hydraulic system and has the capability of controlling flight until propellant depletion with one J-2 engine inoperative. The closed-system concept used for the engine actuation system (EAS) was determined to be the one most likely to give the required system cleanliness. In this approach the system is completely cleaned, built up, filled and bled, and partially checked out in the manufacturing clean room. The system is then installed as a complete system on the stage.

The engine position feedback control loop is closed within the system by means of mechanical feedback devices located within each servoactuator. The servoactuator position accuracy is within ±51 minutes of the commanded position. Gimbaling capability is shown in Figure 31. The gimbaling rate is greater than 8 degrees per second under design loads of 24,000 pounds during separation and 30,000 pounds during S-II boost.

The accumulator stores hydraulic power for engine gimbaling during S-IC/S-II separation transients. The accumulator is sized to perform this function until such time as sufficient flow, as a function of J-2 engine speed, is available from the main pump. Second-plane separation will not be prevented by one J-2 engine inoperative or failure of one servoactuator.

The design incorporates a temperature control function that operates in conjunction with GSE switching circuits to protect the hydraulic system from overheating or from the cryogenic environment.

Figure 31. Gimbal Capability

DATE
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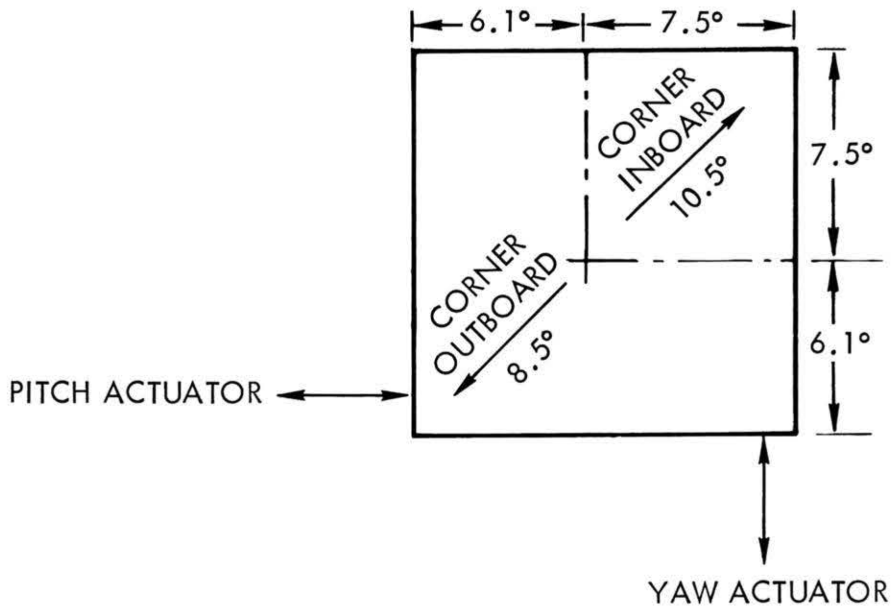
CONTROL NO.



The servoactuators are compatible with the engine alignment requirement of 0 degrees 27 minutes. They incorporate an effective piston area of 13.0 square inches, a dual element potentiometer, a locking device that actuates upon loss of hydraulic pressure, and a cylinder bypass valve for both manual and remote operation. The main hydraulic pump incorporates a thermal barrier to isolate the pump from the LOX turbine environment.

SYSTEM DESCRIPTION

The flight control system is composed of the following two subsystems:

1. Flight control, which is the electrical portion and is located within the IU (Figure 32)

2. The engine actuation system, which is the mechanical portion and is located within the S-II stage engine compartment

Flight Control

The Saturn V flight control system during stage S-II burn consists of the following main subsystems: digital computer, data adapter, flight control computer, and inertial platform, all located in the instrumentation unit above the S-IVB.

The inertial orientation of the Saturn V is continuously generated in the gimbal angle pivot resolvers of the inertial platform and transmitted to the digital computer via the data adapter. In the digital computer, the gimbal angle signal is resolved with the command attitude, and an attitude error is generated. These attitude-error commands are then transmitted via the data adapter as input signals to the flight control computer.

The attitude-error and attitude-rate signals are filtered by shaping networks and given the proper gain in the flight control computer. These signals are then fed as engine commands to the servoactuator magnetic amplifiers located in the flight control computer (one amplifier per servoactuator). These amplifiers form a dc servoactuator command current proportional to the commanded engine position. Relays in the IU switch the commands to the S-II stage during S-IC/S-II separation.

Engine Actuation System

The engine actuation system is a 3500-psi closed hydraulic system that provides power and forces to gimbal the J-2 engines. A block diagram of the system is shown in Figure 33. The engine position feedback control

Figure 32. Saturn V/S-II Flight Control Block Diagram

DATE
SPEAKER
CONTROL NO.

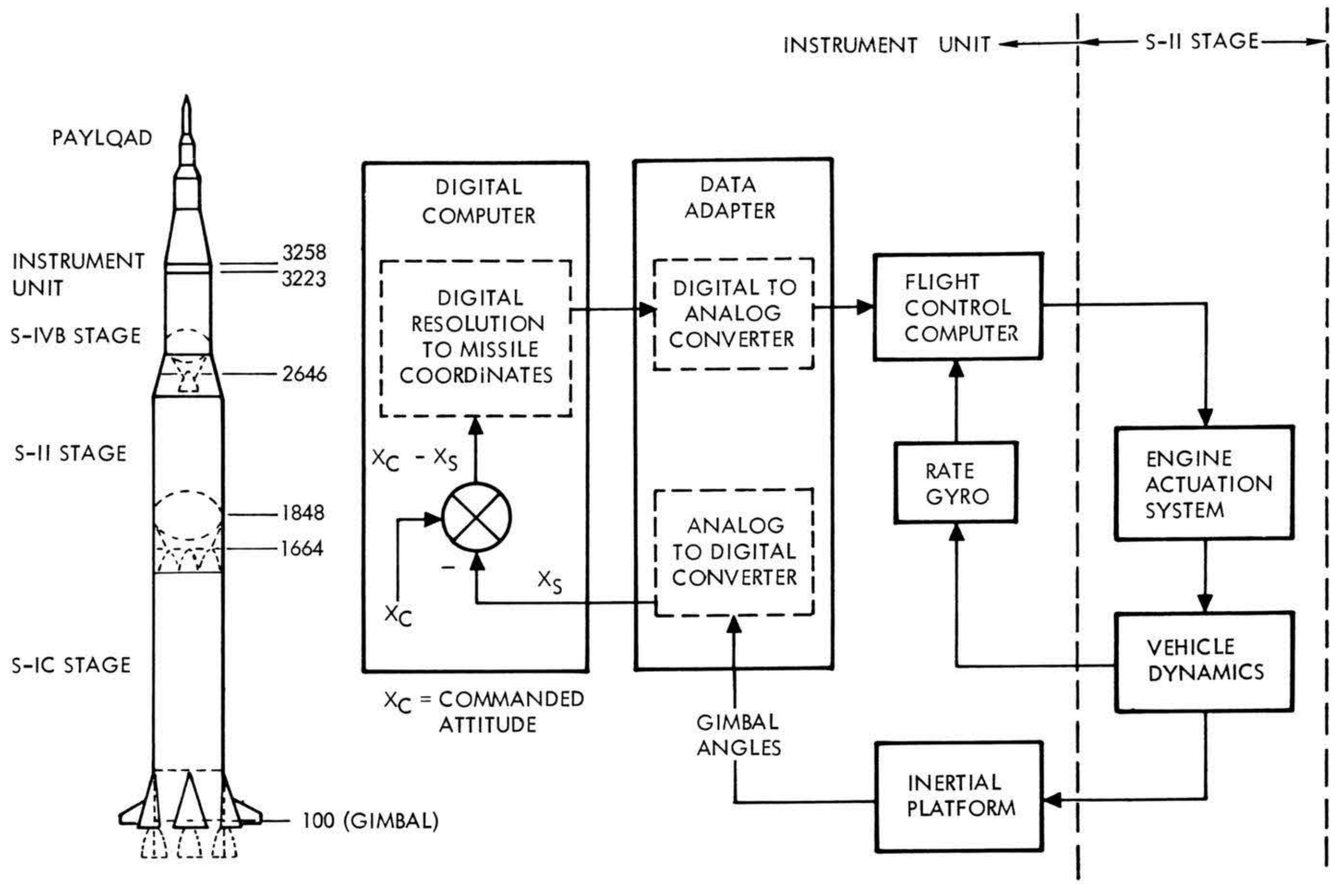
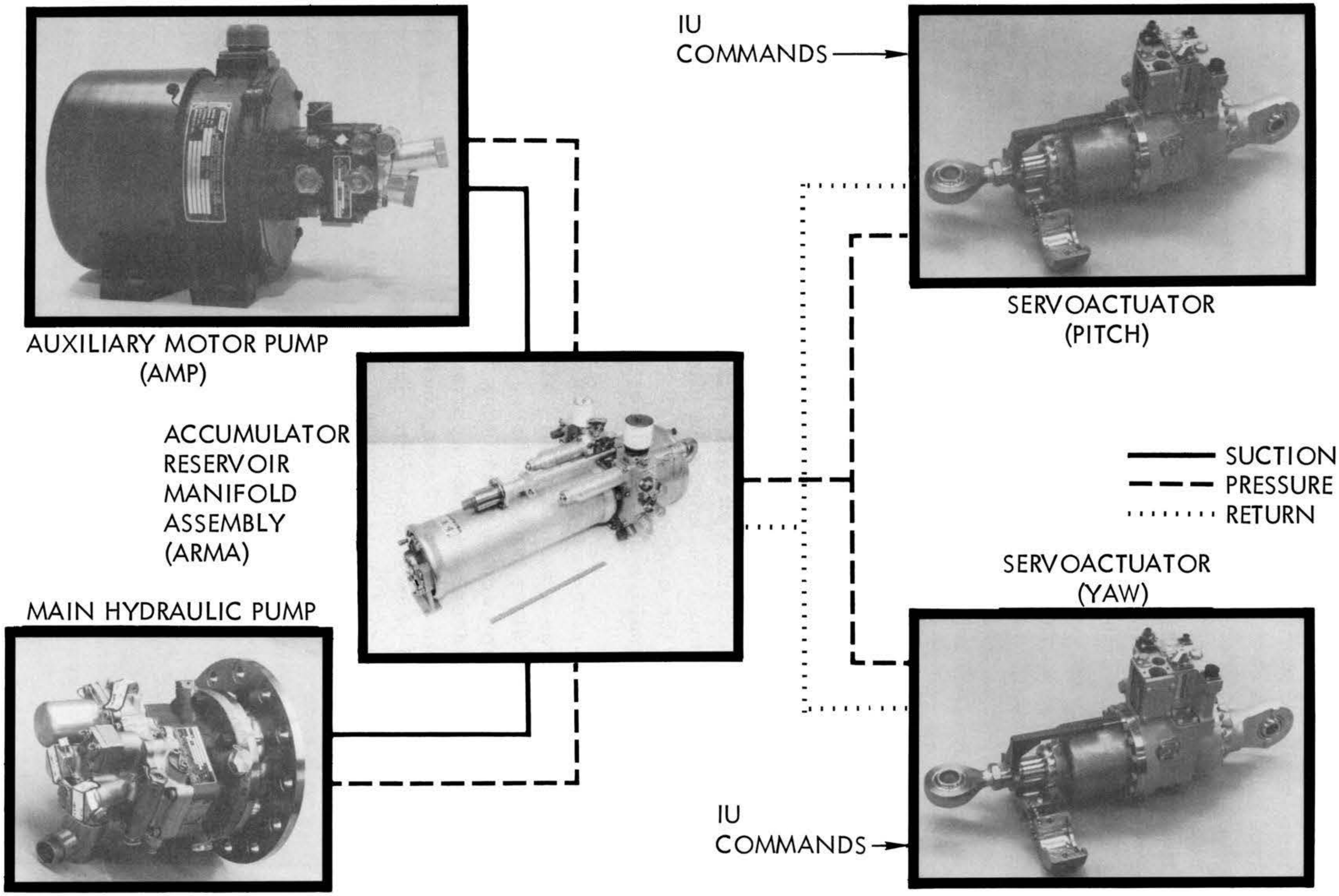


Figure 33. Engine Actuation System (EAS) Block Diagram

DATE

SPEAKER

CONTROL NO.



loop is closed within the system by means of mechanical feedback devices located within each servoactuator. A complete, separate, and identical system is provided for each gimbaled J-2 engine. The system provides power for full-rate gimbaling of the engine during firing (hot gimbaling) and limited-rate gimbaling during nonfiring (cold gimbaling) operations. Major system components include an engine driven main pump; an auxiliary electric motor driven pump; two electrically controlled, hydraulically powered servoactuators utilizing mechanical feedback and containing an actuator lock-up valve; and an accumulator reservoir manifold assembly (ARMA), which, in addition to the accumulator and reservoir, includes the main system filters, ground hydraulic power quick disconnect couplings, and relief valves. Fluid is distributed throughout the system by flexible hose assemblies and rigid tubing.

The ARMA panel assembly, which includes the auxiliary motor pump, is mounted on the stage thrust structure, and the main pump is mounted on the J-2 LOX turbopump drive pad. The servoactuators are attached to the J-2 engine and S-II stage thrust structure attach points (Figure 34).

Two servoactuators on each engine respond to separate commands from the IU to gimbal the engine in pitch, yaw, and roll axes. One servo-actuator deflects the engine for pitch control and one deflects for yaw control. The two servoactuators operate differentially to provide roll control.

After first-plane separation and after control switching is accomplished, the engine receives a start signal. After a predetermined period of chill-down, the engine start tank discharge valve opens. At this time, the oxidizer turbopump accelerates, thus accelerating the main hydraulic pump. When system pressure reaches approximately 1500 psi, the servoactuators unlock and start to position the engines in accordance with the command signal, which had been switched in. Shortly thereafter, the accumulator lockup valve solenoid is deenergized, unlocking the accumulator to provide the main source of power to gimbal the engine during the separation transient. At 4 to 5 seconds after separation, the main hydraulic pump starts replenishing the fluid in the accumulator in addition to supplying system demand. Power for all subsequent gimbaling during S-II stage boost is provided by the main pump, supplemented by the accumulator during peak demands.

SEQUENCE OF OPERATIONS

The sequence of the most important events during the operation of the flight control system is shown in Figure 35.

Figure 34. Typical EAS Installation

DATE
SPEAKER
CONTROL NO.

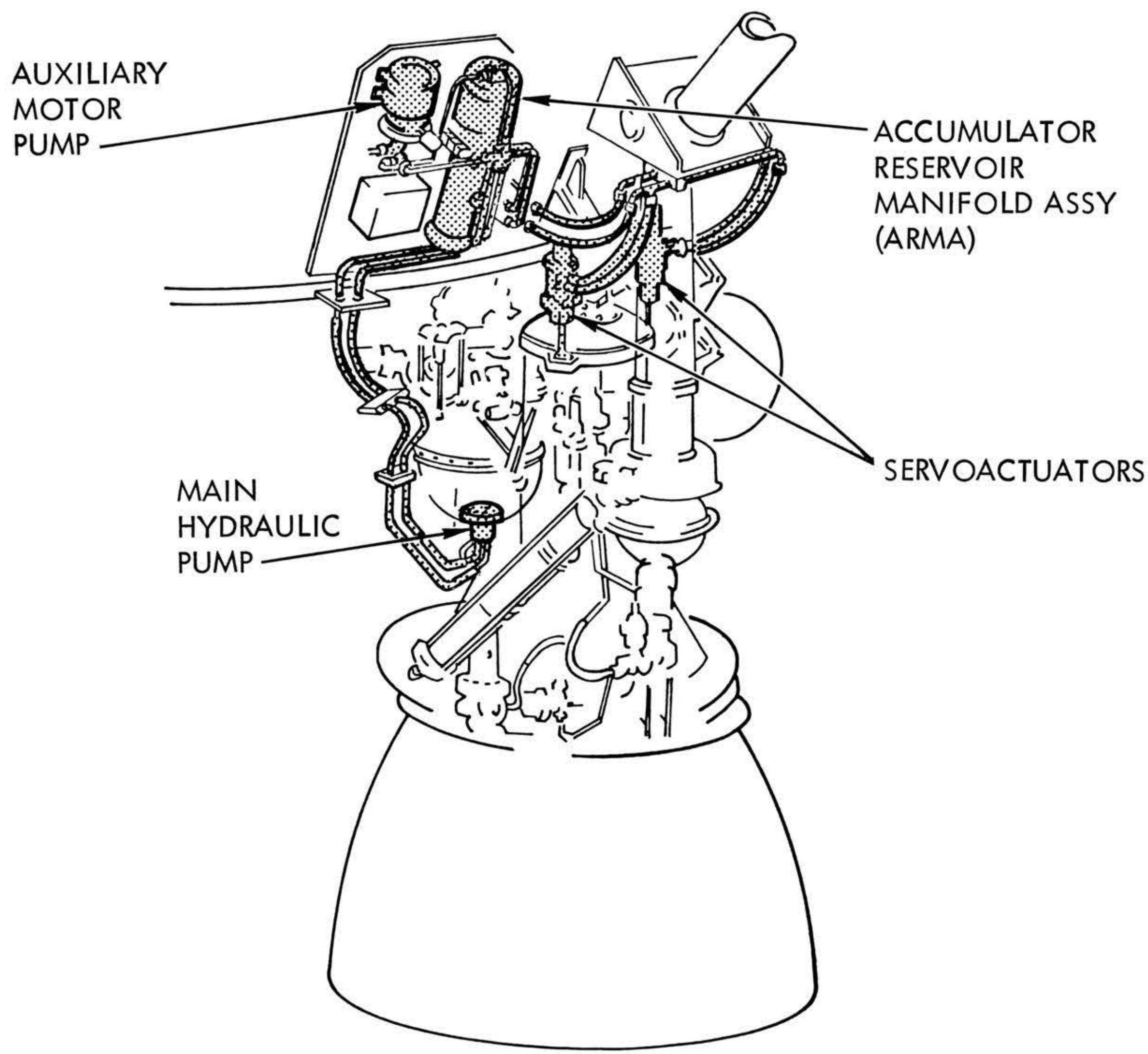
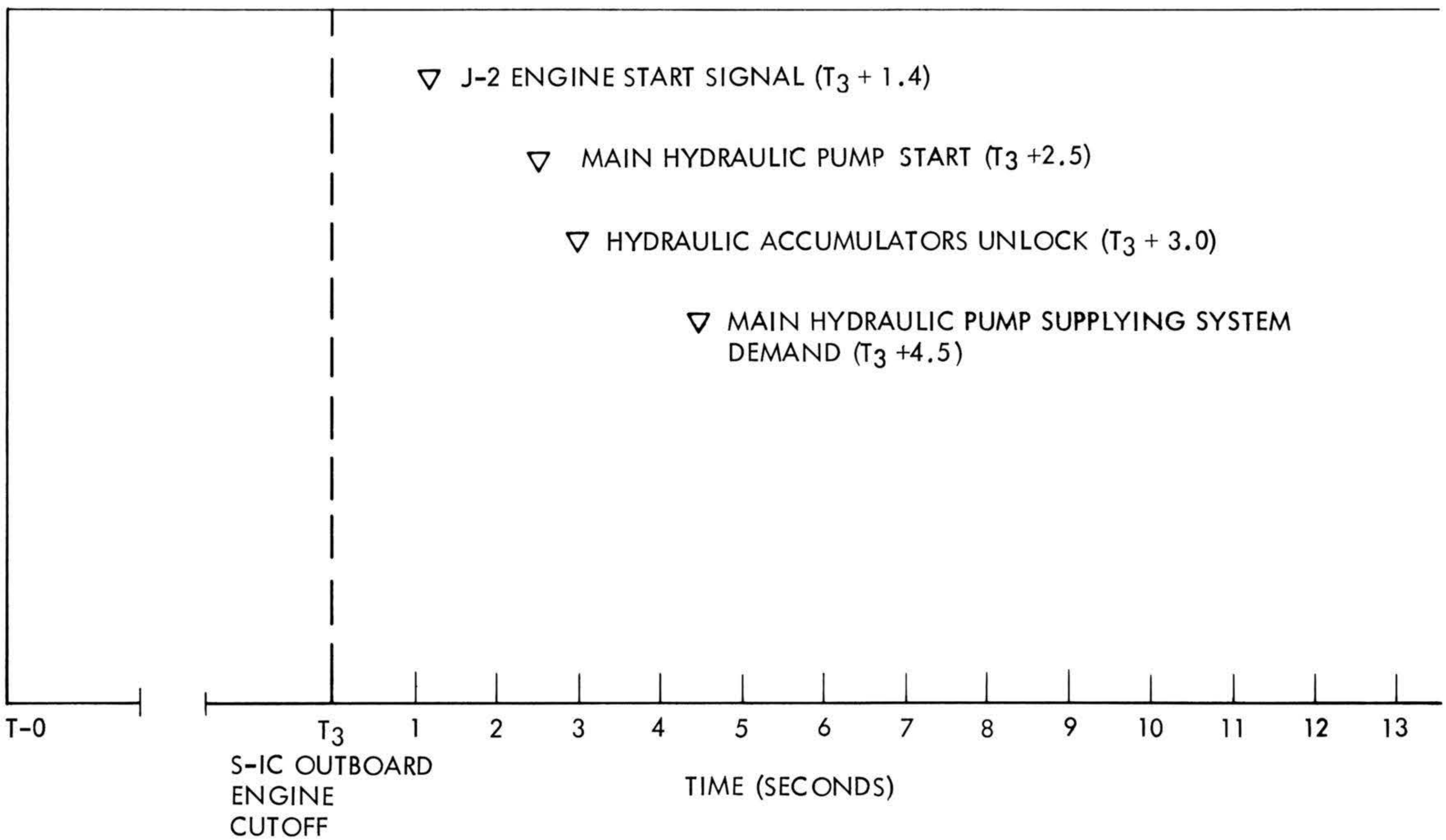


Figure 28. Sequence of Operations

DATE ______
SPEAKER ______
CONTROL NO. ______



CONDITIONS AT LIFTOFF

The accumulators have been pressurized to a pressure greater than 3000 psia (red line), and the accumulator lockup valve has been closed (locked up) to maintain the accumulator at the proper pressure and fluid level. The auxiliary pumps are only required for ground operation and have been shut off. The reservoir piston position indicates the oil volume within the reservoir to be greater than 6 cubic inches (red line).

The pitch and yaw actuators are at zero degrees deflection.

MSC CONSOLE DISPLAY

The following measurements concerning the flight control system are displayed at MSC:

Hydraulic accumulator oil pressure (D0103-201/4)
Reservoir piston position (G0007-201/4)
Pitch actuator position (G0001-101/4)
Yaw actuator position (G0002-101/4)

PERFORMANCE

Figures 36 through 39 show the comparison between predicted and actual AS-501 flight data for one typical engine for the measurements listed above. Figures 40 through 42 show additional data for a typical engine.

	Figure 36. Accumulator Hydraulic Pressure	DATE ______ SPEAKER ______ CONTROL NO. ______

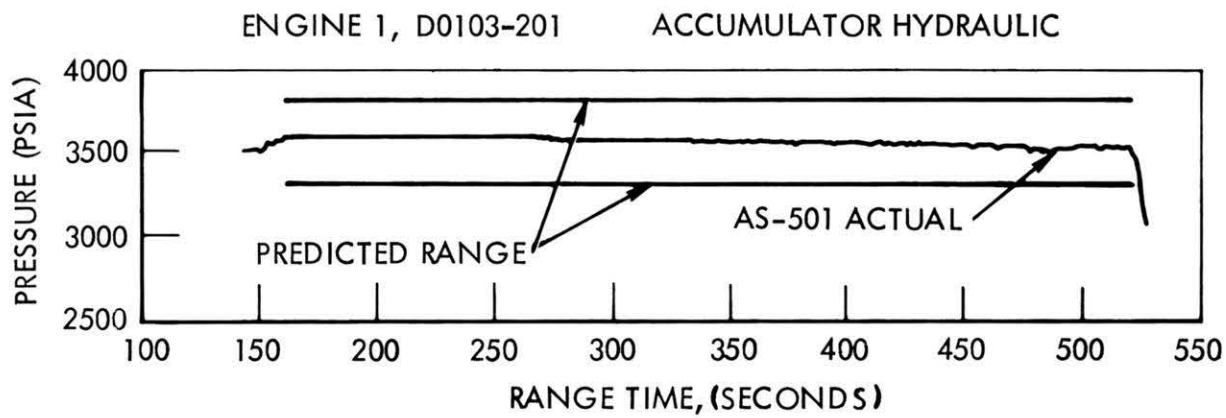


Figure 37. Reservoir Piston Position

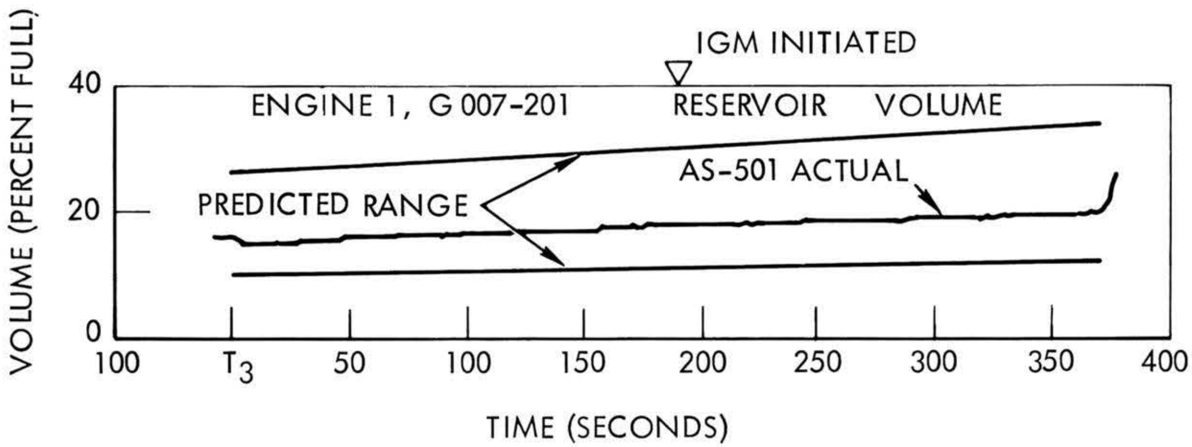
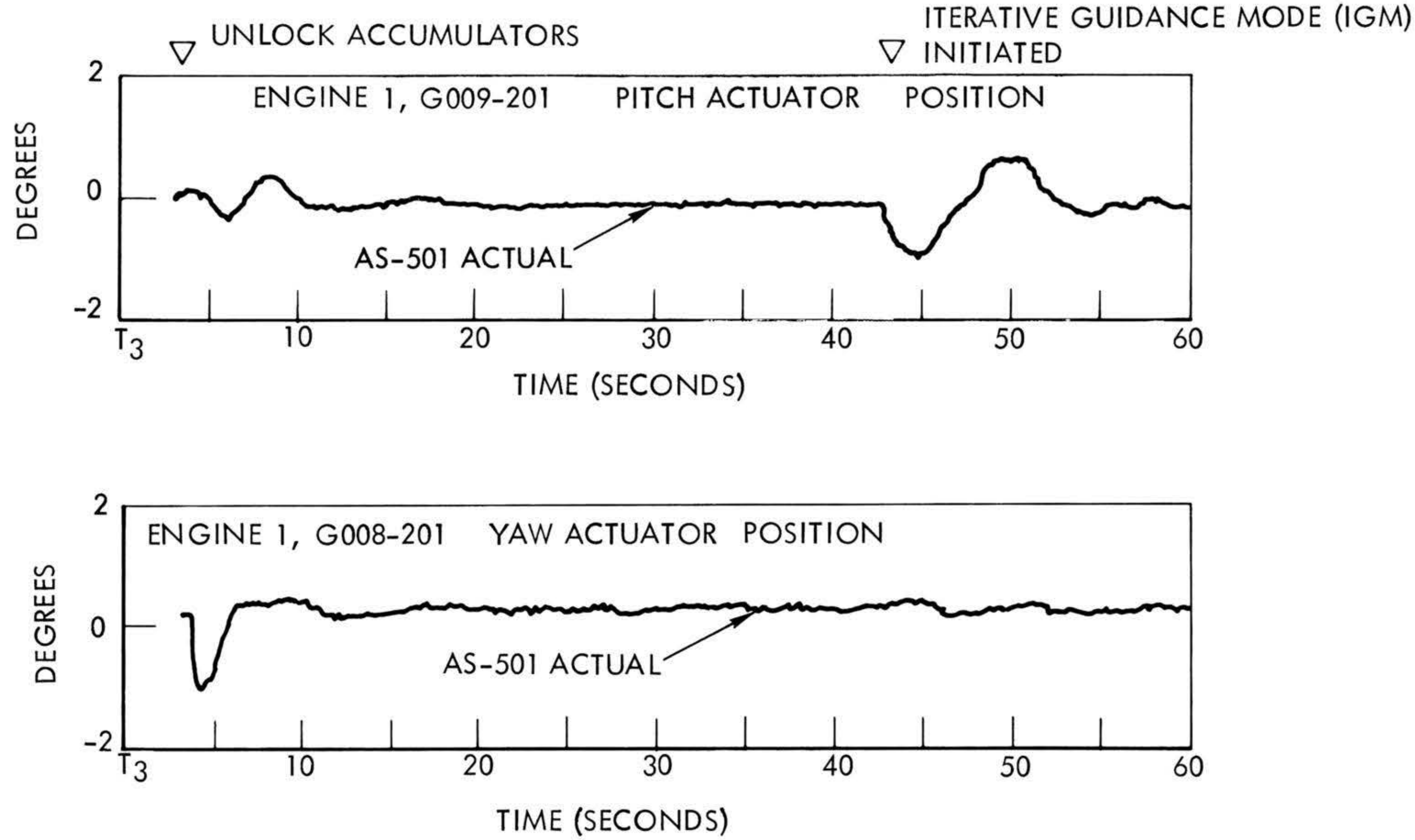


Figure 38. Yaw and Pitch Actuator Position

DATE
SPEAKER
CONTROL NO.



NOTE:
NO SIGNIFICANT ACTIVITY AFTER 210 SECONDS

Figure 39. Yaw Actuator Command

DATE
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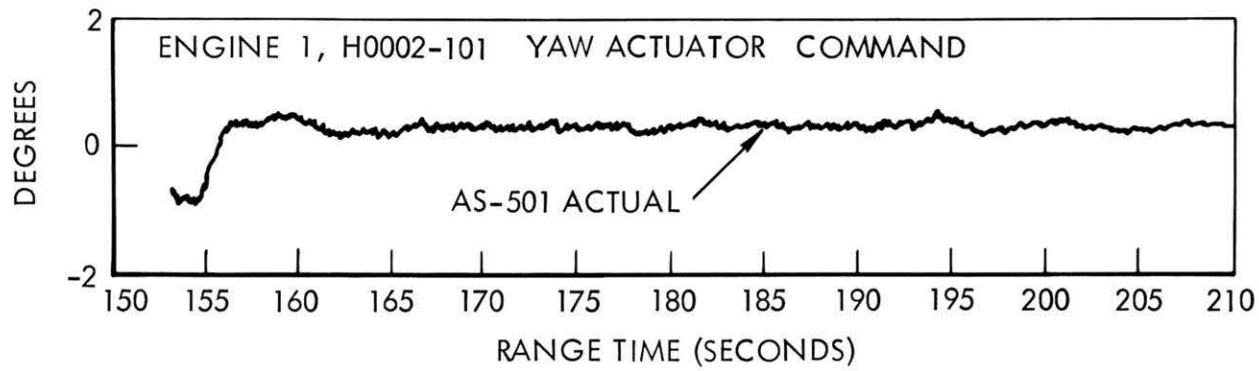
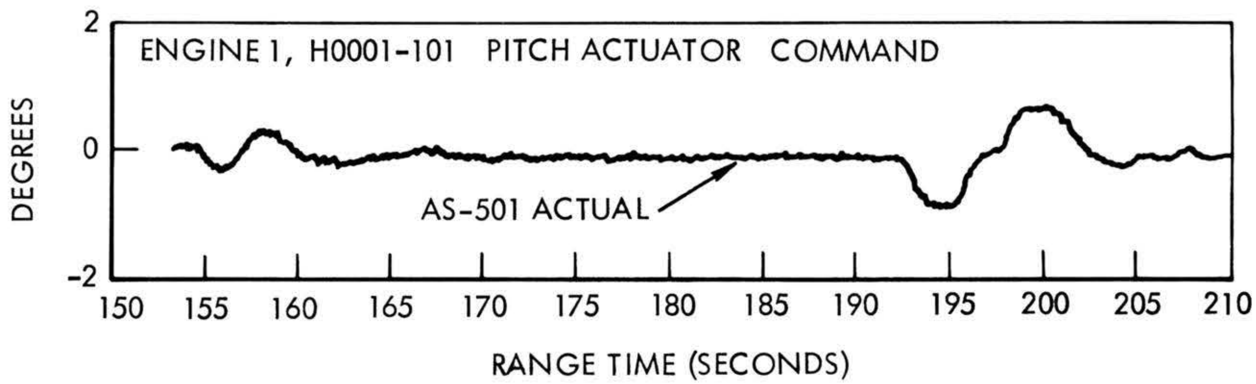


NOTE:
NO SIGNIFICANT ACTIVITY AFTER 210 SECONDS

Figure 40. Pitch Actuator Command



NOTE:
NO SIGNIFICANT ACTIVITY AFTER 210 SECONDS

Figure 41. Reservoir Hydraulic Pressure

DATE ______
SPEAKER ______
CONTROL NO. ______

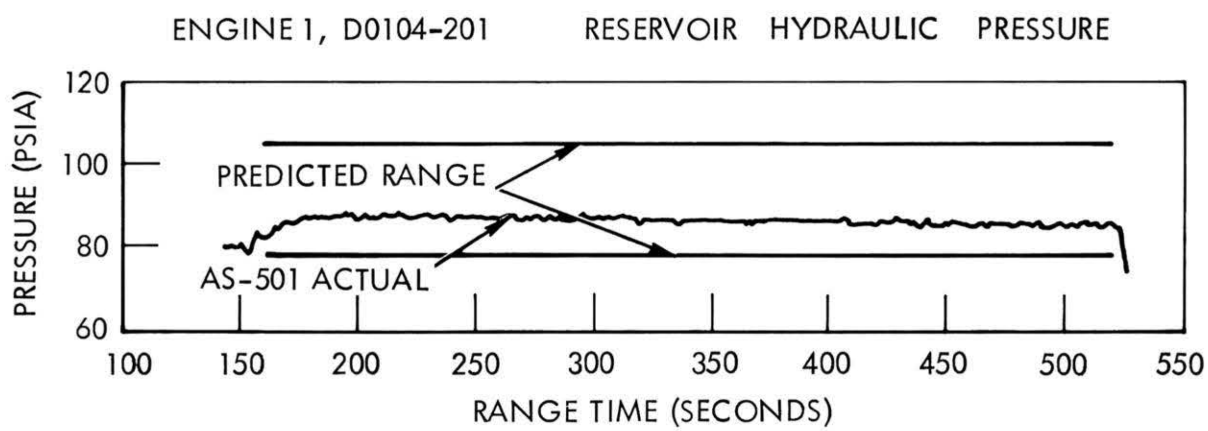
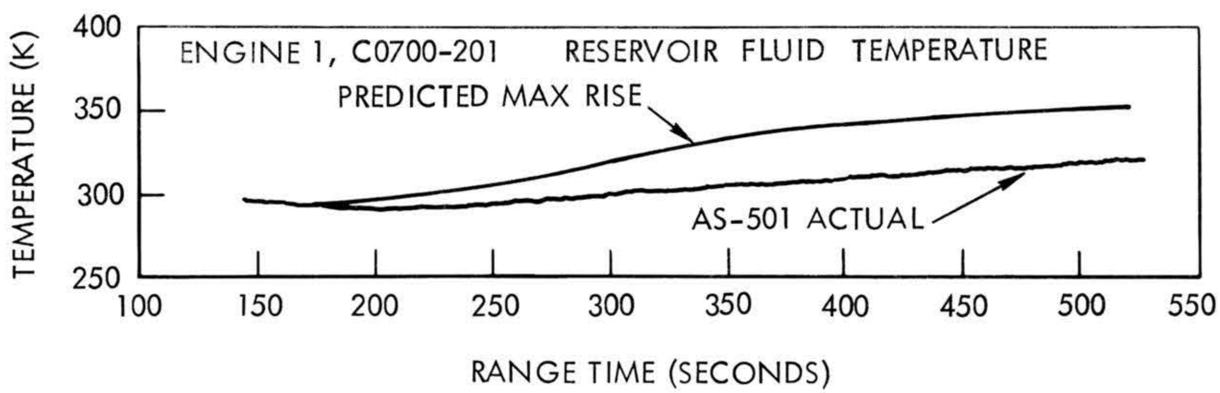


Figure 42. Reservoir Tempeature Fluid

DATE ____________
SPEAKER ____________
CONTROL NO. ____________



SECTION IV. S-II STAGE RECIRCULATION SYSTEM

FUNCTION

The purpose of propellant recirculation is to reduce the temperature of the pumps and some of the lines through which the propellants will flow during the operation of the J-2 engine. This is done to prevent the formation of gas that would occur if the pumps and lines were not prechilled, and that would result in either a slow engine start or failure to sustain operation. In addition, the liquid must be subcooled to assist in providing the required NPSH at engine start.

The valve actuation section provides the pneumatic capability to actuate the components of the recirculation section at the time and in the manner required.

FUNCTION OF RECIRCULATION SYSTEM SECTIONS

The recirculation system consists of the following sections:

a. The engine recirculation section is an arrangement of lines, valves, and pumps through which fuel and oxidizer flow into their respective engine pumps and are then returned to the propellant tanks. The recirculation design requirements are imposed upon the stage by the basic starting characteristics and requirements of the J-2 engine. At initiation of J-2 engine start, the engine pump must be supplied with liquid propellant subcooled sufficiently to prevent the formation of vapor, or cavitation will occur at the pump inlet. The margin required to prevent vapor formation as fluid is accelerated into the pumping elements is referred to as net positive suction head (NPSH). NPSH is equal to the actual fluid pressure less the vapor pressure of the fluid for the existing temperature and is measured in feet of the working fluid.

b. The helium injection section (an airborne assemblage of receiver, components, and lines) injects helium into the return leg of the LOX recirculation section, thereby reducing the density of the fluid and promoting the flow of circulating LOX.

c. The valve actuation section (another assemblage of receiver; components, lines, and stored helium) provides the power by which valve components of the recirculation section can be actuated at the beginning and end of S-II burn.

LOX RECIRCULATION AND HELIUM INJECTION SECTION

REQUIREMENTS

It has been established that the fluid in the engine pump discharge high-pressure duct must be subcooled 3 degrees F or more at the initiation of engine start. This requirement is needed to prevent formation of gas in the high-pressure duct. Gas in the high-pressure duct can result in slow thrust buildup and/or destructive pressure surges.

DESCRIPTION

The LOX recirculation configuration for all S-II flight vehicles is illustrated schematically by Figure 43. This configuration consists of the following provisions and components: the LOX feed duct for the J-2 engine prevalves, flanges, and instrumentation bosses. The outboard engine feed ducts are vacuum-jacketed, while the engine flexible duct, LOX sump, LOX pump discharge duct, gas generator bleed valve, and a portion of the engine bleed line are insulated. The individual return line from each engine and the return line valves are uninsulated. Figure 44 shows the location of the return lines from engine panels to aft bulkhead.

The flow path is from the LOX sump through the prevalve, feed duct, engine flex duct, engine LOX pump, LOX pump discharge duct, gas generator bleed valve, gas generator bleed line, and back to the LOX tank through the return line and return valves. The return line valves are of a pneumatically actuated normally open design and are closed 5 seconds after engine start command. The purpose of the prevalves and return line valves is to isolate each engine from the tank at engine shutdown and in the event of a line failure.

Helium injection ports are located in the lower portion of each return line with check valves in each port to isolate the LOX from the airborne helium supply. The recirculation operation depends upon minimizing the heat leak into the LOX on the feed side of the loop and in the engine and allowing heat to enter the system through the uninsulated return lines. The reduction in density caused by the heat added to the fluid in the return line produces a driving force that causes flow from the colder inlet through the return lines to the tank. Helium injection is used to augment the flow by mixing gas with the fluid in the return lines, thereby further reducing the mean density and thus increasing the driving force. Figures 45 and 46 show the location and some of the details of the helium injection section.

	Figure 43. LOX Recirculation and Helium Injection Systems	DATE ______ SPEAKER ______ CONTROL NO. ______

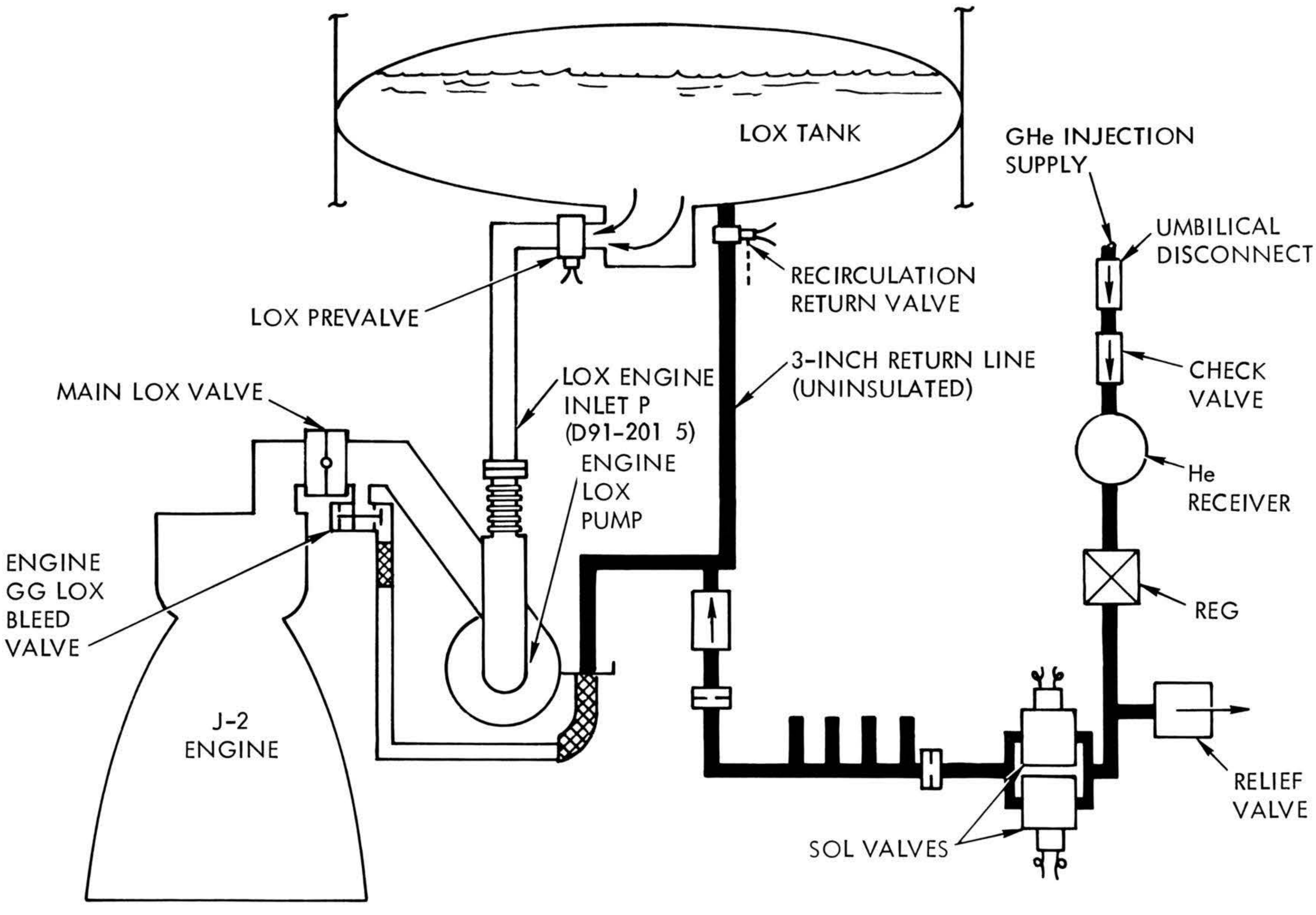


Figure 44. LOX Recirculation Return Lines

DATE ______
SPEAKER ______
CONTROL NO. ______

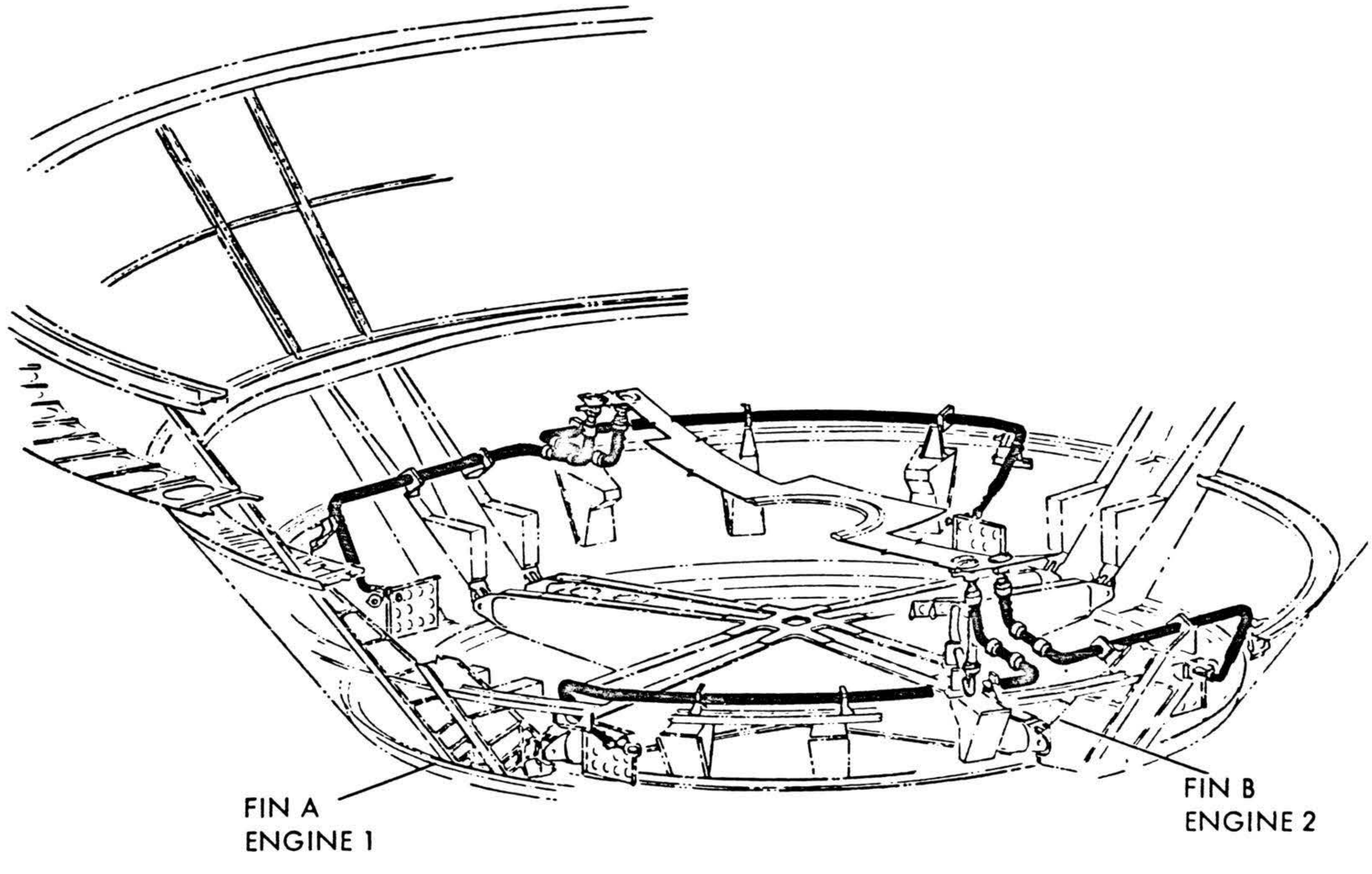


Figure 45. Helium Injection Section

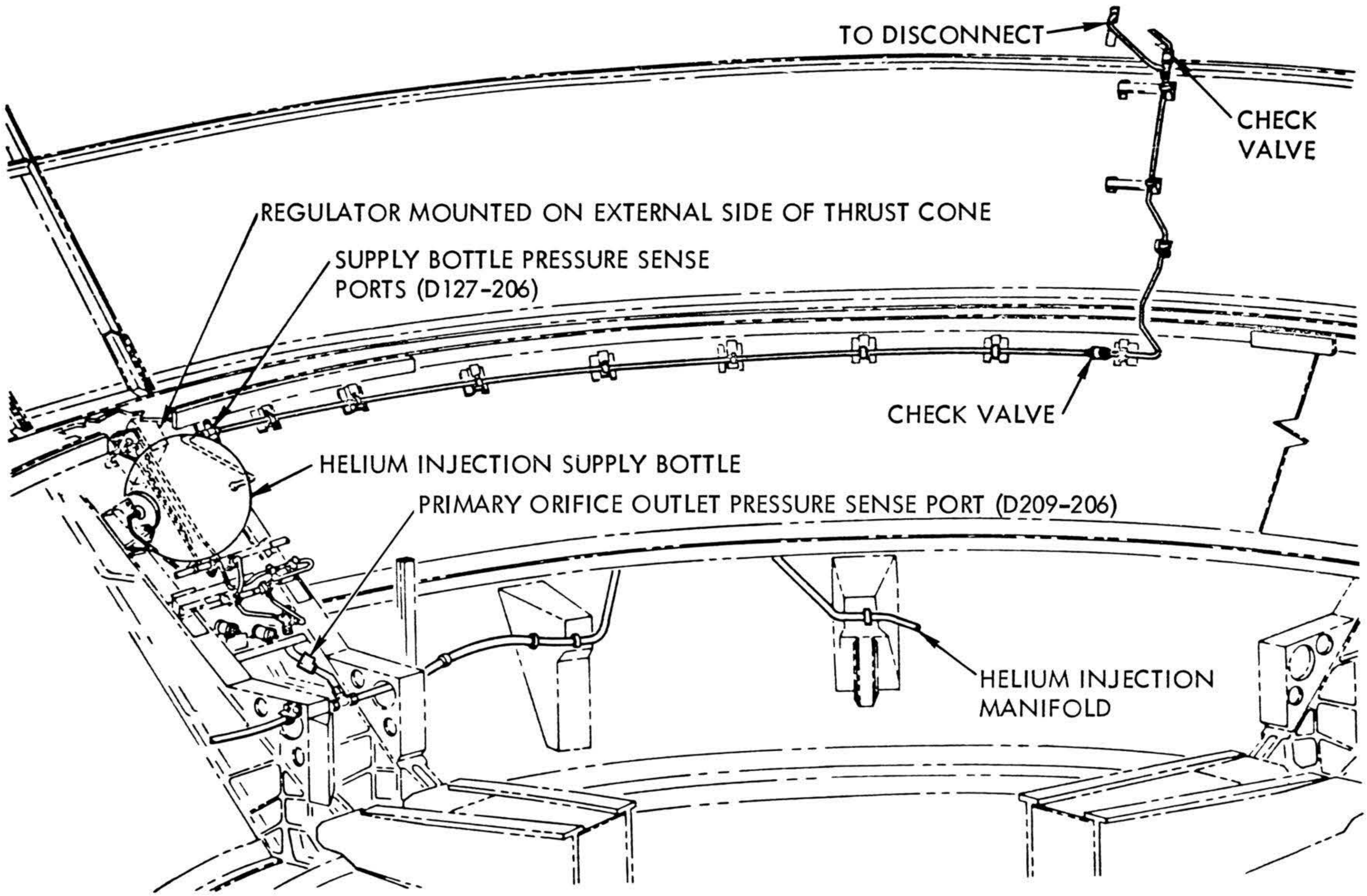
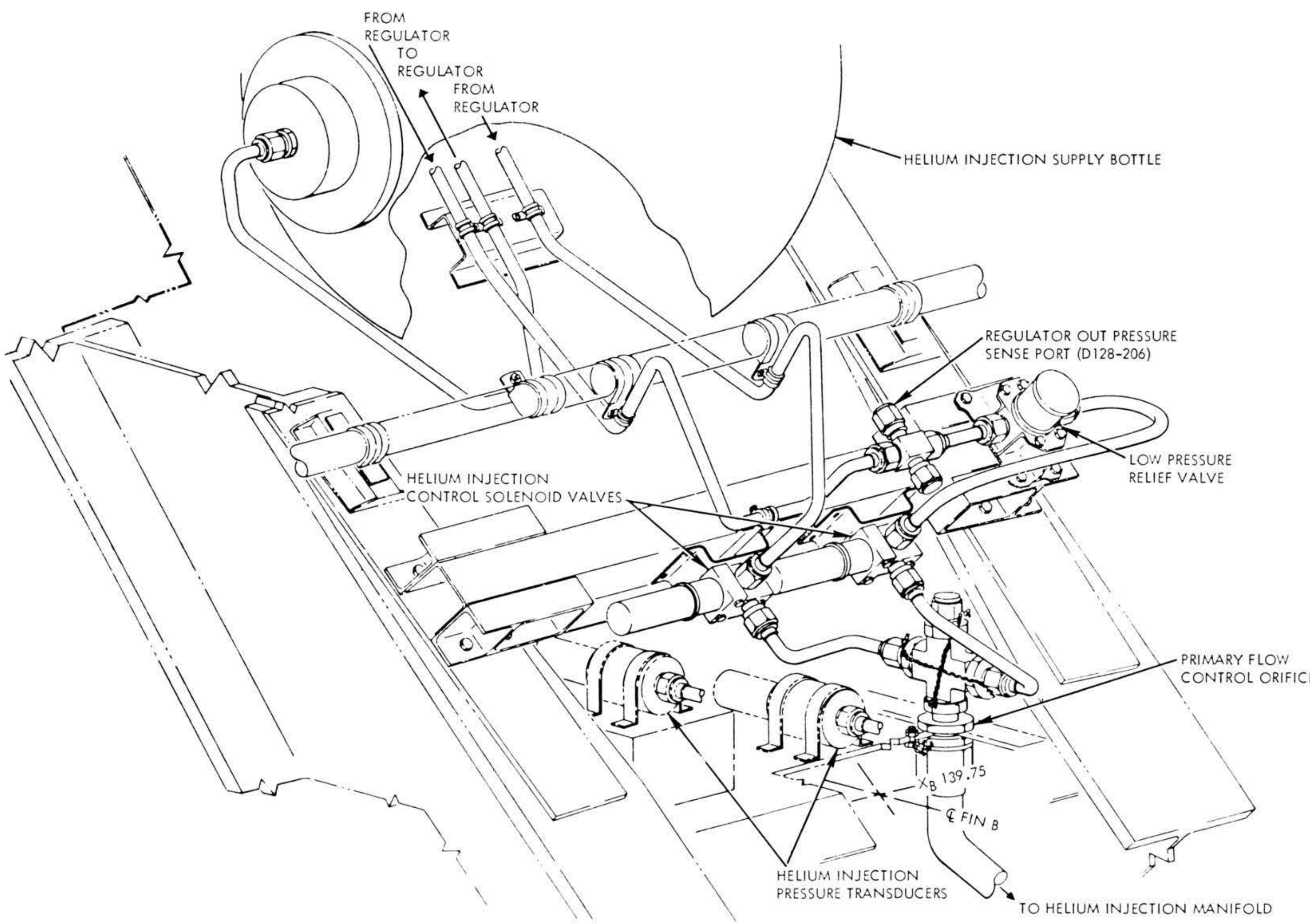


	Figure 46. Details of Helium Injection Section Installation	DATE ____ SPEAKER ____ CONTROL NO. ____



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LH_2 RECIRCULATION SECTION

REQUIREMENTS

There is no requirement for subcooling of the fuel in the engine pump discharge as there is for the LOX high pressure duct. The fuel temperature requirements are limited to the LH_2 pump inlet.

DESCRIPTION

The LH_2 recirculation section is shown in Figure 47. It consists of a five-pump forward flow force feed recirculation system. The submerged electrically driven cryogenic pumps are mounted in the fuel tank above each main fuel feed duct. A normally open 2-inch valve (pneumatically actuated closed, spring-loaded open) is provided in each pump discharge line, each line being connected to the main fuel duct immediately downstream of the fuel prevalve. The 1-1/2-inch normally open gas generator bleed valve provides a flow path to the engine connect panel on the engine and into a return manifold. From the manifold, the flow enters a single return line. A 2-inch normally open valve is provided in the return line to provide isolation from the tank. All stage lines and valves are vacuum-jacketed or insulated to minimize heat leak. The location of the recirculation lines, other than the propellant feedlines, is shown in Figure 48.

Figure 47. LH_2 Recirculation System

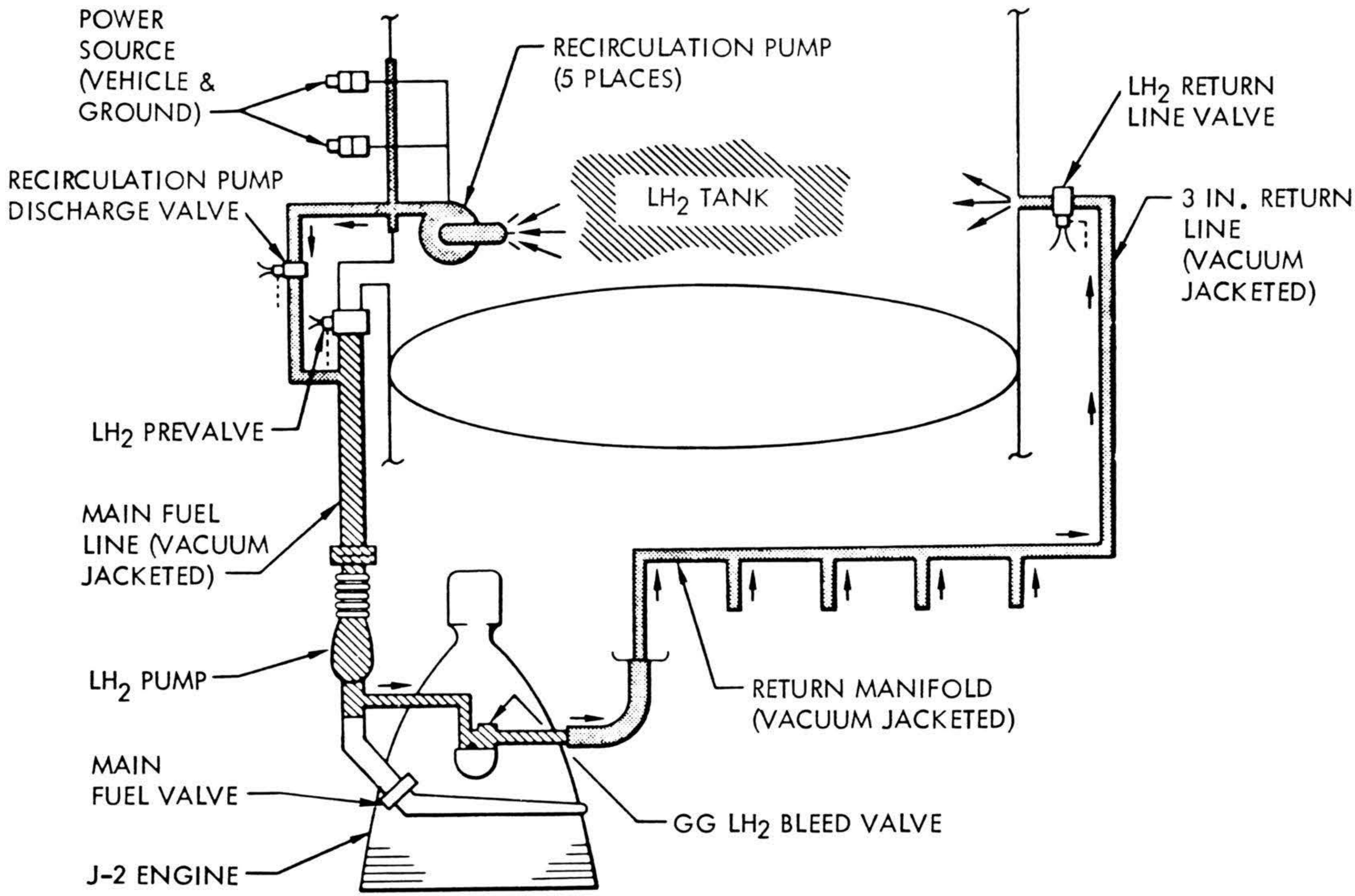

Figure 48. LH_2 Recirculation Prevalve Bypass and Return Lines

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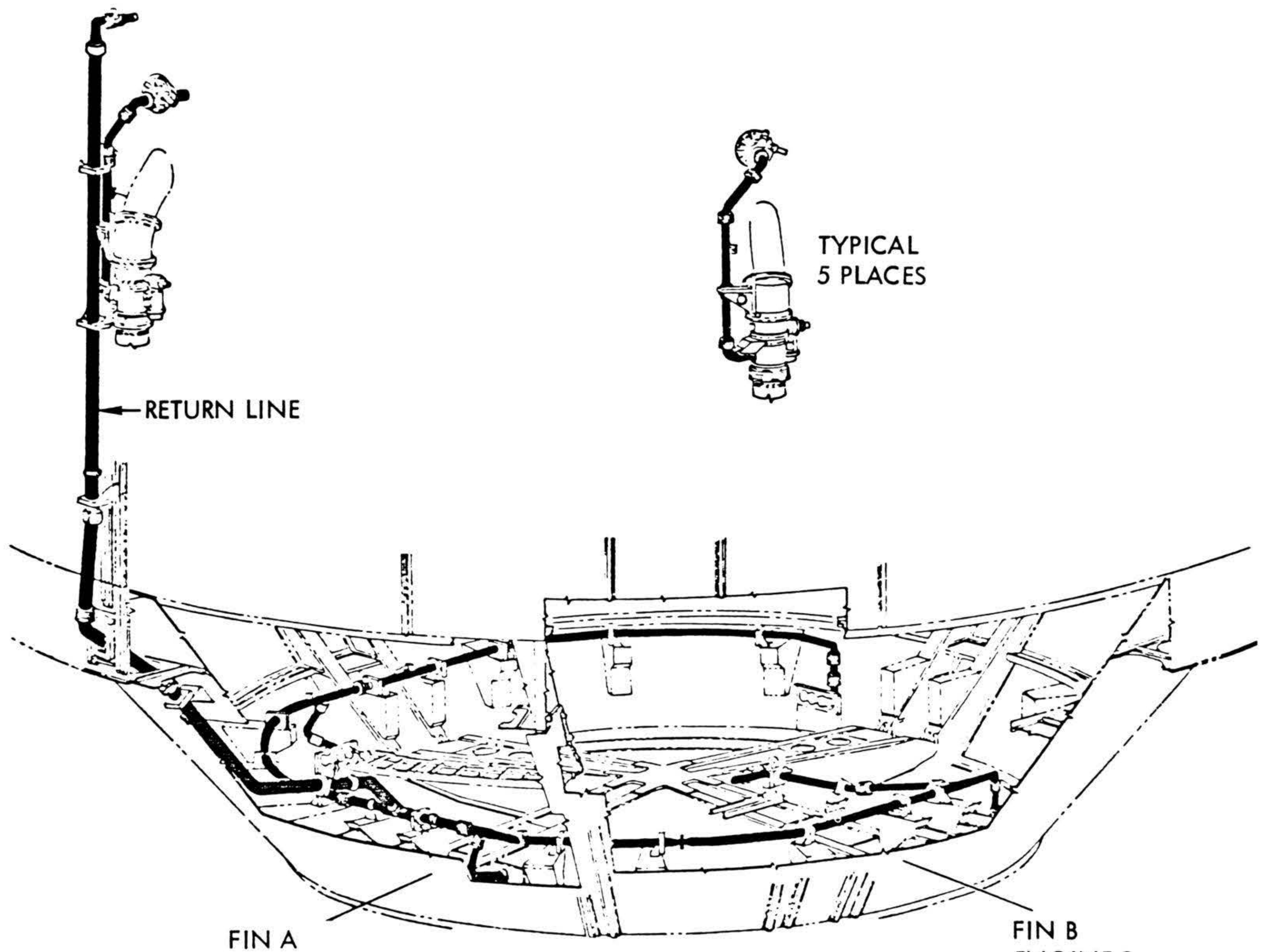

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VALVE ACTUATION SECTION

REQUIREMENTS

Requirements of valve actuation are as follows:

a. Maximum leakage of 4.46 scfm (33 psi/min) during S-IC boost

b. Maximum leakage of 6.8 scfm (85 psi/min) during S-II boost

c. Minimum pressure of 550 psig for valve actuation at all times

d. Close 11 recirculation valves once, at J-2 engine start

f. Close five LOX prevalves and five hydrogen prevalves once, after J-2 engine cutoff

g. 100-percent margin (minimum) in system storage capacity for flight

DESCRIPTION

Valve actuations in the LH_2 and LOX circulation sections of the subsystem are controlled as shown in Figure 49. Helium gas is used as the pressurant. The gas enters through the disconnect P45 and is stored at 3000 psig in receiver P102. Part of the gas flows through pressure regulator P47 immediately and is stored in surge chambers P48 and P69 at 750 psig. Check valves P55 and P56 prevent loss of this gas in the event of line breakage upstream of the valves. Relief valves P65 and P66 operate at 800 psig and prevent overpressurization of the surge tanks as a result of increased gas temperature.

In the hydrogen leg of the actuation section, the helium gas closes the prevalves P4A through P4E, pump discharge valves F6A through F6E and return line valve F10. Gas to the pump discharge and return line valves is controlled by solenoid valve P53. This is a three-way, normally closed solenoid valve. When it is in its actuated position, helium passes through

Figure 49. Valve Actuation System (Schematic)

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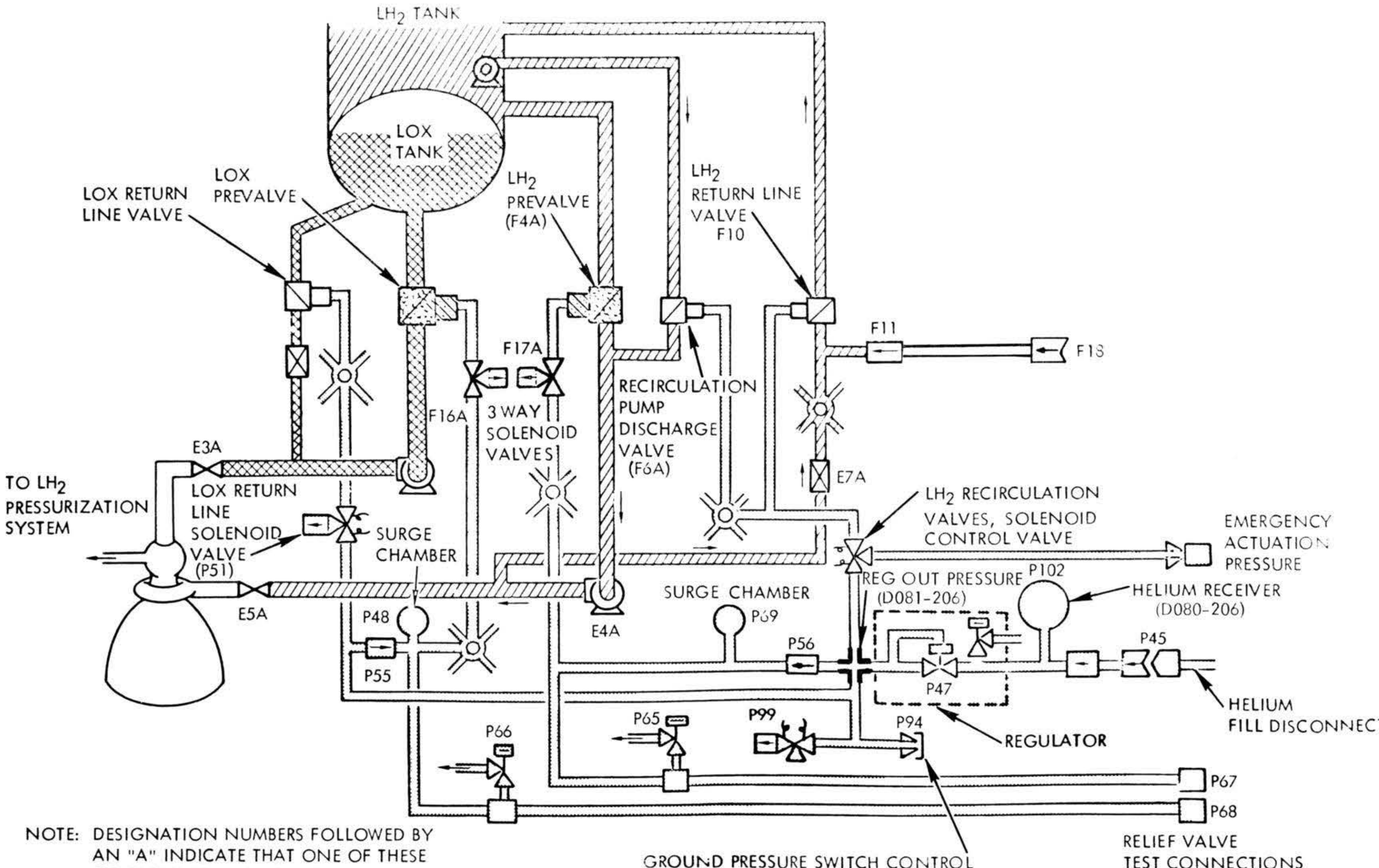
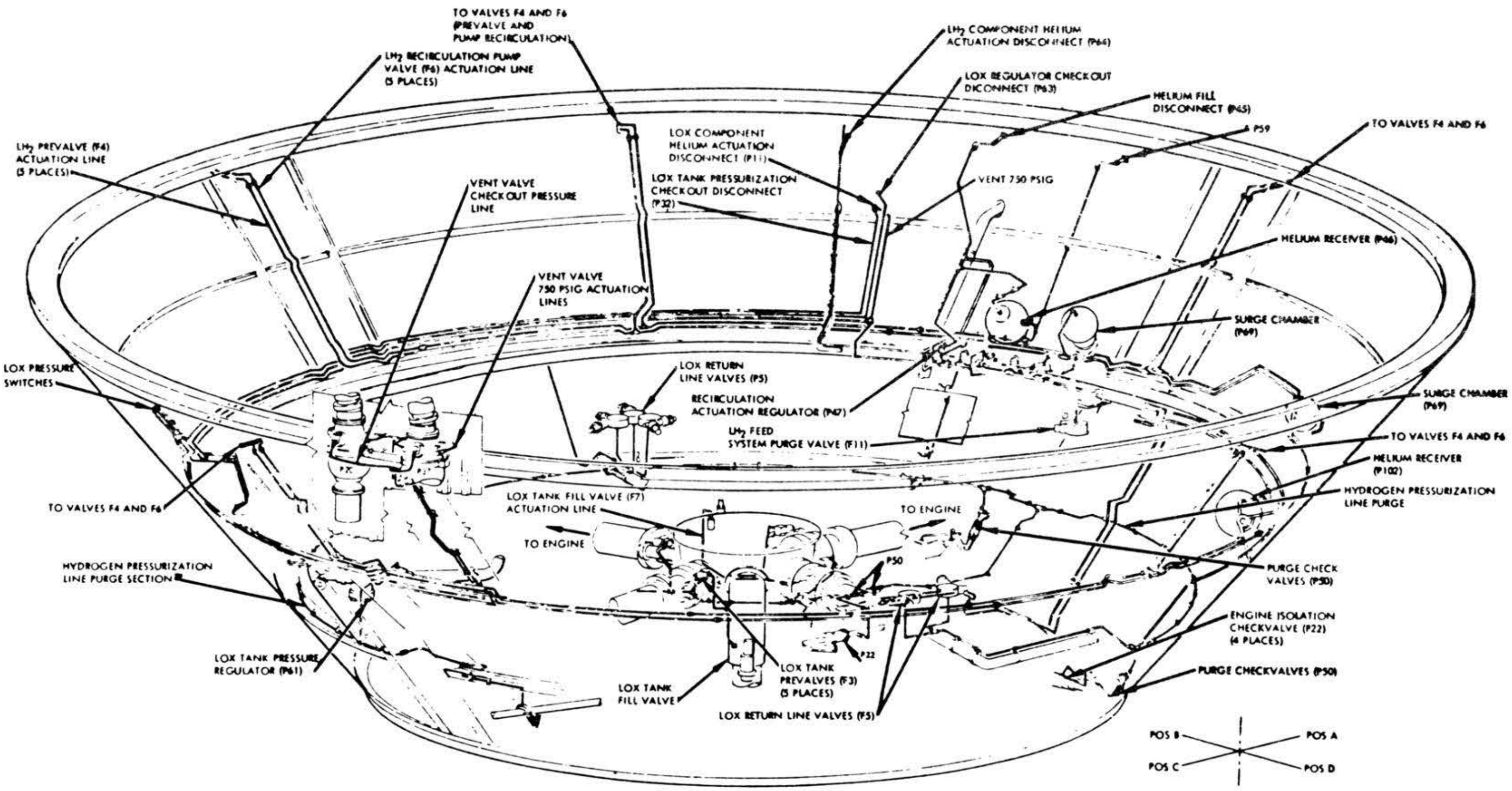


NOTE: DESIGNATION NUMBERS FOLLOWED BY AN "A" INDICATE THAT ONE OF THESE COMPONENTS IS LOCATED IN EACH OF THE FIVE ENGINE LINES.

position, helium passes through to close F6A - F6E and F10. In its deenergized position the solenoid valve P53 vents helium from these valves through B-nut P72 and causes them to return to their normally open condition. The actuating chambers of the prevalves are directly connected to a surge chamber without intermediate valving. Helium flow to the LOX return line valves E5 is controlled by solenoid valve P51. This valve is also a three-way, normally closed valve. The LH_2 and the LOX tank prevalves have individual solenoid valves for actuation. For S-II-2, these individual solenoid valves are four-way types that actuate the prevalves both open and closed. For S-II-3 and subsequent stages, these solenoid valves are of the three-way type and are only used for actuating the prevalves closed.

Gas is applied through test connectors P67 and P68 at a pressure high enough to actuate the relief valves P65 and P66 as a part of the functional checkout procedure. These connectors can also vent the gas trapped downstream of the check valves (P55 and P56) if required. A solenoid valve P99 is used to bleed down the section upstream of the check valves when necessary. An axonometric drawing of the valve actuation section is shown in Figure 50.

Figure 50. Valve Actuation System



SYSTEM STATUS AT LIFTOFF

At the time of liftoff, both the LOX and LH_2 recirculation systems are in operation. The LH_2 recirculation pumps are operating on stage-supplied power, and the helium for the LOX system helium injection system is being supplied by onboard stage storage. Receivers for helium injection system and the valve actuation systems are charged to 2800-3450 psig early in the countdown and are maintained at this pressure level until 30 seconds prior to liftoff.

SEQUENCE OF OPERATION

Events and sequence of occurrence concerning the recirculation system during flight are shown in Figure 51.

Figure 51. Sequence of Operation Recirculation System

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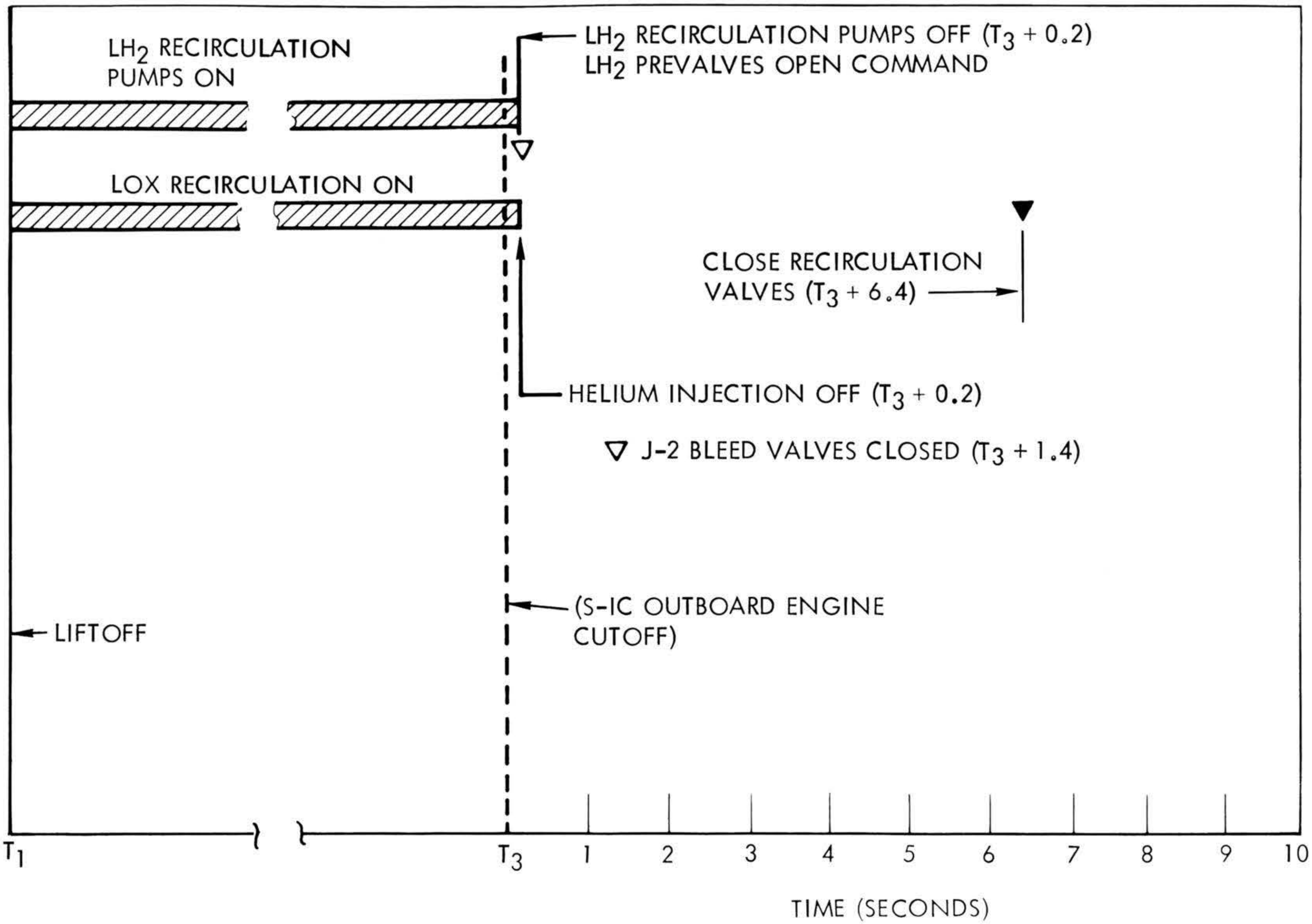

MANNED SPACE CENTER DISPLAYS

Five items concerning the recirculation system are displayed at the Manned Space Center. They are:

a. Recirculation bus voltage

b. Recirculation battery current

c. Valve actuation system helium bottle pressure (D0080-206)

d. LH_2 prevalves position (K174/178-207 and K190/194-207)

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SYSTEM PERFORMANCE

Data concerning the recirculation bus voltage and recirculation battery current will be presented in the electrical section.

A comparison of the predicted values and actual values obtained from the AS-501 flight are shown in Figure 52.

As the LOX and LH_2 prevalves positions are discretes, no curves are presented.

Other flight data concerning the recirculation system not displayed at MSC are presented in Figures 53 through 56 for backup purposes.

Figure 52. S-II-1 Valve Actuation System Receiver Pressure - D008-206

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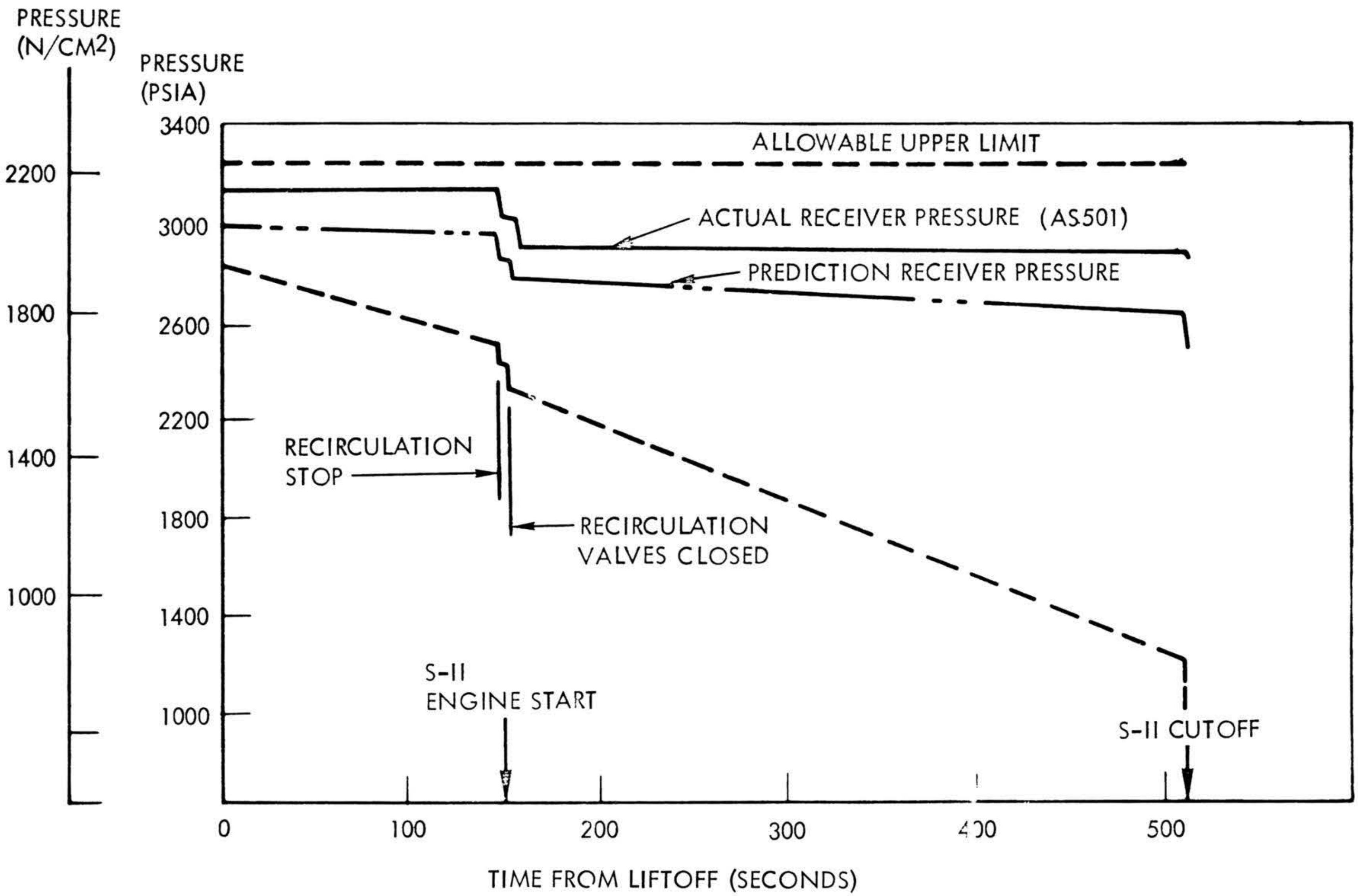

Figure 53. Predicted S-II-2 LOX Recirculation System Flight Performance LOX Pump Discharge Temperature

DATE ____________
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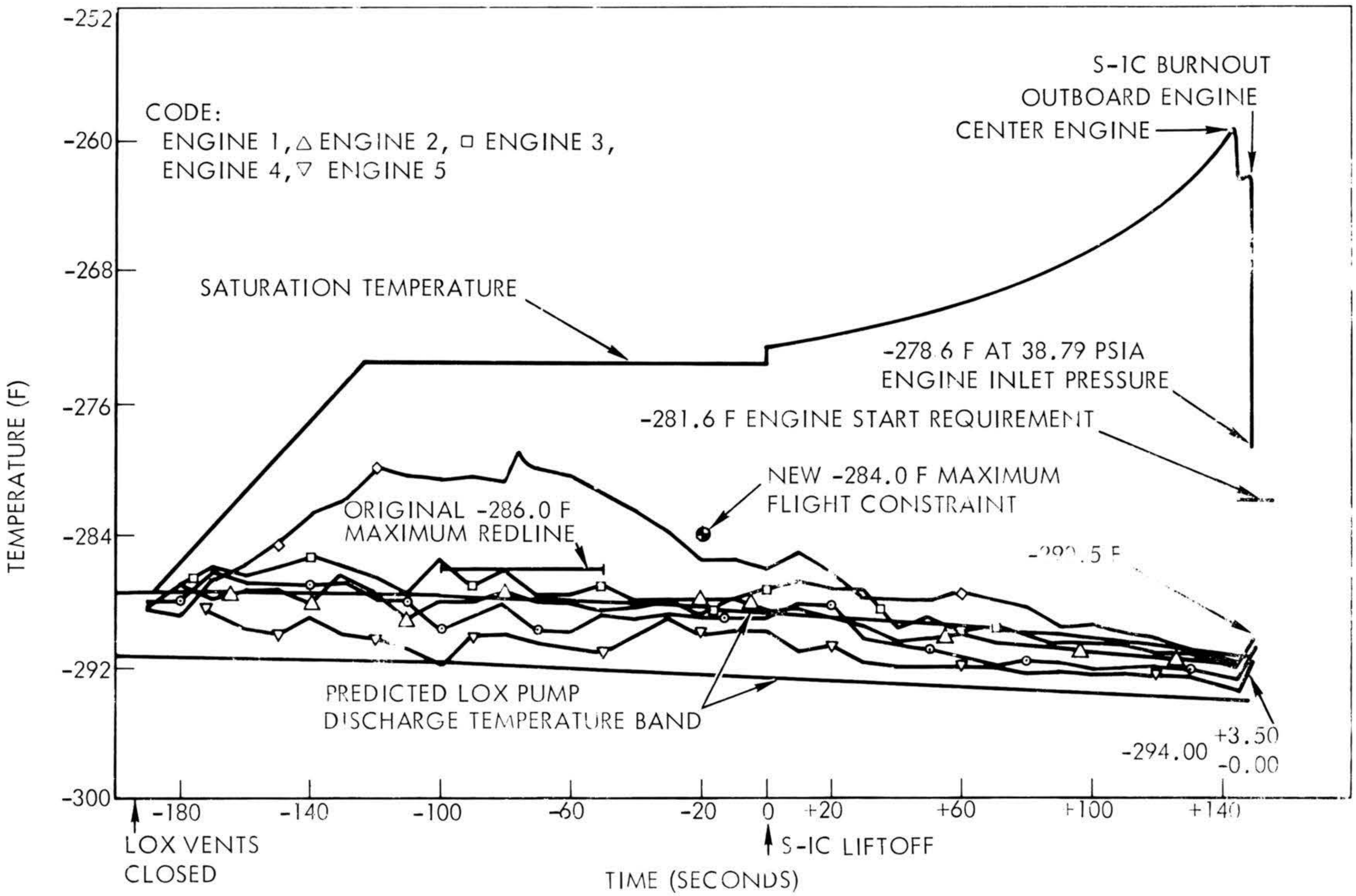


Figure 54. Predicted S-II-2 LOX Recirculation System Flight Performance LOX Pump Inlet Temperature

DATE ____________
SPEAKER ____________
CONTROL NO. ____________

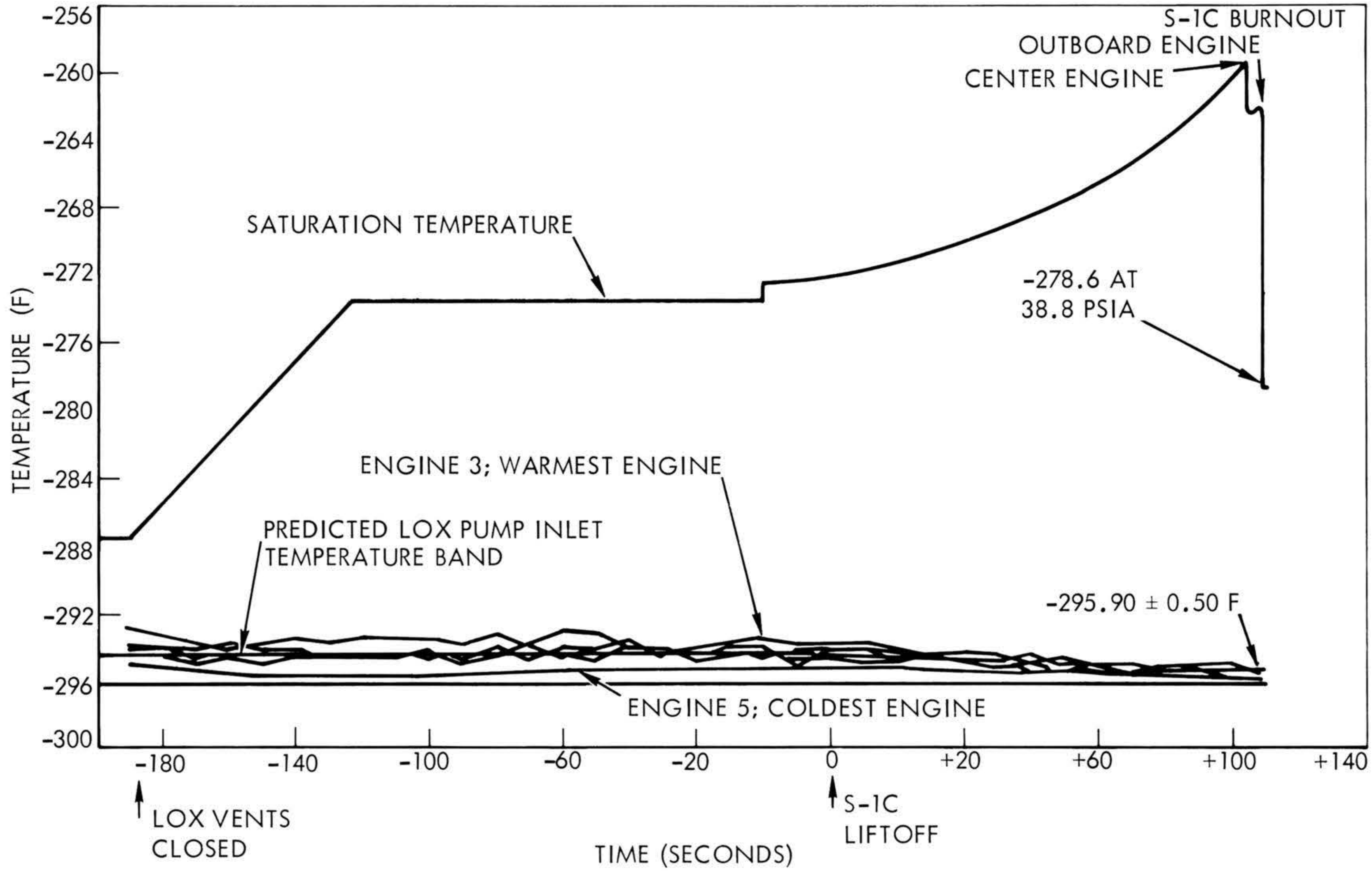


	Figure 55. Predicted S-II-2 Helium Injection System Flight Performance	DATE ____ SPEAKER ____ CONTROL NO. ____

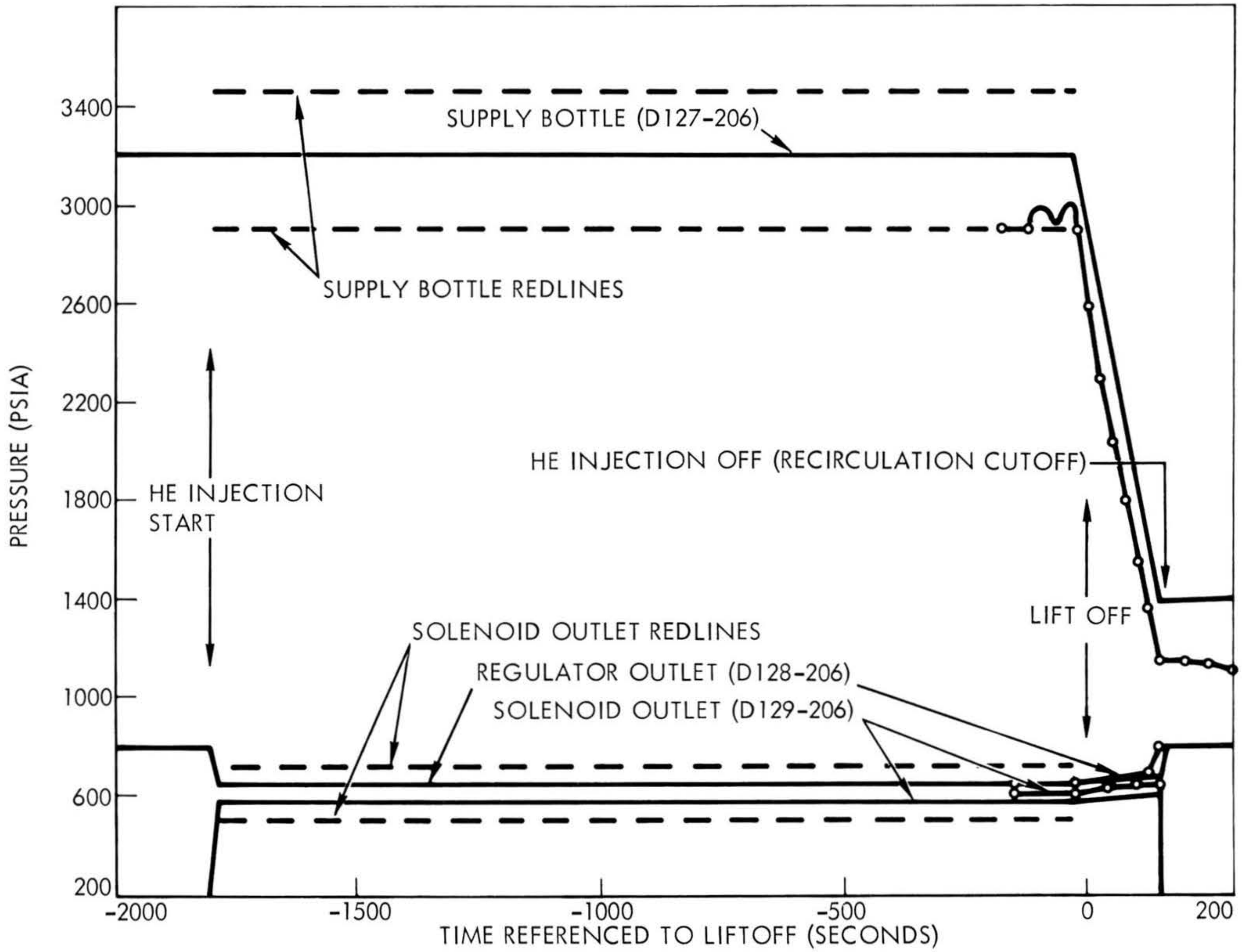
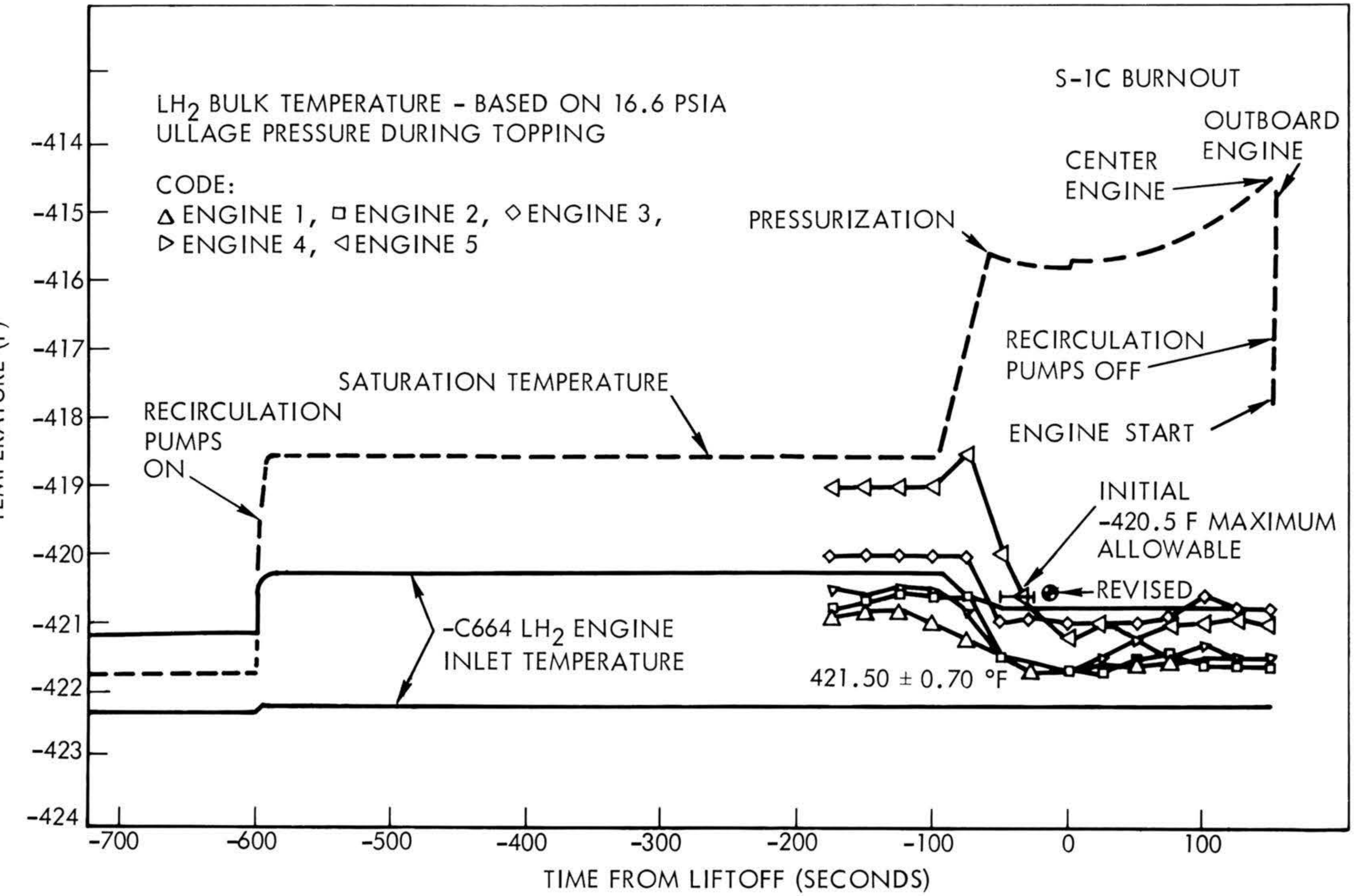


	Figure 56. Predicted S-II-2 LH_2 Recirculation System Flight Performance Based on Actual Telemetry Readings	DATE ______ SPEAKER ______ CONTROL NO. ______



SYSTEM VARIATIONS

On AS-502 and subsequent stages the forward section of feedlines fairings are sealed. In addition, the flanges of the LH_2 feedlines and recirculation lines are insulated.

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SECTION V. S-II STAGE PRESSURIZATION SYSTEM

FUNCTION

There are two basic functions of the S-II stage inflight propellant tank pressurization system: (1) to meet engine pressure requirements and (2) to help maintain stage structural integrity. Engine pressure requirements are met by ensuring a proper net positive suction head (NPSH) at the engine propellant pump inlets. Without this pressurization, the engine pumps would be unable to function. Maintenance of stage structural integrity is twofold: the stage structure must be protected from overpressurization to avoid rupture and from underpressurization to avoid buckling during S-IC boost.

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SUBSYSTEMS

The propellant tank pressurization system is composed of two subsystems, the propellant tank pressurization subsystem and the propellant tank venting subsystems.

PROPELLANT TANK PRESSURIZATION SUBSYSTEM

This subsystem actually supplies the positive propellant tank pressure to ensure that engine NPSH requirements are met and that structural requirements are satisfied during S-IC boost.

PROPELLANT TANK VENTING SUBSYSTEM

In guarding against overpressurization, this subsystem helps assure proper engine operation and structural integrity. The potential sources of overpressurization are propellant boiloff and pressurization system malfunction.

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PRESSURIZATION SYSTEM FEATURES

This section describes the functional subsystems. No hardware description is included in this section because this description is not considered necessary to understanding the system or its operation.

PRESSURIZATION SUBSYSTEM FEATURES

The propellant tank pressurization subsystem comprises two sections: LOX-tank pressurization and LH_2 tank pressurization. These are shown in Figure 57.

GOX is formed by evaporating LOX in one coil of the four-coil heat exchanger that is supplied with the engine. Heat for evaporation comes from the exhaust gases of the LOX-pump turbine. Gas from the five engines is collected in a manifold and conducted through a regulator and gas distributor into the LOX tank ullage space. The regulator senses the pressure in the vent line, which is directly connected to the ullage space, and opens or closes to control the rate of flow of pressurant.

GH_2 is bled from the engine injector and is collected from the four outboard engines in a manifold; it is then conducted up the side of the stage, through a regulator and gas distributor, and into the ullage space The regulator senses the pressure in the vent line, which is connected directly to the ullage space, and maintains the ullage pressure by regulating the rate of pressurant flow.

During the first 320 (AS-501 and AS-502; 300 seconds for AS-503 and subsequently flights) seconds of S-II flight, the GH_2 regulator acts to control the rate of pressurant flow to the LH_2 tank. At the end of this period, the regulator is opened to its full-open position (step pressurization), and the pressure in the tank is allowed to rise to the vent-valve cracking pressure.

Because propellant tank pressurization during flight requires the engine to be operative, it is obvious that from liftoff and until the S-II engines fire, no active tank pressurization system exists. To maintain the structural integrity of the stage and to ensure that the engines start properly, the tanks are prepressurized at a high enough level to allow a reasonable amount of pressure decay between liftoff and the time when the onboard pressurization system is active.

Figure 57. Propellant Tank Pressurization System

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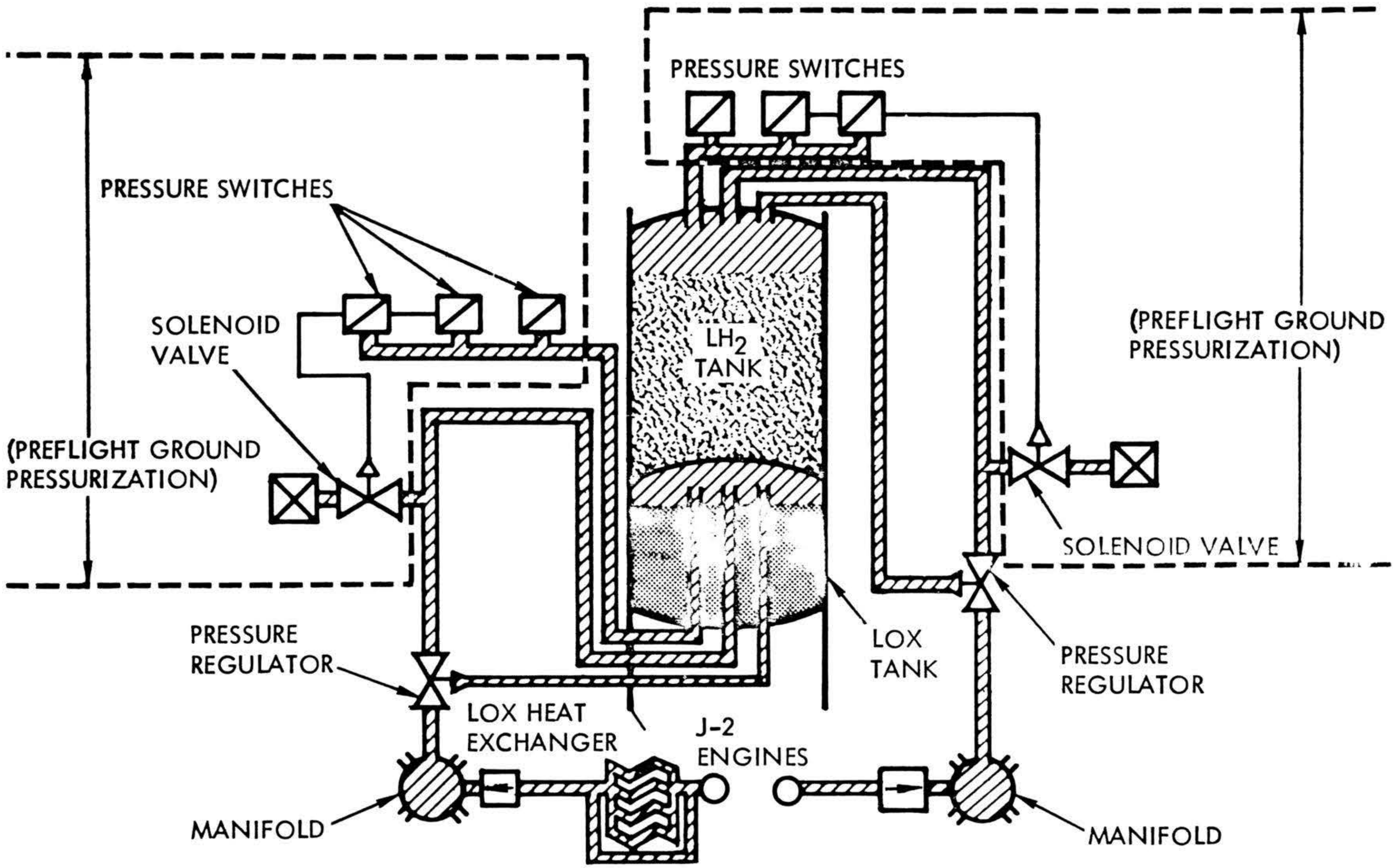
CONTROL NO. ____________



VENTING SUBSYSTEM FEATURES

The vent valves are intended to prevent overpressurization by permitting the outflow of excessive gas. In flight, the vent valves are opened by excessive tank pressures that act through a pilot mechanism. Gas from all valves is vented directly overboard. Figure 58 is a schematic of the venting sections. Axonimetric views are shown in Figures 59 and 60.

The LH_2 tank venting is controlled by two 7-inch-diameter valves. These valves are located at the end of two vacuum-jacketed lines that lead from the tank ullage space and discharge through the vent disconnects.

The LOX tank is vented by conducting excess gas in a vent line that branches into two 7-inch lines. Two vent valves control the discharge of excess gas by sensing the vent line pressure and opening when the pressure reaches a predetermined level.

Figure 58. Propellant Tanks Vent System

DATE ____________
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CONTROL NO. ____________

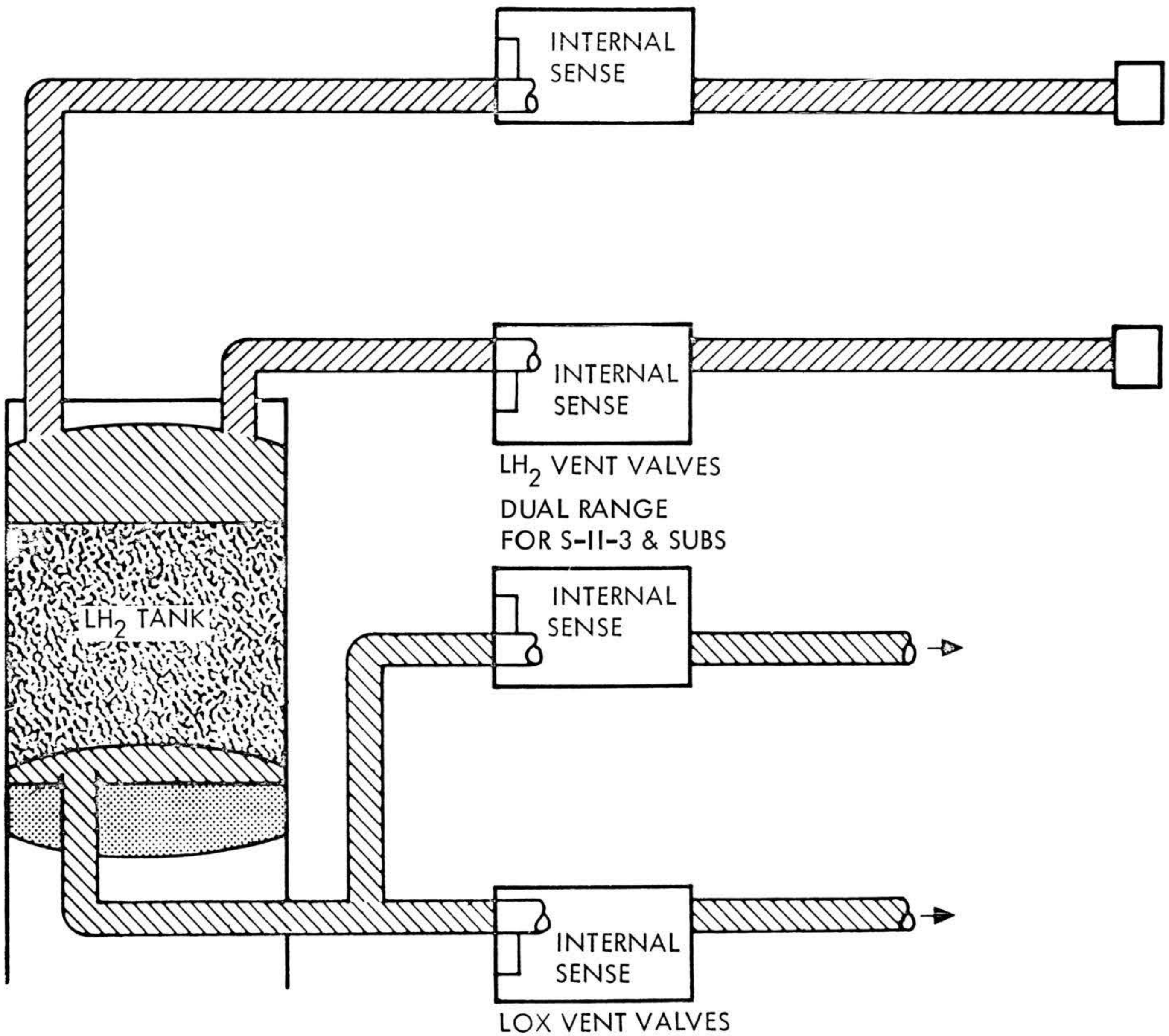

	Figure 59. LOX Tank and Aft Section Configuration	DATE ________ SPEAKER ________ CONTROL NO. ________

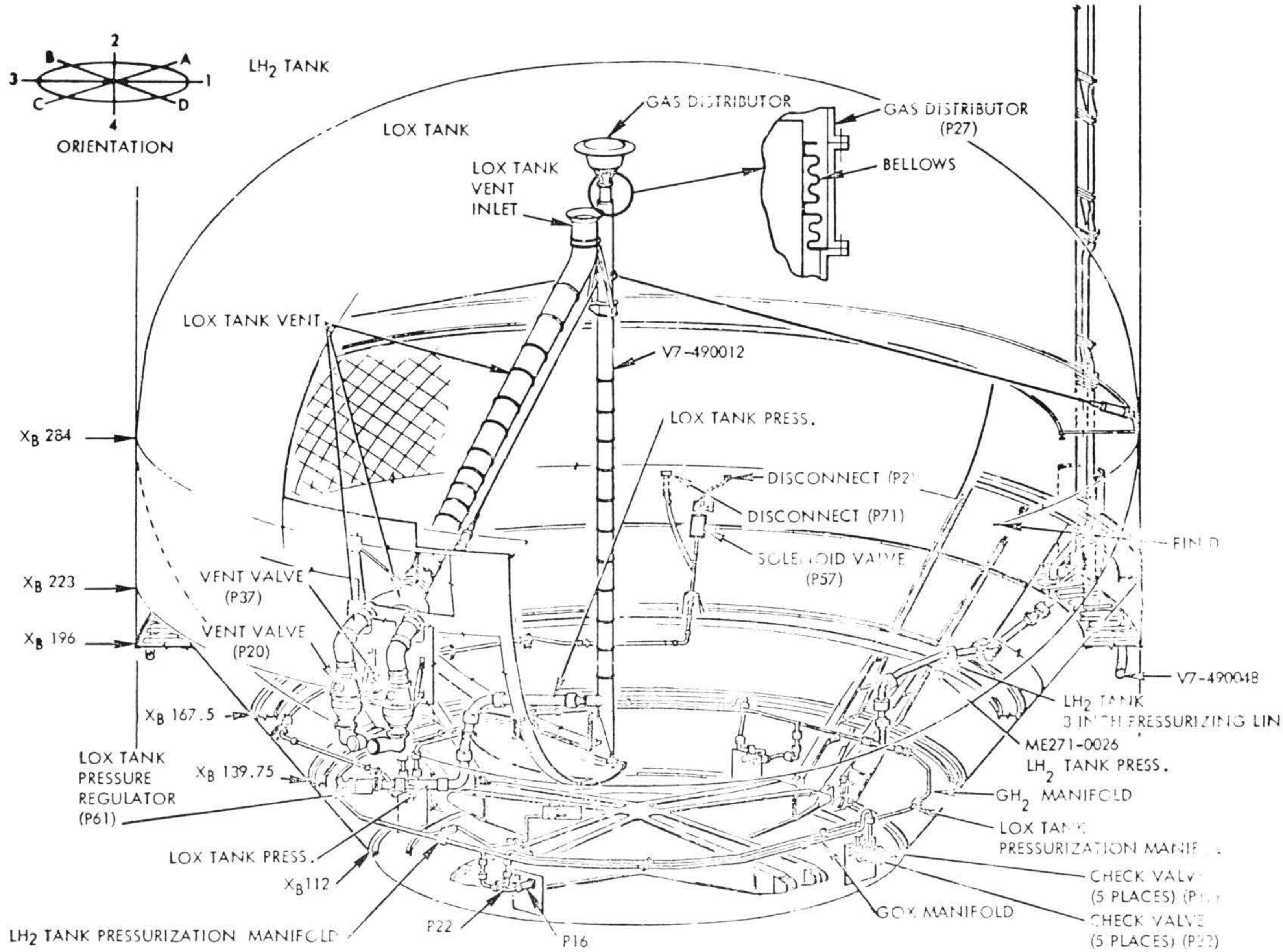

Figure 60. LH_2 Tank Forward Bulkhead Showing Sections of Pressurizing Sections

DATE
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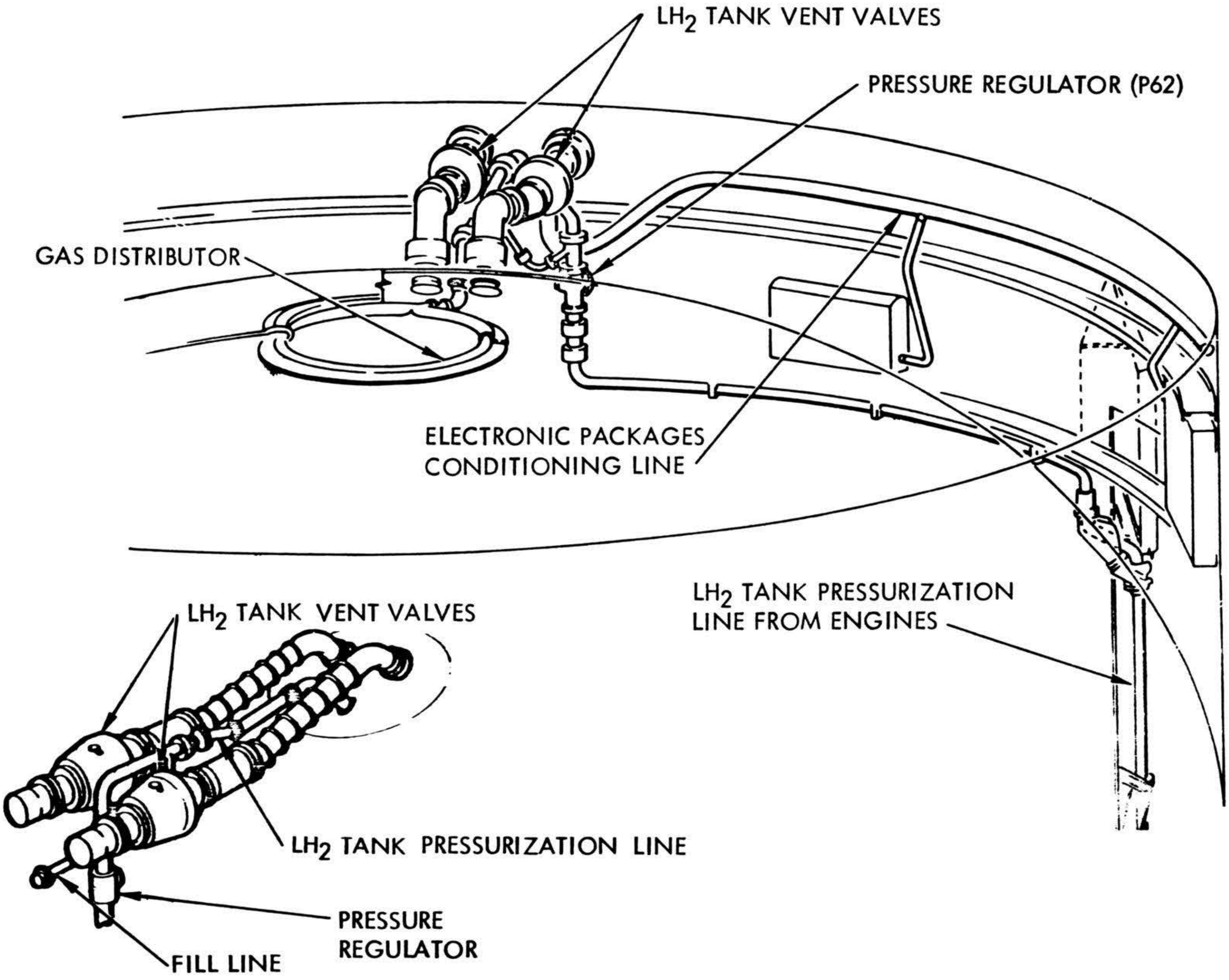

CONDITIONS AT LIFTOFF

LOX TANK

Prior to liftoff, the AS-501 was pressurized to the vent valves high-pressure setting of 39 to 42 psia. For AS-502 and subsequent missions, the LOX tank will be pressurized to the pressure switch setting of 37 to 39 psia.

LH_2 TANK

Prior to liftoff, the AS-501 was pressurized to the pressure switch setting of 31 to 33 psia. The AS-502 will be pressurized to the vent valve high-pressure setting of 30.5 to 33.0 psia. For AS-503 and subsequent missions, the LH_2 tank will be pressurized to the pressure switch setting of 34 to 36 psia.

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PERFORMANCE AND REQUIREMENTS

Figures 61 through 65 show operational limits, requirements, and AS-501 flight performance. Also shown in these figures are the changes that occur because of stage variations (shown in Figure 68). Figures 66 and 67 show the NPSH requirements and the AS-501 actuals.

LOX TANK PRESSURIZATION (AS-501 PERFORMANCE)

The LOX tank pressure exhibited its characteristic drop of about 3 psi during the first 15 seconds from engine start. The regulator controlled the ullage pressure within its control band until approximately 440 seconds, at which time the pressure dropped below the control band of 36.0 psia. The pressure continued to decay, and at cutoff it was 34.8 psia. Figure 61 shows the LOX tank ullage pressure during S-II burn. There is a direct relationship between the LOX tank GOX flow demand and the heat exchanger performance. The heat exchanger outlet temperatures versus time were very low during the last 60 seconds of flight.

NOTE: Further evaluation indicates that a blockage existed in the Engine 4 heat exchanger. This blockage and resultant decay of ullage pressure below the lower performance band at approximately T3 + 290 seconds (Figure 61) has been adjusted to be no failure within the pressurization system. Although the pressure did drop below the design performance level for the last 60 seconds of S-II flight, it was well within the minimum requirement for that period.

LH_2 TANK PRESSURIZATION (AS-501 PERFORMANCE)

LH_2 tank pressurization was normal. The regulator controlled the ullage pressure within the control band until step pressurization was initiated at 320 seconds from engine start. The ullage pressure increased after step pressurization, and at cutoff was at 32.0 psia, which agrees with the prediction.

Figure 61. AS-501 LOX Tank Ullage Pressure Requirements and Actuals

DATE
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CONTROL NO.

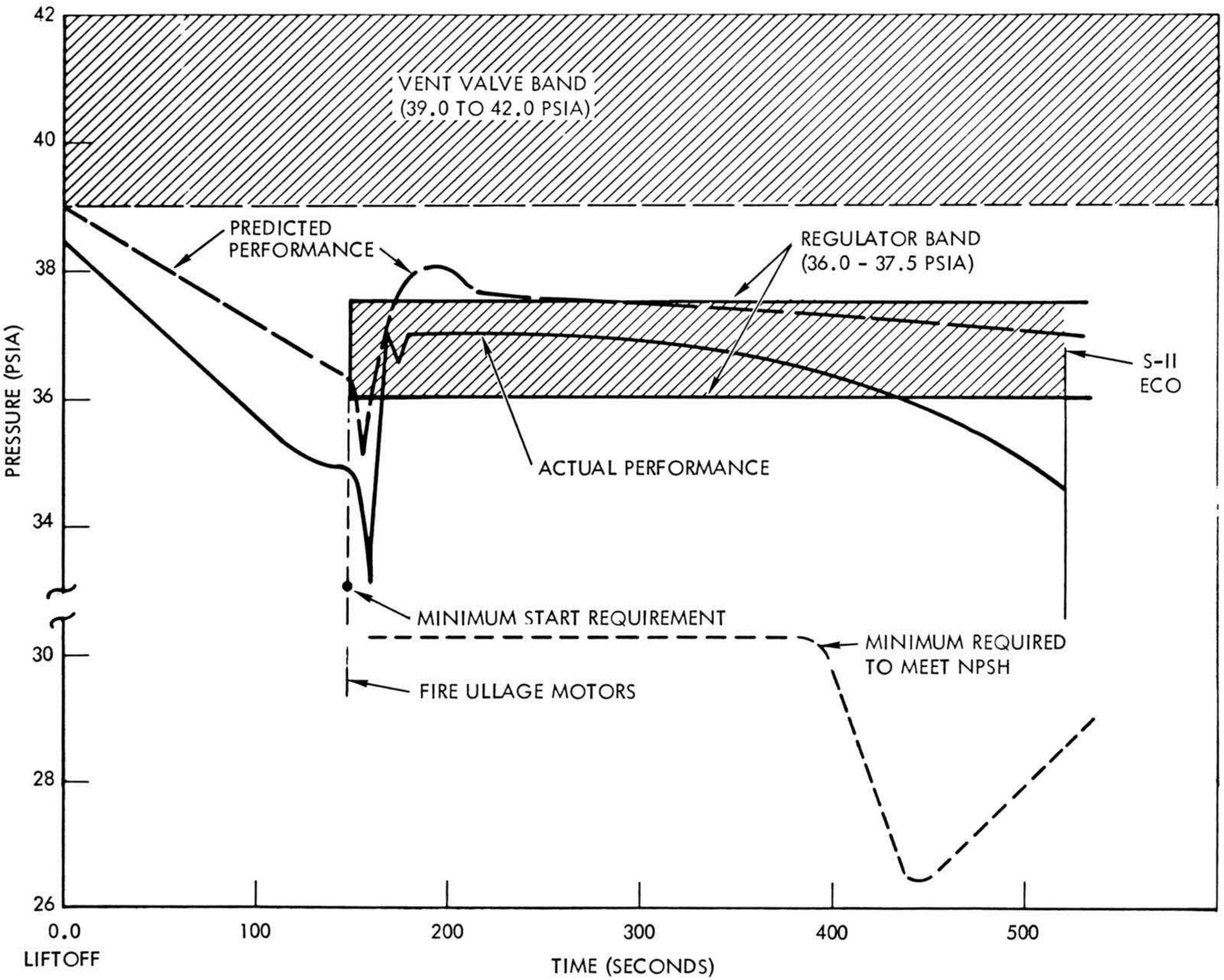

Figure 62. AS-503/S-II-3 and Subsequent Stages LOX Tank Ullage Pressure Requirements

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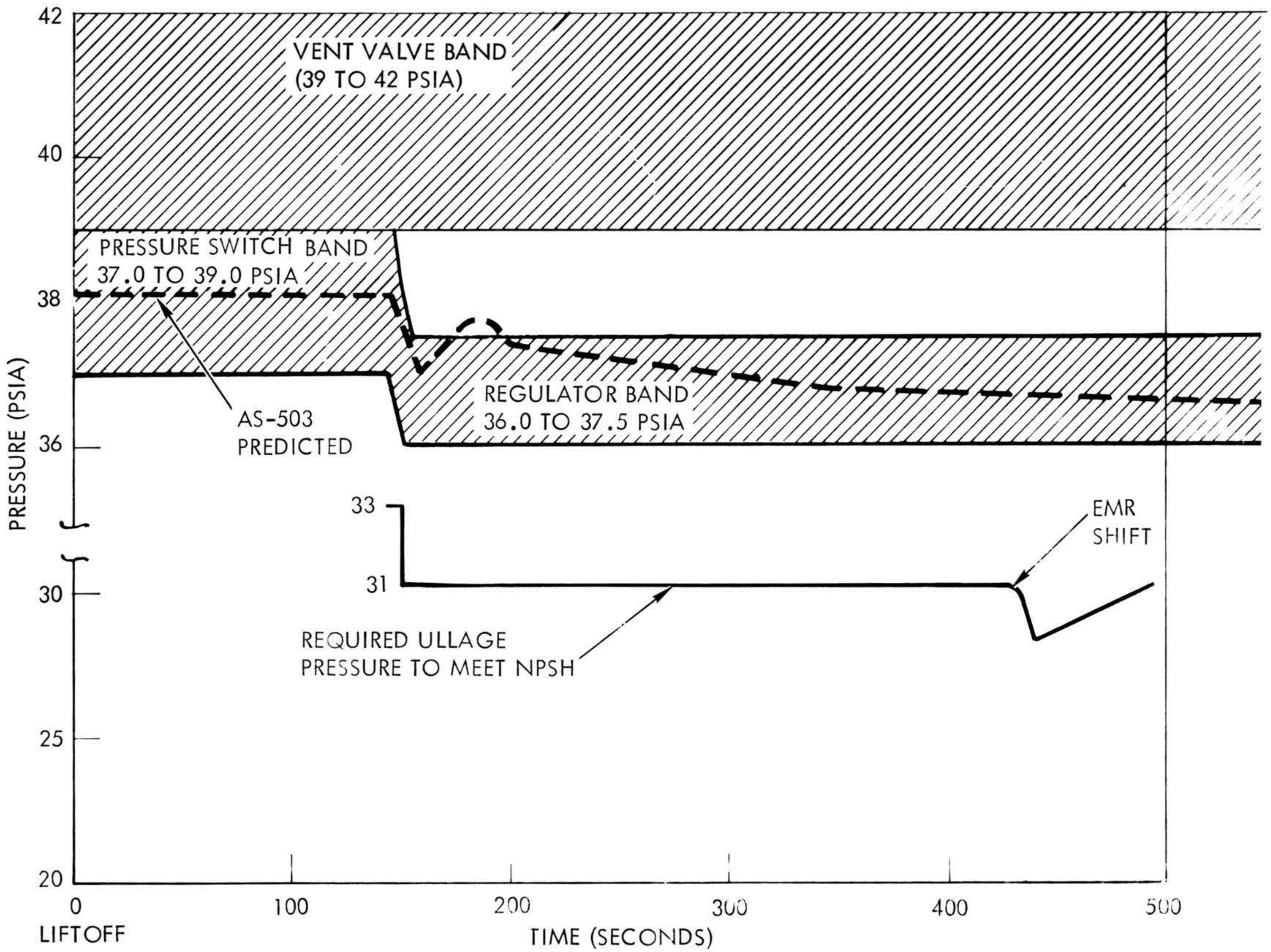

	Figure 63. AS-501 LH_2 Ullage Pressure Requirements and Actuals	DATE ____ SPEAKER ____ CONTROL NO. ____

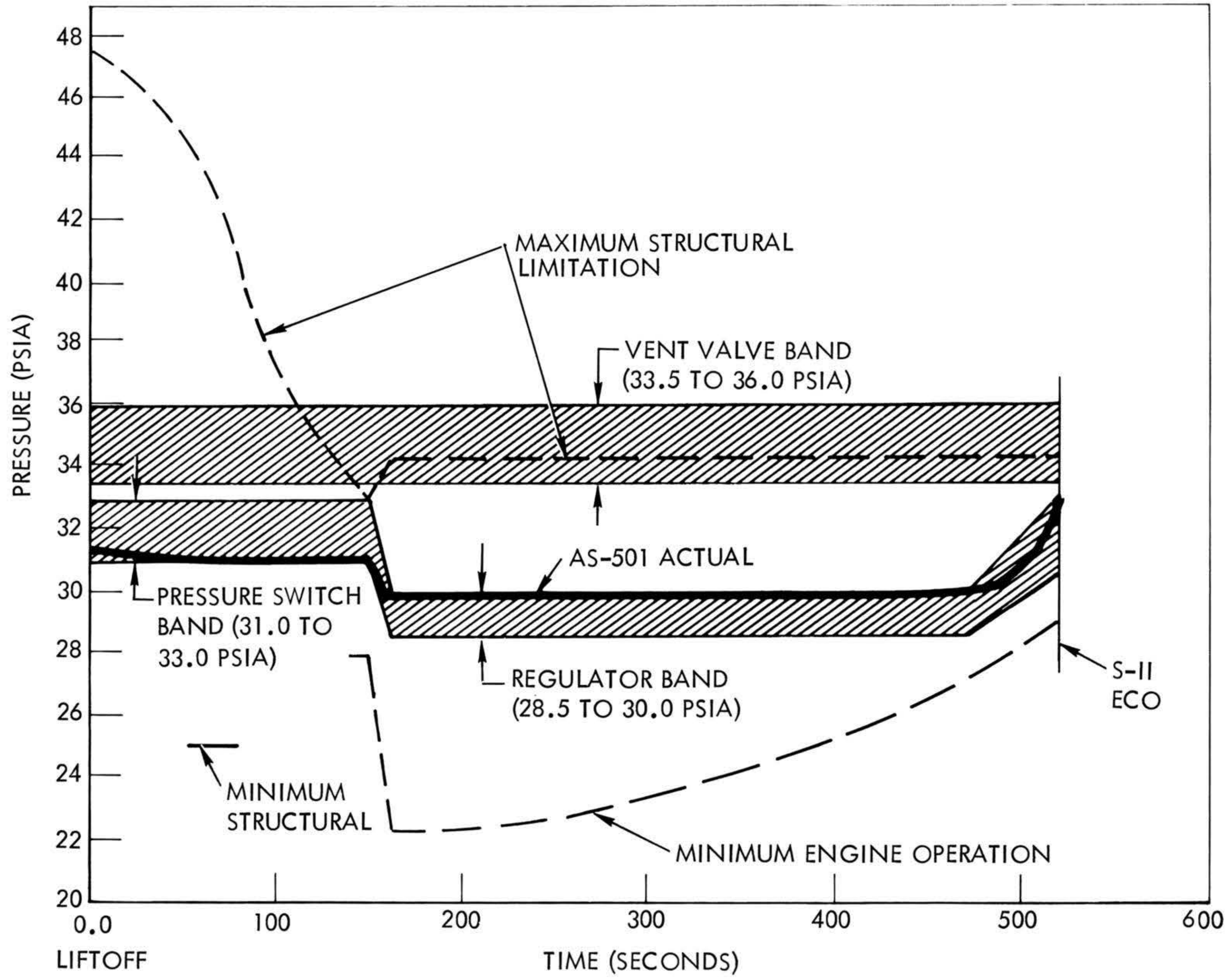

Figure 64. AS-502 LH_2 Ullage Pressure Requirements

DATE

SPEAKER

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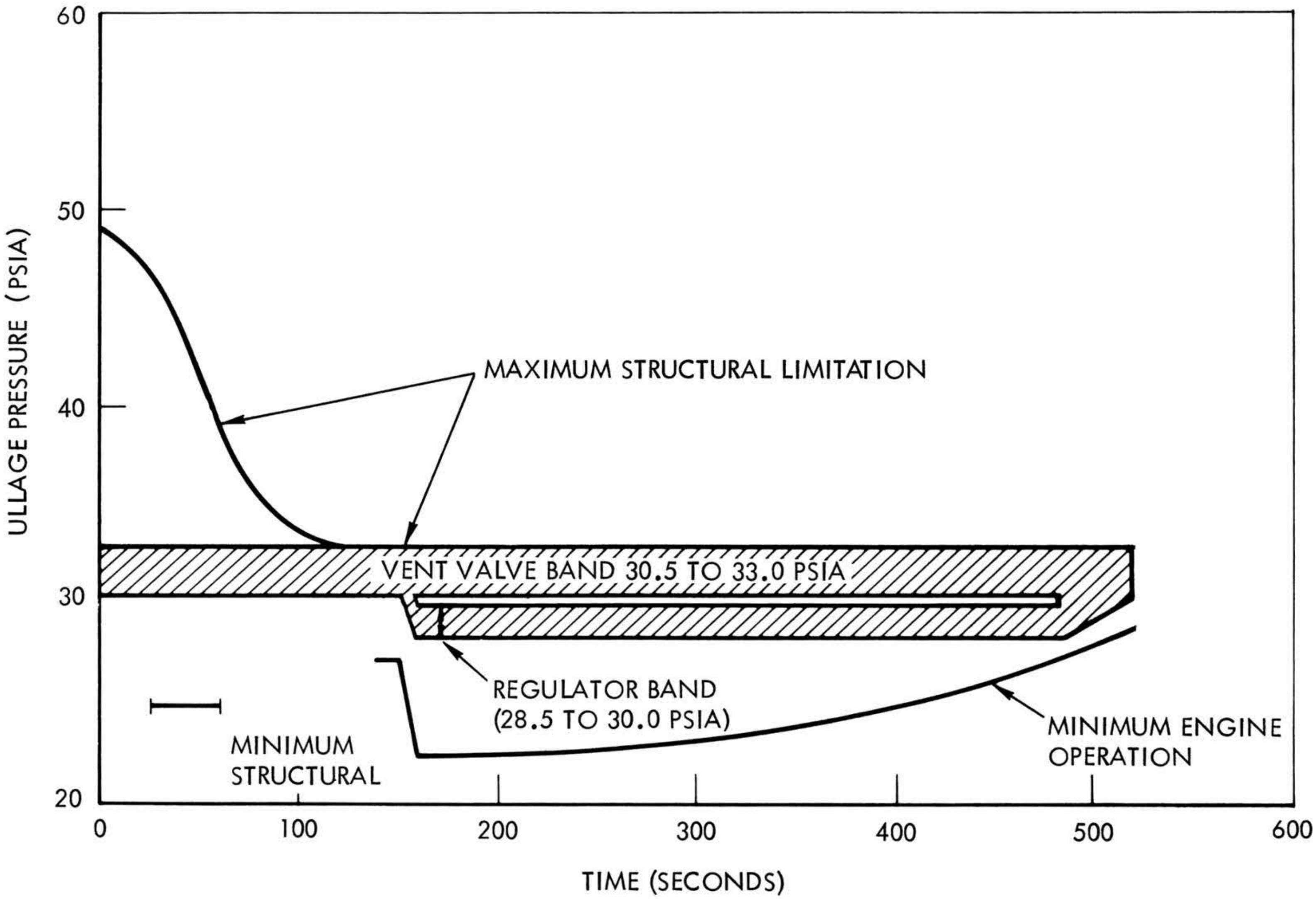

Figure 65. AS-503 and Subsequent Stages LH_2 Ullage Pressure Requirements

DATE
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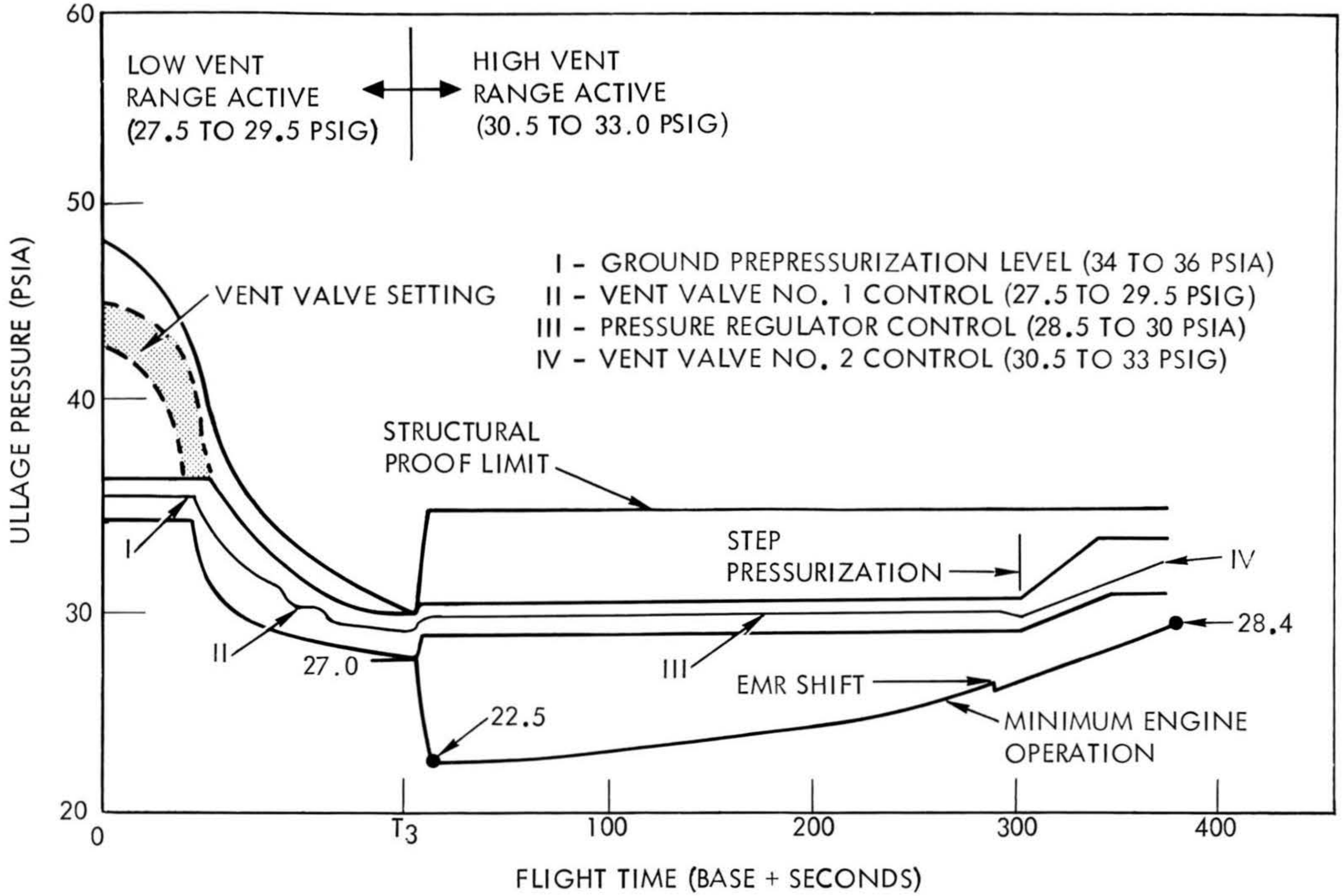

Figure 66. AS-501 and Subsequent Stages Engine LOX NPSH Flight Requirements

DATE ____
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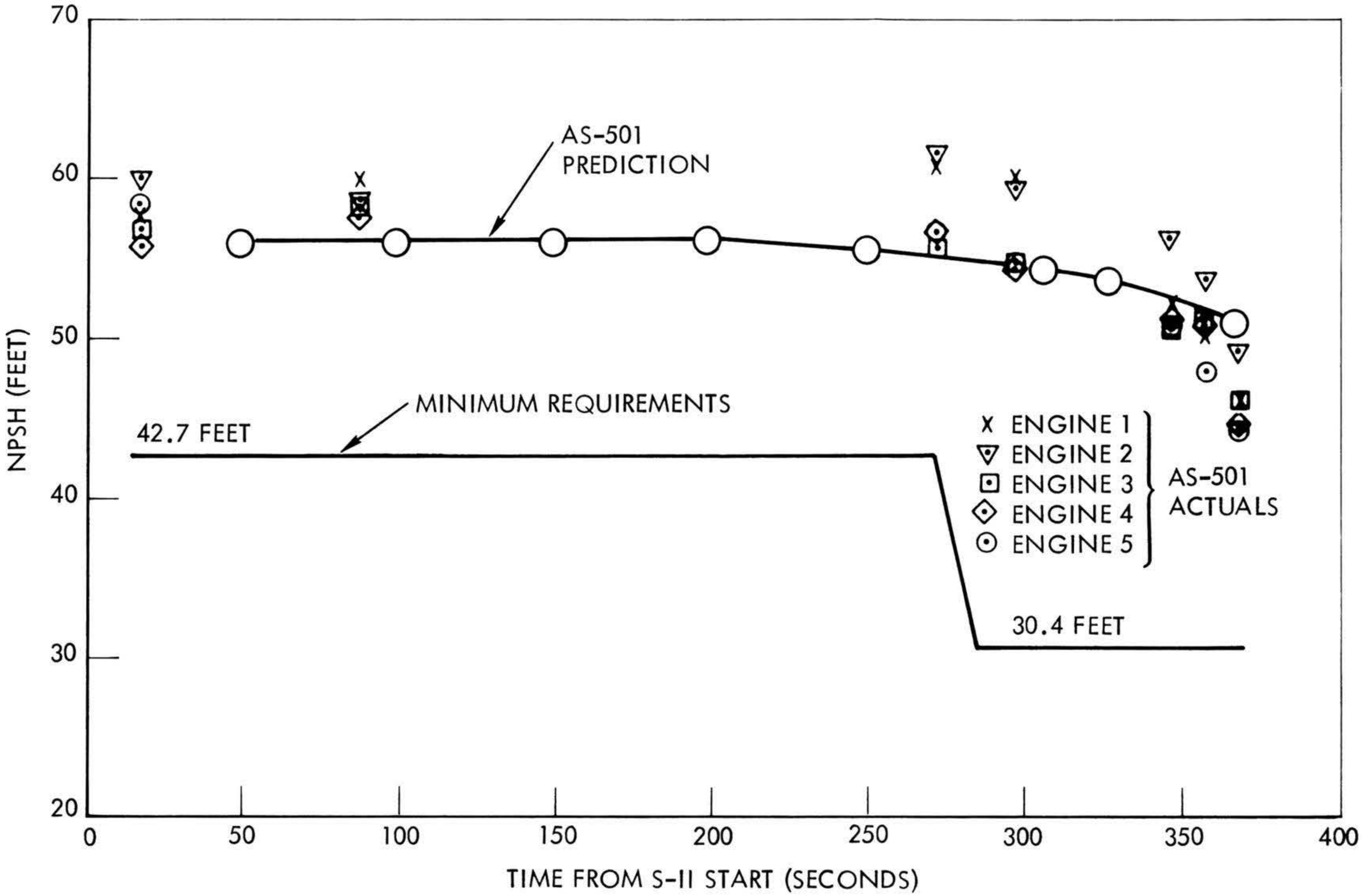

	Figure 67. AS-501 and Subsequent Stages Engine LH_2 NPSH Flight Requirements	DATE ______ SPEAKER ______ CONTROL NO. ______

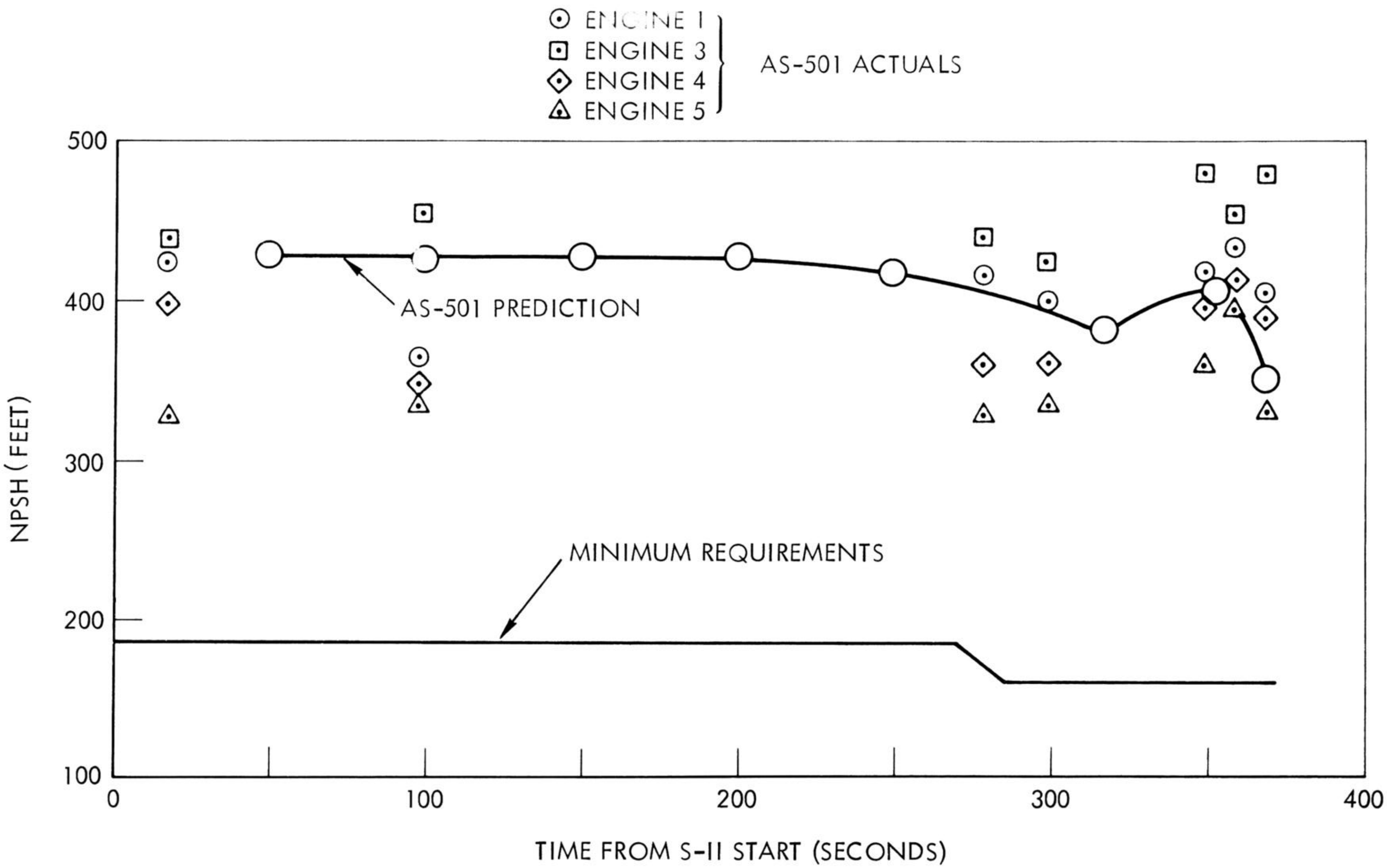

Figure 68. Stage Variation Summary

DATE ____________
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● LOX TANK

PREPRESSURIZATION PRIOR TO S-IC LAUNCH	S-II-1	39 - 42 PSIA
	S-II-2 AND SUBS	37 - 39 PSIA
PRESSURIZATION DURING S-II BOOST	S-II-1 AND SUBS	36 - 37.5 PSIA
VENT VALVE SETTING: S-IC AND S-II BOOST	S-II-1 AND SUBS	39 - 42 PSIA

NOTE: ON S-II-2 AND SUBS, THE COMMON BULKHEAD IS EVACUATED BEFORE S-IC LAUNCH TO 3 PSIA MAXIMUM TO MINIMIZE LOX ULLAGE PRESSURE DECAY.

● LH_2 TANK

	S-II-1	S-II-2	S-II-3 AND SUBS
PREPRESSURIZE PRIOR TO S-IC LAUNCH	31 TO 33 PSIA	30.5 TO 33 PSIA	34 TO 36 PSIA
VENTING DURING S-IC BOOST	34 TO 36 PSIA	30.5 TO 33 PSIA	27.5 TO 29.5 PSIG
VENTING DURING S-II BOOST	34 TO 36 PSIA	30.5 TO 33 PSIA	30.5 TO 33 PSIG
PRESSURIZATION DURING S-II BOOST:			
BEGIN WITH REGULAR SETTING	28.5 TO 30 PSIA	28.5 TO 30 PSIA	28.5 TO 30 PSIA
AND AT TIME	T_3 + 320 SECONDS	T_3 + 320 SECONDS	T_3 + 300 SECONDS
STEP PRESSURIZE TO VENT VALVE SETTING	33.0 PSIA MAX	30.5 TO 33 PSIA	30.5 TO 33 PSIG

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STAGE VARIATIONS SUMMARY

Figure 68 presents a summary of all major operational changes between the AS-501 (S-II-1) and subsequent mission vehicles.