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MEMORANDUM ON

MERCURY-REDSTONE BOOSTER PROBLEMS [redacted]

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Langley Field, Virginia

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X64 80705

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NASA - Space Task Group
Langley Field, Virginia
March 20, 1961

MEMORANDUM For Project Director

Subject: Mercury-Redstone booster problems

1. This memorandum discusses the booster problems determined from Mercury-Redstone flights MR-1A and MR-2 that led to the decision by the Marshall Space Flight Center that a booster test flight is necessary before the MR-3 flight. Planned fixes for these problems are described. Some background on the propulsion system is presented as an appendix.

2. Problems outlined:

(a) Rudder and carbon vane vibration

(b) Instrumentation compartment vibration

(c) Thrust controller

(d) H_2O_2 tank pressure regulator

(e) Cutoff arming time

(f) Roll-abort sensor

(g) H_2O_2 system corrosion

(h) Man-hole LOX leak

(i) Velocity integrator

3. Problem discussion and proposed corrections:

(a) Rudder and carbon vane vibration. - The control system picked up oscillations near the second bending mode natural frequency of the booster on flight MR-1A which resulted in a sustained vibration

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of the booster control elements (rudders and vanes). The magnitude and time of this vibration was very near the predicted life span of the servo control motors. The order of vibration on MR-2 was one-third that of MR-1A.

MSFC has referred to this phenomenon as a "structural feedback loop", and in block diagram form appears as follows:

Control Side Force

Bending Deflection

Structural Bending Dynamics

Control Element

Control Sensor

Control Servo System Loop

Shaping Network

Control Deflection

Control Command Signal

This problem was caused by the lowered second bending frequency of the Mercury-Redstone booster-capsule combination. Figure 1 shows a comparison of second bending frequencies of a conventional Redstone missile, Jupiter C configuration, and the Mercury-Redstone booster-capsule combination. As can be seen, the normal 20-45 normal second bending frequency of the Redstone has been reduced to 6-9 cps. Control oscillations were more pronounced late in flight where the second mode natural frequency is around 9 cps.

To eliminate this problem of structural feedback, filters have been added to the shaping network which reduce gains at the second mode bending frequency which effectively damp the system.

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Analog studies show the gain to be reduced as shown in figure 2. As can be seen in the figure, the gain has been reduced by a factor of approximately 30 at 9 cps. To a lesser extent, the gain at the first mode bending frequency (3. 3 cps) has also been reduced.

The writer inspected the analog test setup which includes the control servo system loop hardware, the control sensor (LEV-3) and booster tail section. Several runs were made for his observation with and without the filtering network. The results were satisfactory and conformed to gain reductions as outlined. Records of typical runs were brought back to the Space Task Group.

An inquiry was made as to the structural loading due to the structural oscillations. Figure 3 shows the bending moment plotted versus vehicle station. As can be seen, the bending moments produced are considerably less than ultimate limit points. Thus, it can be concluded that no structural problem exists due to this oscillation.

(b) Instrumentation compartment vibration. - High frequency vibration in the area of the instrumentation compartment of the booster occurred on Mercury-Redstone flights MR-1A and MR-2. The nature of the vibration indicates that it is aerodynamically excited and probably is due to the lower capsule clamp ring. Vibration level in this area for a standard Redstone booster is $\pm 1g$ maximum. On MR-2 flight it was greater than $\pm 6g$ maximum. Instrumentation was limited to $\pm 6g$ so that the amount over $\pm 6g$ is not known.

An attempt to damp this vibration will be made on the Mercury-Redstone booster test flight. An "undercoat" type of material has been applied to the upper part of the instrumentation compartment as shown in figure 4. The material is a mesh with lead filings and ground asbestos with a resinous filler. It is about 1/4-inch thick. Around 210 pounds of the material has been applied. It is expected that this material will effectively damp the vibration. However, the pickups will be calibrated to $\pm 12g$ on the MR-BD flight so that if the vibration level remains the same as on MR-2, the system will be capable of measurement. Bottomed during actual flight

(c) Thrust controller. - MR-2 flew with the servo control valve wide open. This allowed full flow of H_2O_2 to the steam generator with consequent greater than normal propellent flow. An engine flow

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schematic is shown in figure 5. Figure 6 shows a plot of control valve blade position versus time. Also plotted on the figure for comparison is the curve for the normal MR-1A flight. As can be seen from the figure, the control valve blade stayed at its full open position of 45° throughout the flight except for three attempts to correct. Early in the flight an attempt at correction was made at around 32 seconds and again at 125 seconds and 132 seconds. This thrust controller malfunction caused greater than normal burning rate which resulted in premature fuel depletion and abort signal generation.

Several reasons have been advanced for failure of the thrust controller to function. Some are:

(1) Ice forming at the suppressor in the transducer sensing line

(2) Shifting null setting

(3) Gas leak in the transducer sensing line

None of these reasons can be proved conclusively, and in fact, inspection of figure 6 appears to rule out both (1) and (2) because of the three attempts at thrust correction. A continuing study of the cause for malfunction is underway both at MSFC and by an outside contractor.

A number of corrective actions have been taken to prevent future thrust controller malfunctions and will be accomplished prior to the MR-BD flight. These are:

(1) Install shield on computer assembly and transducer (Fig. 7)

(2) Verify that the surge suppressor is dry

(3) Insulate surge suppressor and bushing

(4) Cover holes on computer assembly and transducer and transducer mounting plate with tape

(5) Tape computer assembly base and chassis

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(6) Check computer dial lock

(7) Connect sensing line heaters at T-65 and verify operation

(8) Restrict servo valve setting to 25 percent at the lower end to assure better T/W ratio at lift-off

Figure 8 shows the variation of thrust chamber pressure with time during the launch phase. It can be seen that even with the control valve blade closed there is adequate thrust for lift-off. However, item no. 8 improves this margin.

The thrust controller normally regulates thrust to ±7.5%. Consideration was given early in the program to eliminate the controller because it has failed, both open and closed, on other Redstone flights. A review on its advantages and disadvantages resulted in the decision to retain it, however.

These advantages and disadvantages are listed below:

Advantages in Retaining

(1) Thrust controlled within ±1 percent of nominal, thereby reducing guidance requirements to compensate for thrust deviations.

(2) In the event of malfunction, thrust would never exceed ±7.5 percent (72,000 lbs - 84,000 lbs) of nominal, thereby guaranteeing safe takeoff.

(3) Flight performance is more predictable and reproducible.

(4) Impact point of capsule would be more predictable for recovery.

(5) Wider variation in control pressure regulator setting and H_2O_2 tank pressures can be tolerated.

(6) Wider variation in H_2O_2 temperature and concentration can be tolerated.

[redacted]

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(7) Four reported malfunctions out of 46 flights. These did not cause failure in meeting flight mission.

Advantages in Removing

(1) Eliminate three connection points where H_2O_2 and combustion gas leakage can occur.

(2) Eliminate the possibility of icing in transducer sensing line due to entrance of water lead start.

(3) Reduce the number of engine components (mechanical and electrical) susceptible to malfunction.

(4) Reduce the thrust level error band in the event of a cumulative malfunction of the thrust controller and regulator.

(d) H_2O_2 tank pressure regulator. - The H_2O_2 tank pressure was higher than expected by an unknown amount. Although the measured tank pressure was 610 psig, this value is considered unreliable as the normal measuring range of the pressure gage is 0-600 psig. The pressure regulator was set at 590 psig prior to the flight. Based on test data, it was expected that the pressure loss between the regulator and tank would be 30 psi. Thus, a tank pressure of 560 psig was expected. Calculations have been made based on throttle wide open and combustion chamber pressure which indicates the tank pressure was at about 580 psig during flight. Thus if tank pressure had risen to 750 psig, maximum allowable before relief valve opening, even faster propellent depletion would have occurred.

On MR-BD and future flights, a higher range H_2O_2 regulator pressure gage will be installed and the pressure will be monitored in the blockhouse to determine that excessive drifting does not occur prior to launch.

(e) Cutoff arming time. - On the MR-2 flight the integrating accelerometer velocity cutoff arming was set at 137.5 seconds. Due to fuel depletion occurring at 137.0 seconds, it could not perform its function. As described earlier, the wide open thrust controller caused this condition.

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Because of this malfunction, a new set of event times has been set for the MR-BD flight and is proposed for subsequent Mercury-Redstone flight tests. These times are as follows:

129.5 seconds ..... Relay latch in from chamber pressure (This relay is in series with the lift-off and cutoff relay and was installed to prevent reoccurrence of the MR-1 incident)

131.0 seconds ..... Velocity cutoff arming

135.0 seconds ..... Switch thrust chamber switch from abort mode to fuel depletion mode

142.5 seconds ..... Calculated cutoff

145.0 seconds ..... Timer cutoff

It can be noted that the time for cutoff arming and thrust chamber pressure abort disarming has been separated. On MR-2 both of these events were at 137.5 seconds. Also note that a backup timer has been added to assure cutoff at 145 seconds should the velocity cutoff fail to give a cutoff signal.

2 addit. timers

(f) Roll-rate abort sensor. - On MR-2 flight the roll-rate abort sensor experienced a value of about 8°/sec. The peak could not be established since the roll angular velocity was on a commutated channel. The abort setting was at 12°/sec. This close approach to the set value and further considerations of the abort system has led to a MSFC decision to eliminate the roll-rate sensor. In establishing the roll-rate as an abort parameter, the normal Redstone roll behavior was used as a guide. However, it has now been established that the Mercury-Redstone has a somewhat different roll-rate behavior than the standard Redstone. Mr. Brandner, of Marshall Space Flight Center, who did much original work on the automatic abort system, considers the roll-rate abort sensor deletion justifiable based on two points:

(1) Deletion removes one possible source of spurious actuation.

[redacted]

(2) Roll-rate, in itself, will not cause booster breakup; that is, the roll attitude sensors will actuate well before gyro spilling.

(g) <u>H_2O_2 corrosion problems</u>.- The Mercury-Redstone boosters have had mild corrosion in the H_2O_2 system. The tactical Redstone missiles have had serious corrosion problems. Two tactical Redstone missiles were found to have extensive corrosion in their launch condition on the pad. These conditions caused repercussions on the Mercury-Redstone booster program with the result that an extensive investigation on all MR-boosters has been made. The results are summarized below:

	H_2O_2 Activity*	
	As Received	Passivated
MR-1 and MR-1A		
Tee fittings	2	0
Analysis disclosed fittings were fabricated from type 303 steel rather than the specified 304		
MR-2		
Servo valve	2	0
Tee from main tank	2	0
Tee from auxiliary tank	2	0
MR-6		
H_2O_2 system undergoing inspection		
MR-7		
Tests indicate system passive, low evolution rate		

* 0 ... passive
1 ... moderate gassing
2 ... excessive gassing with heating
3 ... extreme gassing
4 ... gassing and spewing
5 ... violent

[redacted]

As a matter of interest, it has been found that the extensive corrosion found on the tactical Redstone missiles was caused by blowback through the catalyst bed, sending dust back into the H_2O_2 liquid system. This is suspected to have been caused by improper pressurization procedures.

(h) Man-hole LOX leak. - Figure 9 shows the LOX man-hole, gasket, and cover. Some leaking has been experienced on the Mercury-Redstone boosters during tests and on MR-1A while at the Cape. The original bolt torque values were specified to be 90 inch pounds. To correct the leak problem, bolt torques have been raised to 175 inch pounds. This has provided a reliable seal.

(i) Velocity integrator. - The velocity integrator allowed an error of +3 percent in cutoff velocity on MR-1A. Since that time, changes have been made that should reduce the maximum error to ±1/2 percent.

The velocity integrator is an integrating accelerometer composed of mainly a precessing gyro and a counter. The actuating assembly of the gyro rotates at constant velocity as long as 1g is imposed on it. At g levels over 1.0, the gyro within the assembly (which is rotating at 24,000 rpm) precesses, thereby increasing the assembly rotational speed, thus causing the counter to run faster.

Previous to the change, the gyro assembly had eight wires going to it as the buss bar was mounted to the rotating assembly as shown in figure 10. These wires caused hysteresis at g levels other than 1.0; at 1g the torques caused by the wire coils had been compensated for. The new design, shown in figure 11, has the buss bar on the frame so that only three wires (required for the gyro motor operation itself) go to the rotating assembly. These are now light flex wires which offer negligible resistance torque.

The new design has been flown on two Pershing missiles and MR-2. Data obtained on these flights, though not complete in one Pershing and MR-2, indicated satisfactory operation.

4. A continuing study and analysis of the Redstone booster is in progress. Subsequent memorandums will deal with the results of

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the MR-BD flight test and a more detailed description and analysis of the guidance and control system.

Jerome B. Hammack
Mercury-Redstone Project Engineer

Enc:
1. Appendix
2. Figures 1 thru 16

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APPENDIX - General Description of Mercury-Redstone A-7 Engine

1. General information. - The rocket engine utilized as the power plant of the Mercury-Redstone booster was manufactured by Rocketdyne and is essentially the same as the A-7 engine employed in the latest tactical versions of the Redstone missile. Views of the engine are shown in figures 12 and 13. The main difference in these two engines is the addition of an auxiliary hydrogen peroxide tank of approximately 13 gallons capacity to give approximately 24 seconds additional burning required for the Mercury-Redstone program. This auxiliary tank can be seen in figure 12. The main hydrogen peroxide tank has a capacity of 76 gallons.

The engine is a 78,000 pound thrust, constant chamber pressure engine. The propellants, liquid oxygen and alcohol, are pump fed to the thrust chamber. The velocity compounded two-stage turbine which drives the pumps is driven by a hydrogen peroxide steam generator system. The turbine, running at approximately 4,800 rpm, drives the two centrifugal pumps through one common shaft. Thrust chamber ignition is accomplished by a pyrotechnic igniter. Figure 14 shows a schematic of the ignition process. The thrust control system maintains a constant engine thrust chamber pressure of approximately 317 psia, by regulating the supply of H_2O_2 to the steam generator. The position of the blade of the servo control valve in the H_2O_2 supply line is controlled by an electrical error signal from the computer. This signal is generated when a difference exists between the desired thrust chamber pressure and the actual thrust chamber pressure. The system operates on a 115 volt, 400 cycle AC power source and consists of an H_2O_2 servo regulator valve, computer, transducer, suppressor, and necessary electrical circuits and plumbing. A preset mixture ratio valve is provided in the fuel system to compensate for fuel temperature and ambient pressure variations.

2. Major components. - The major components of the Mercury-Redstone A-7 engine are thrust chamber, turbopump steam generator, and associated pneumatic, propellant, and electrical control systems. These components are assembled on an engine mount to make the complete engine assembly.

3. Propulsion system operation. - During launch preparations, the thrust chamber cooling jacket is prefilled with approximately 11

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gallons of water to provide an inert liquid load start. When the launch start switch is depressed, the alcohol and the H_2O_2 tanks are pressurized simultaneously. Initial and flight pressurization of these tanks and the control system is provided by seven high pressure gaseous nitrogen spheres. Next, the LOX tank is pressurized. Initial pressurization is from a gaseous nitrogen ground source, flight pressurization is performed by converting liquid oxygen to gaseous oxygen through a heat exchanger. After the correct tank pressures are reached, ignition occurs. At ignition, the thrust chamber pyrotechnic igniter fires, its link breaks, which permits the main LOX valve to open thus allowing LOX to flow to the thrust chamber under combined tank and liquid head pressure. Igniter alcohol is simultaneously directed into the thrust chamber through the center of the injector from the pressurized ground alcohol supply. At this time, LOX rich ignition burning occurs, and the ignition detector link breaks. This energizes the mainstage relay and the hydrogen peroxide valve opens, thus allowing the hydrcgen peroxide to pass through the catalyst bed in the steam generator, resulting in steam pressure buildup. The steam is directed to the turbine blades and drives the turbine, which is directly coupled to the liquid oxygen and fuel pumps. The turbopump accelerates and pressure is built up in the fuel line until it is greater than the ground alcohol igniter supply pressure. At about this time the fuel valve opens, allowing the water lead and alcohol to flow into the combustion chamber and initiate mainstage thrust chamber combustion. Figures 15 and 16 show engine schematics from which the above operation description can be followed.

4. Propulsion system breakdown. -

(a) Electrical control system. - The electrical control system, in conjunction with the pneumatic supply system, provides the primary control over engine operation. A 28 volt direct current power supply provides the control for engine operation during ignition, mainstage and cutoff. The system controls these operations automatically in a predetermined sequence. The sequence is obtained by ladder-type circuits, which require that certain components be completed satisfactorily before operation of the next component can be initiated. Safety circuits and timers in the system automatically initiate cutoff and return the engine to a safe condition if any component fails to operate properly.

(b) Steam generator and exhaust system. - The steam

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APPENDIX (CONT'D)

generator system is that part of the engine which develops steam pressure for turbine operation. A mixture of steam and oxygen is produced by the decomposition of 75 percent hydrogen peroxide in the presence of a catalyst, which is made from porous ceramic stones impregnated with potassium permanganate. The resultant steam flow, at approximately 740°F and 385 psi, provides the power for turbopump operation and then flows through a pneumatic and LOX heat exchanger and exhaust duct. Steam generator output is regulated by a servo valve in the hydrogen peroxide line. This assures correct flow conditions to maintain a constant thrust chamber pressure level.

(c) Pneumatic power supply system. - The pneumatic system supplies gaseous nitrogen, under regulated pressure (approximately 600 psi) and in a sequence determined by the electrical control system, for operating the propellant and hydrogen peroxide valves and for pressurizing the fuel and hydrogen peroxide tanks. Nitrogen gas is supplied from a ground supply until vehicle lift-off.

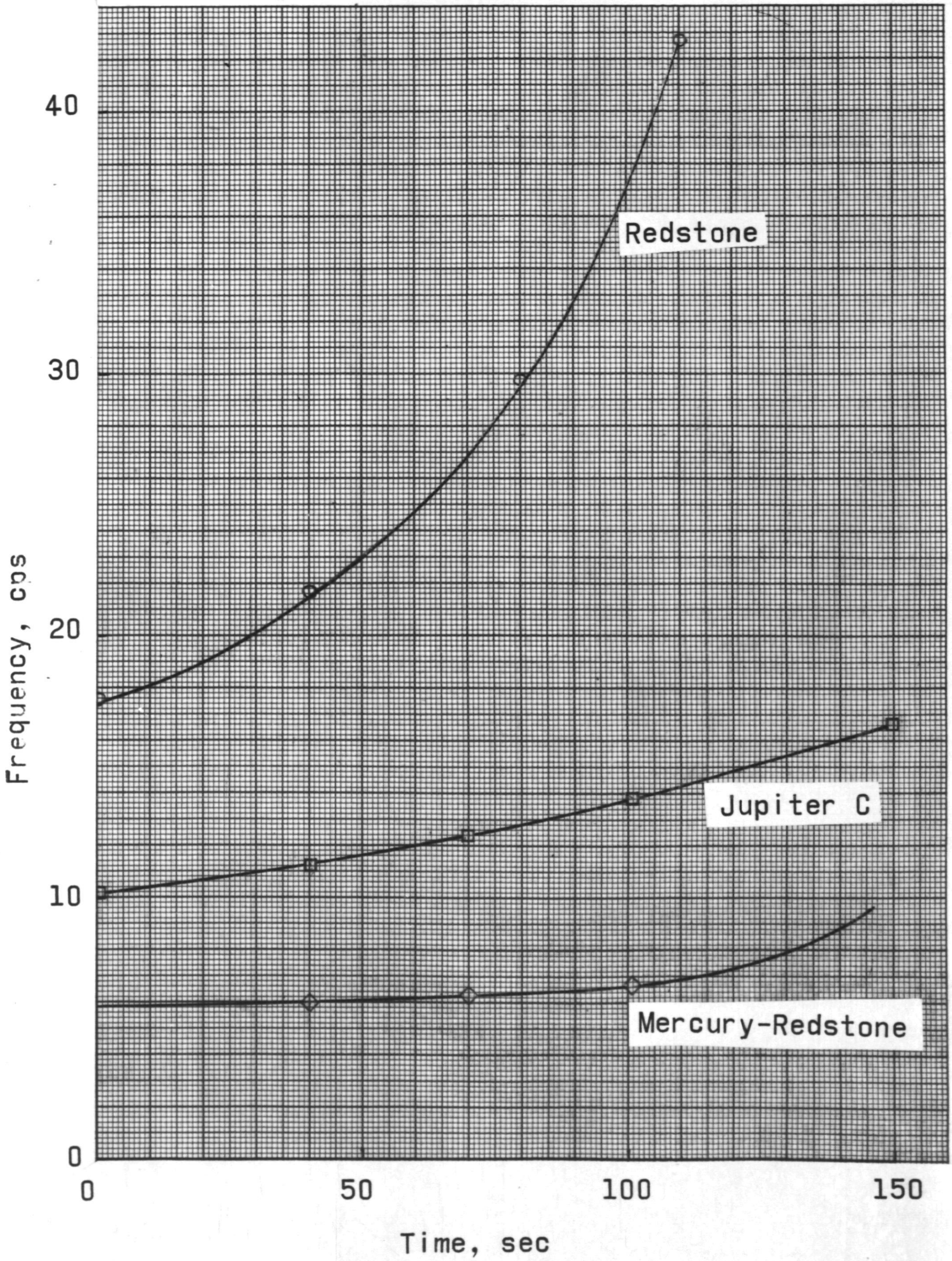

Figure 1.- Second order bending frequency comparison.

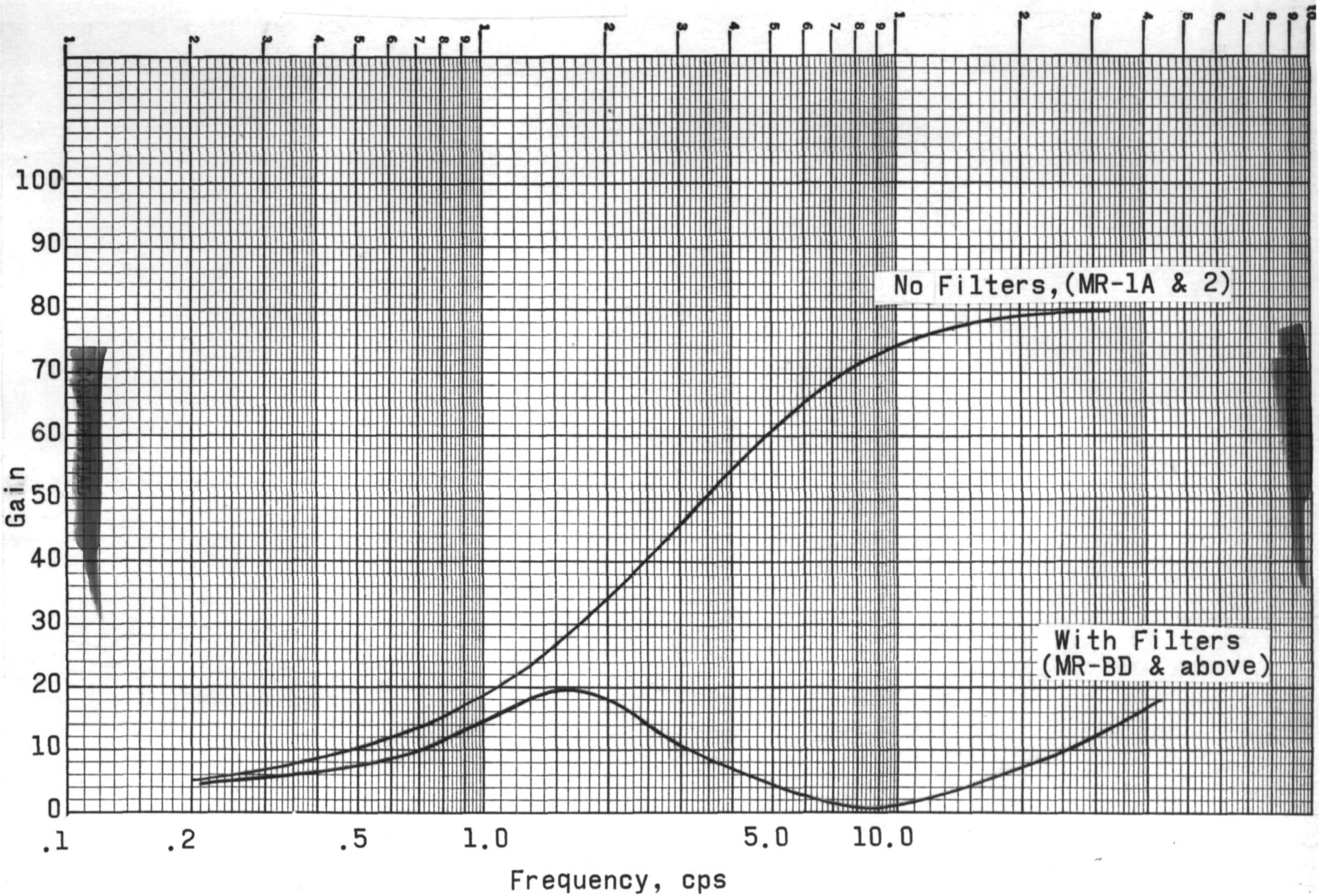

Figure 2.- Control system gain with and without filters.

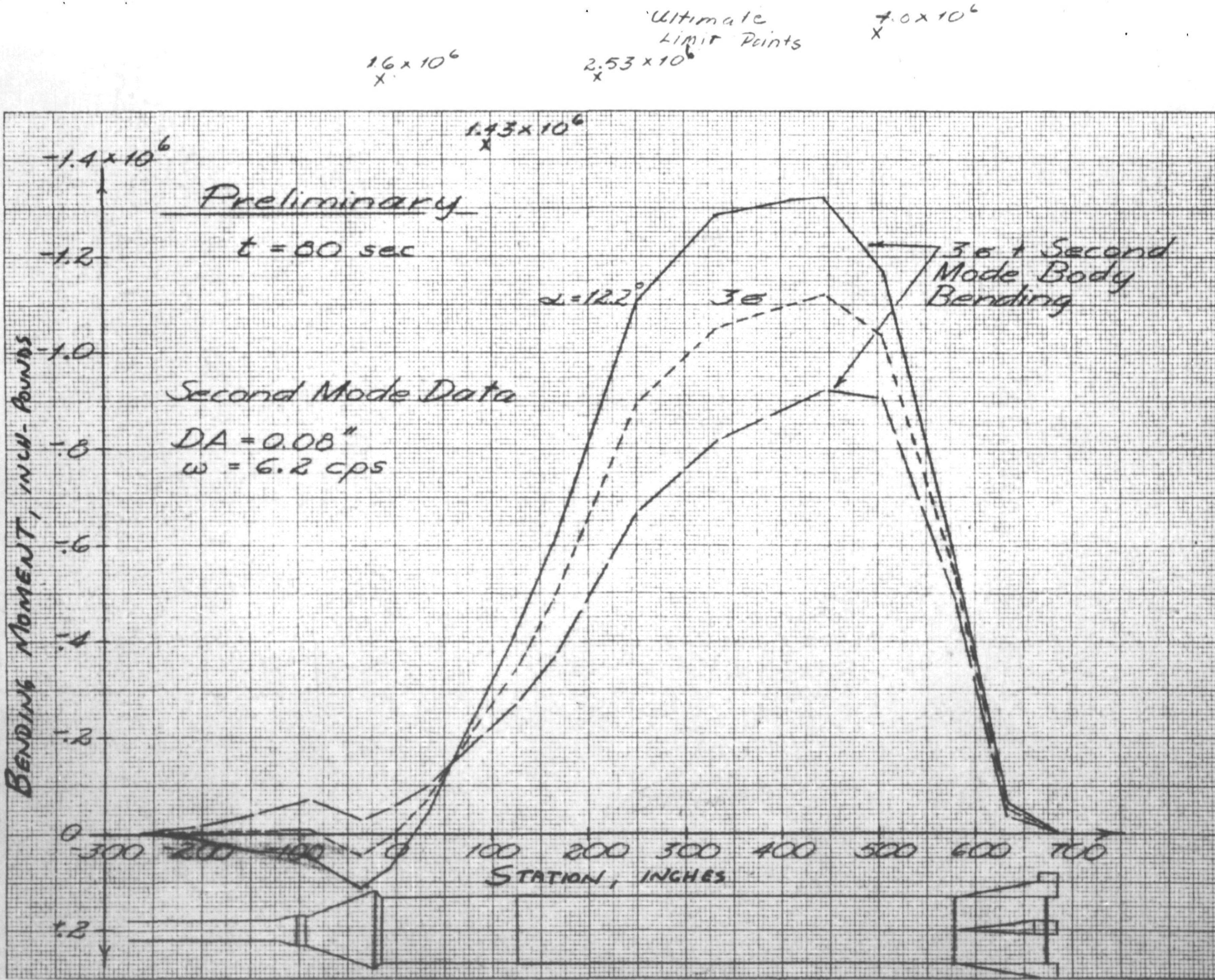

Figure 3.- Second mode bending data at t = 80 sec. (~Max q)

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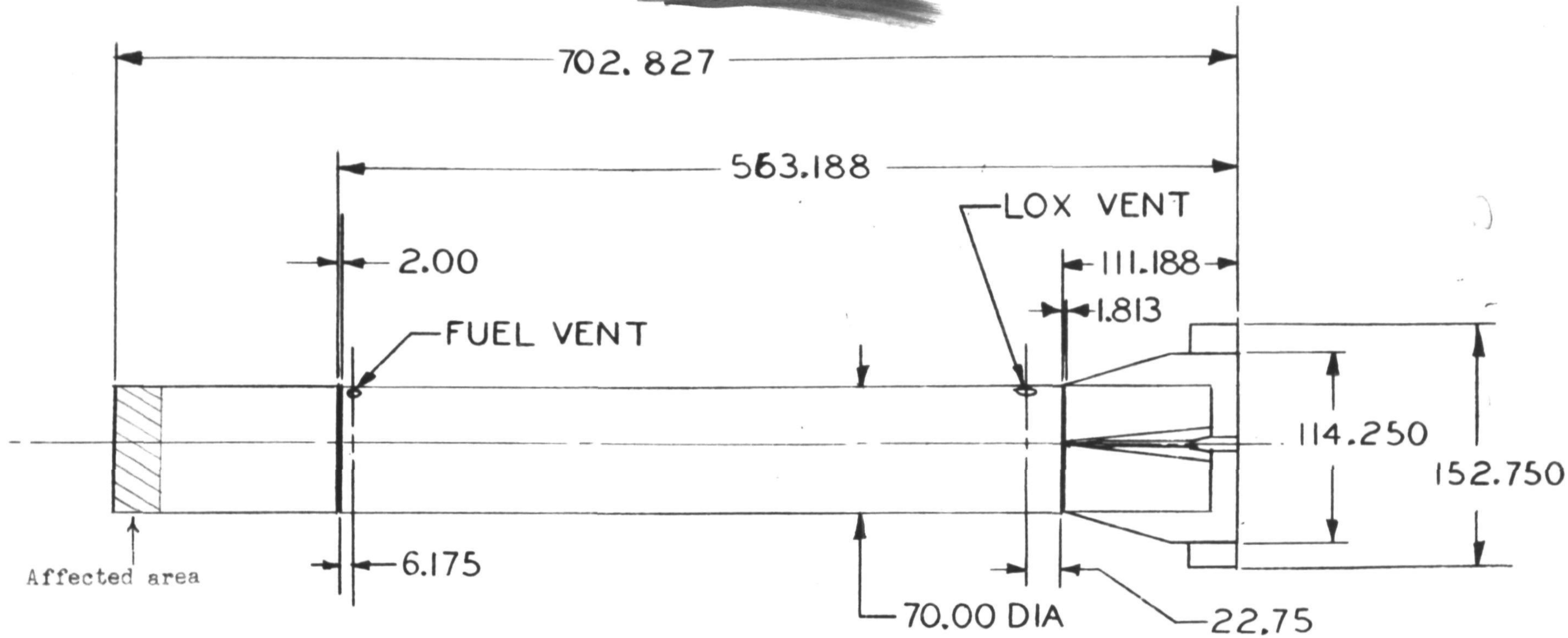

Figure 4.- Area of booster to where dampening material has been applied.

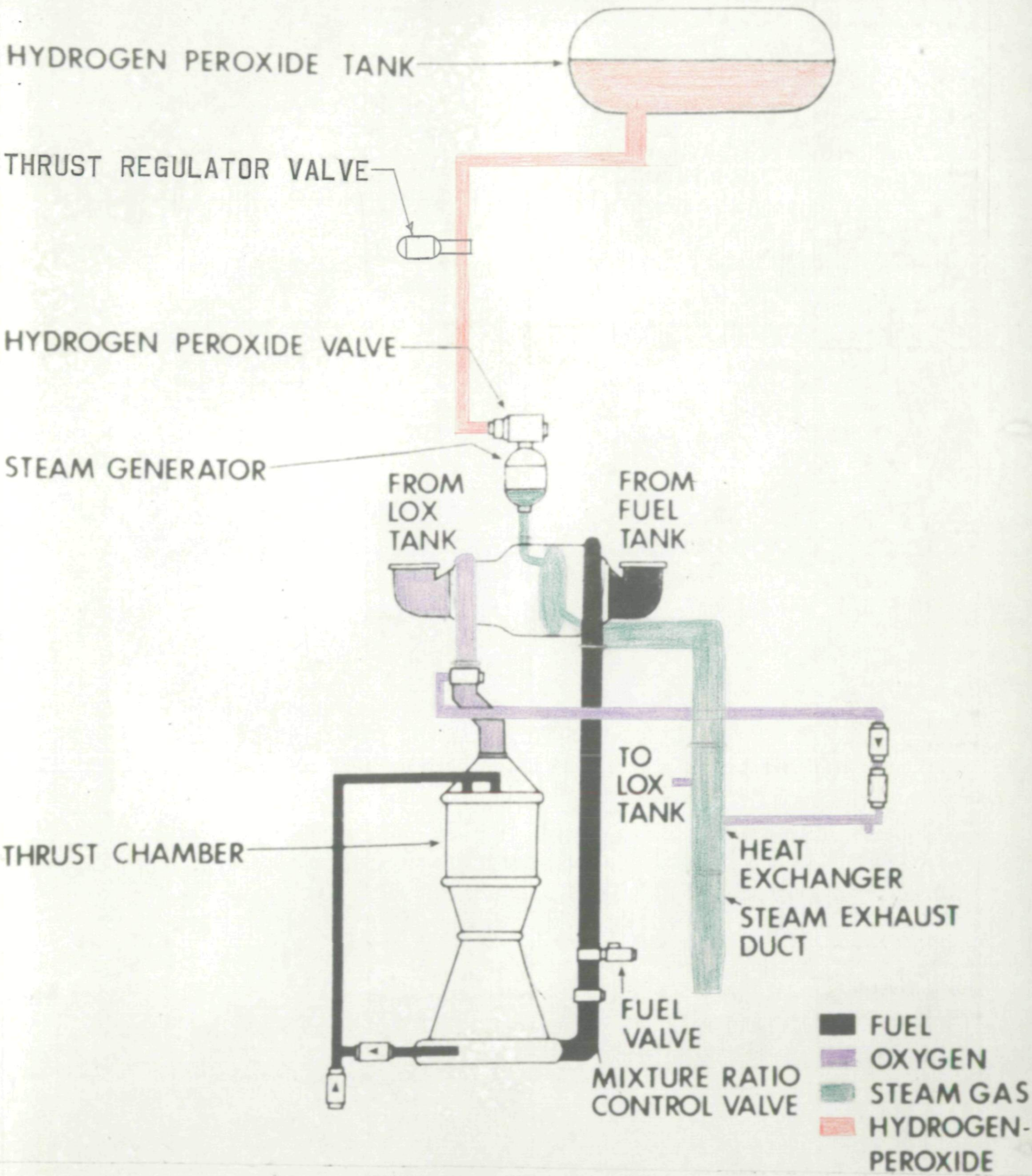

Figure 5.- A7 engine flow schematic.

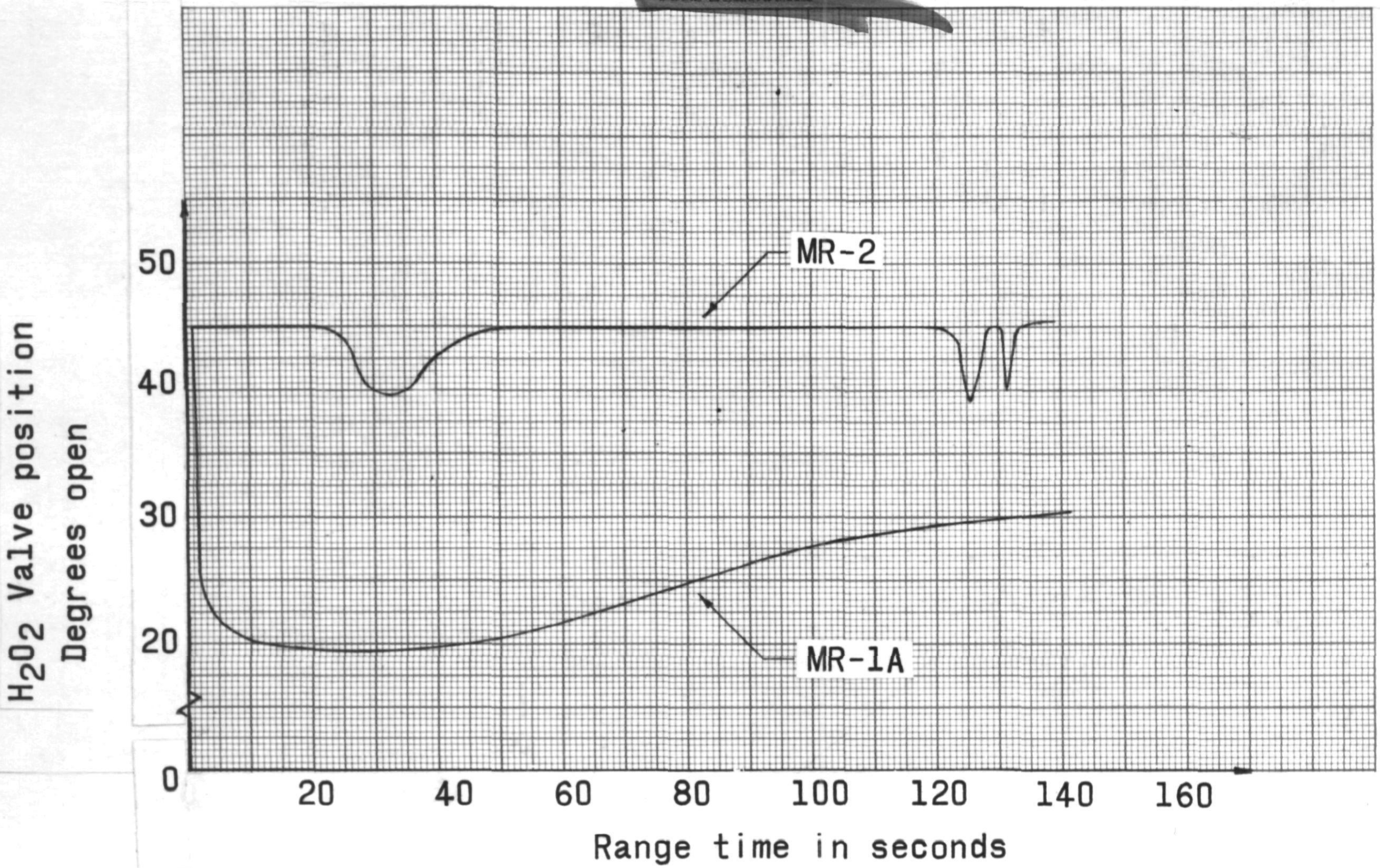

Figure 6.- Hydrogen peroxide valve position vs range time.

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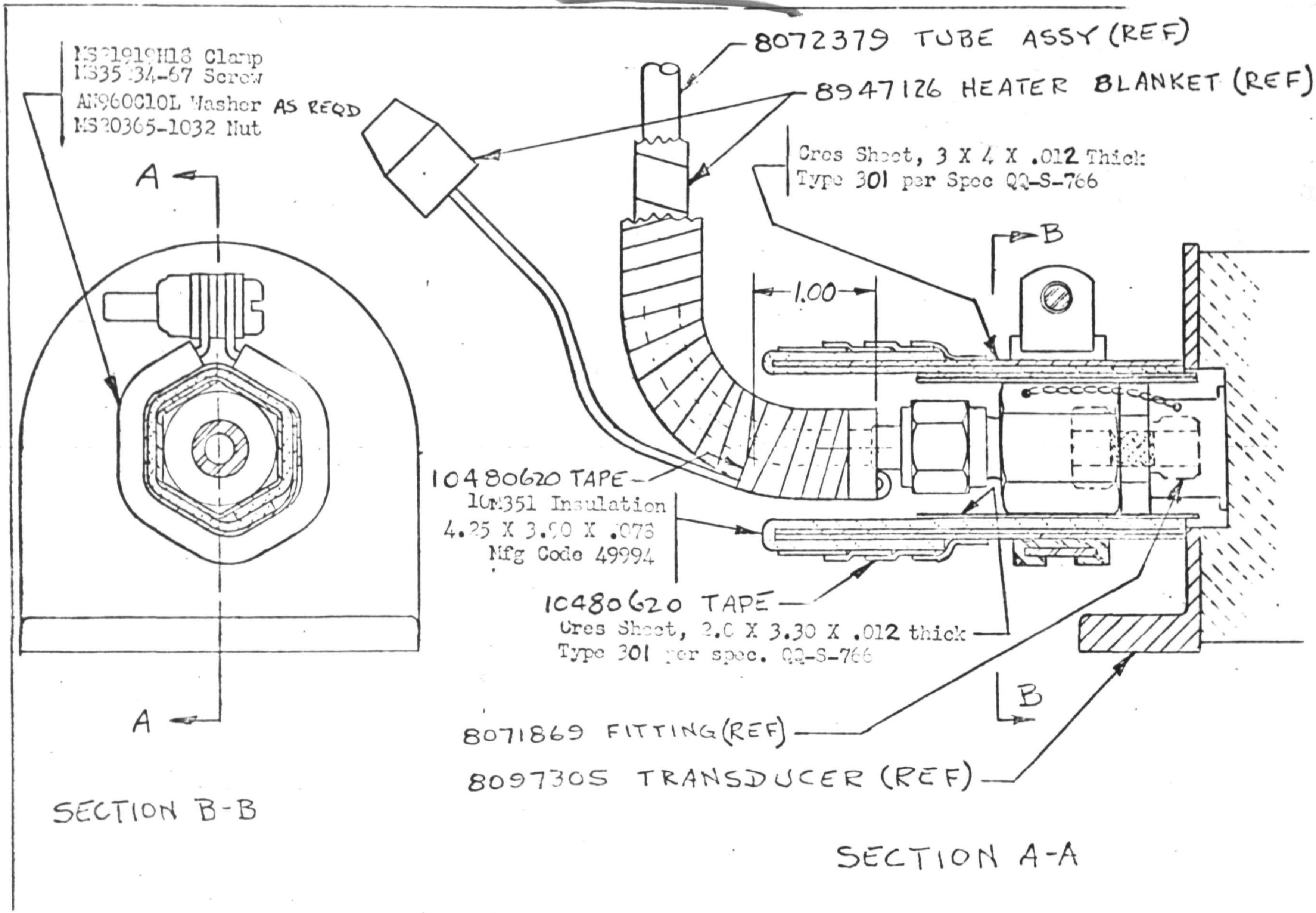

Figure 7.- Shield to prevent icing of transducer surge suppressor fitting.

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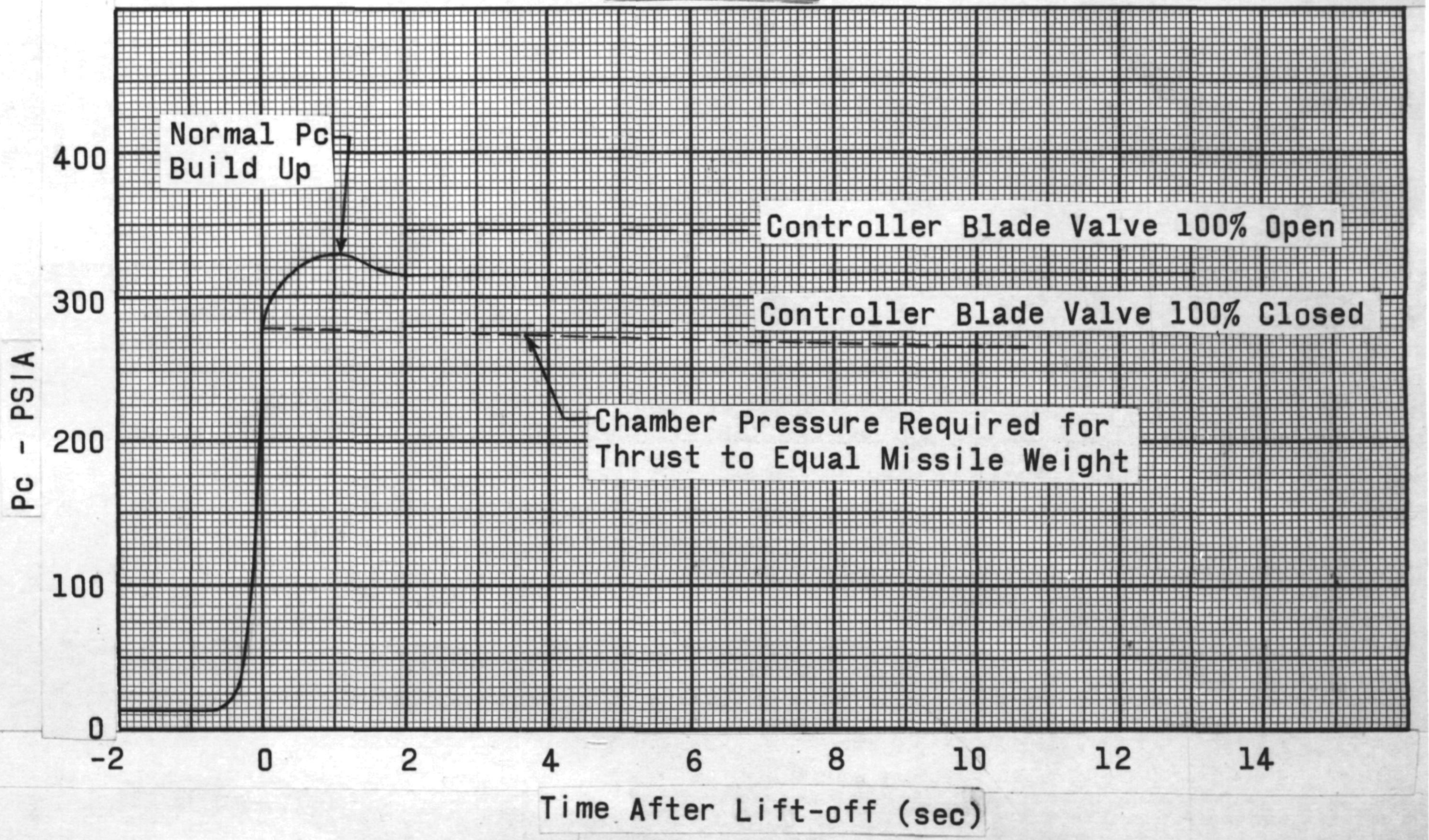

Figure 8.- Required and possible chamber pressures versus flight time for MERCURY Redstone.

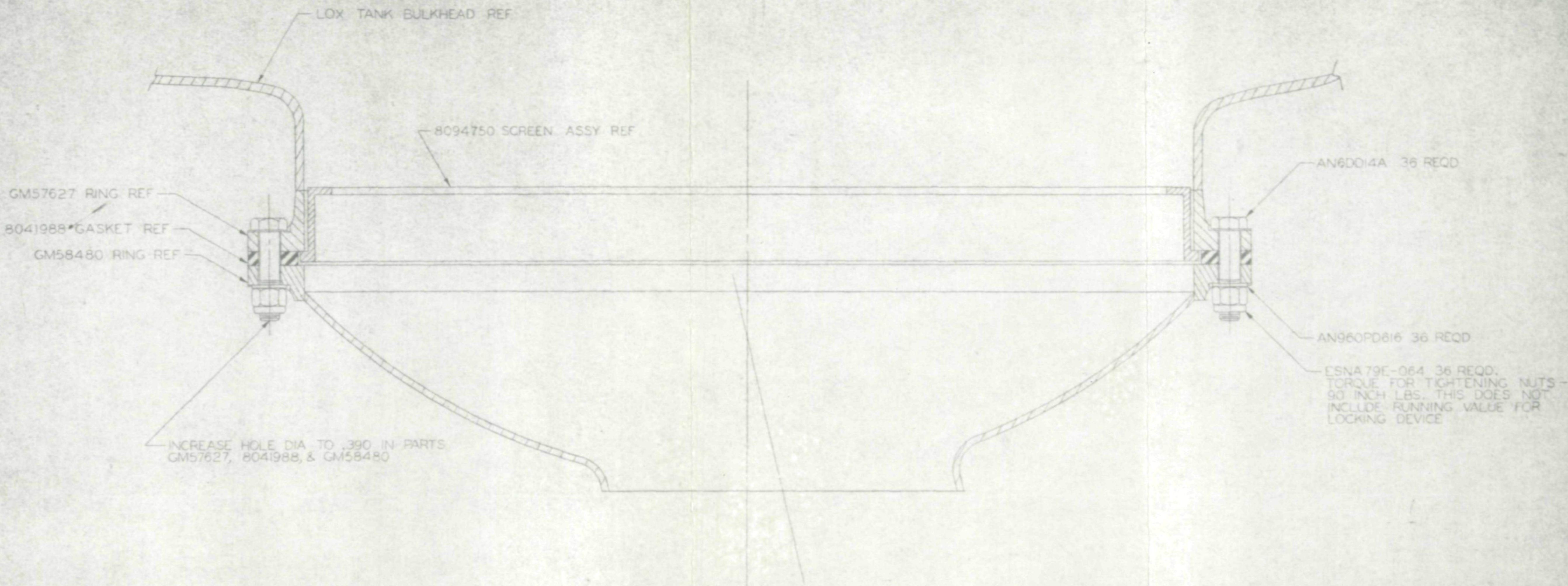

Figure 9.- Lox manhole.

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Figure 10.- Old design gyro assembly with eight coils.

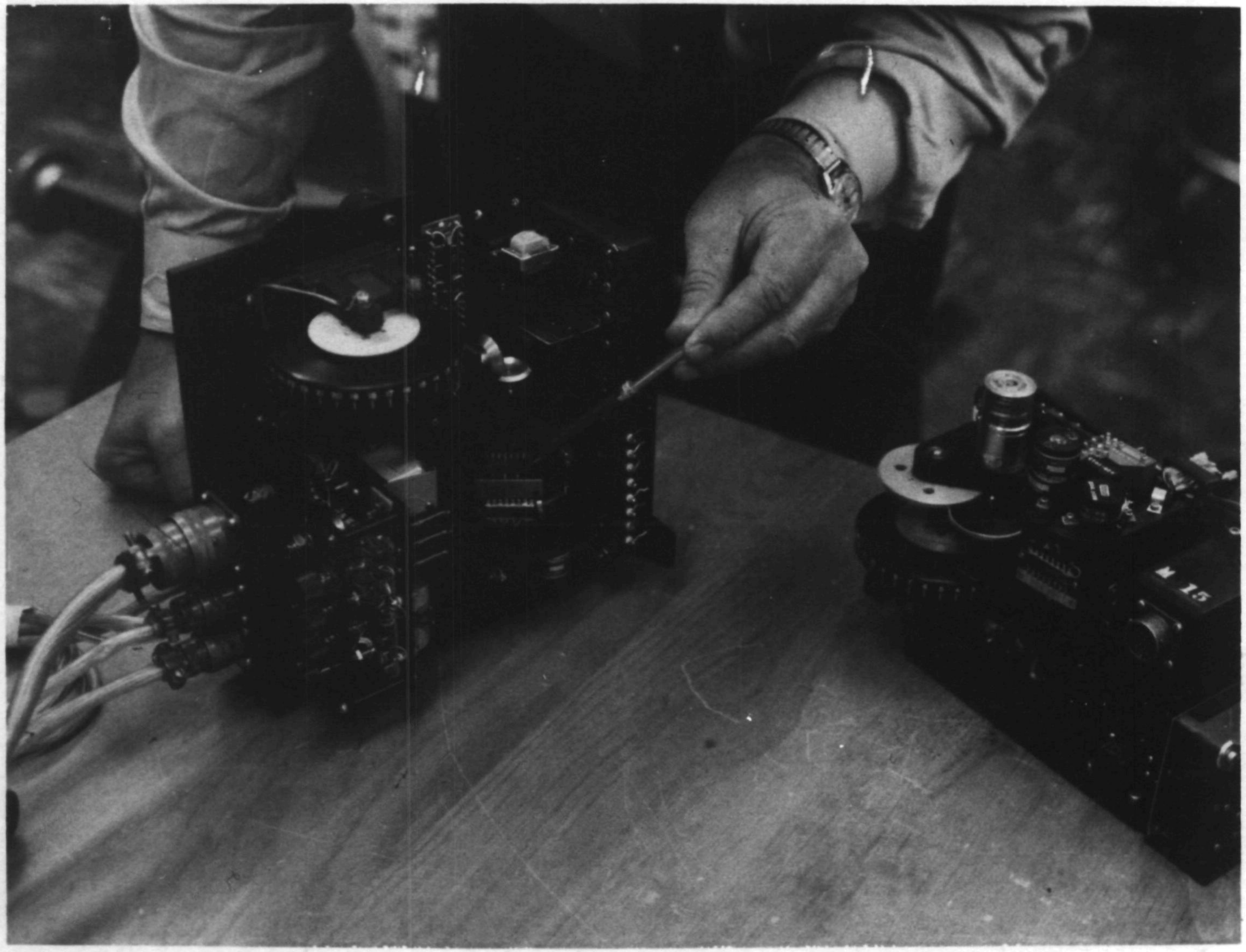

Figure 11.- New design gyro assembly with three flex leads.

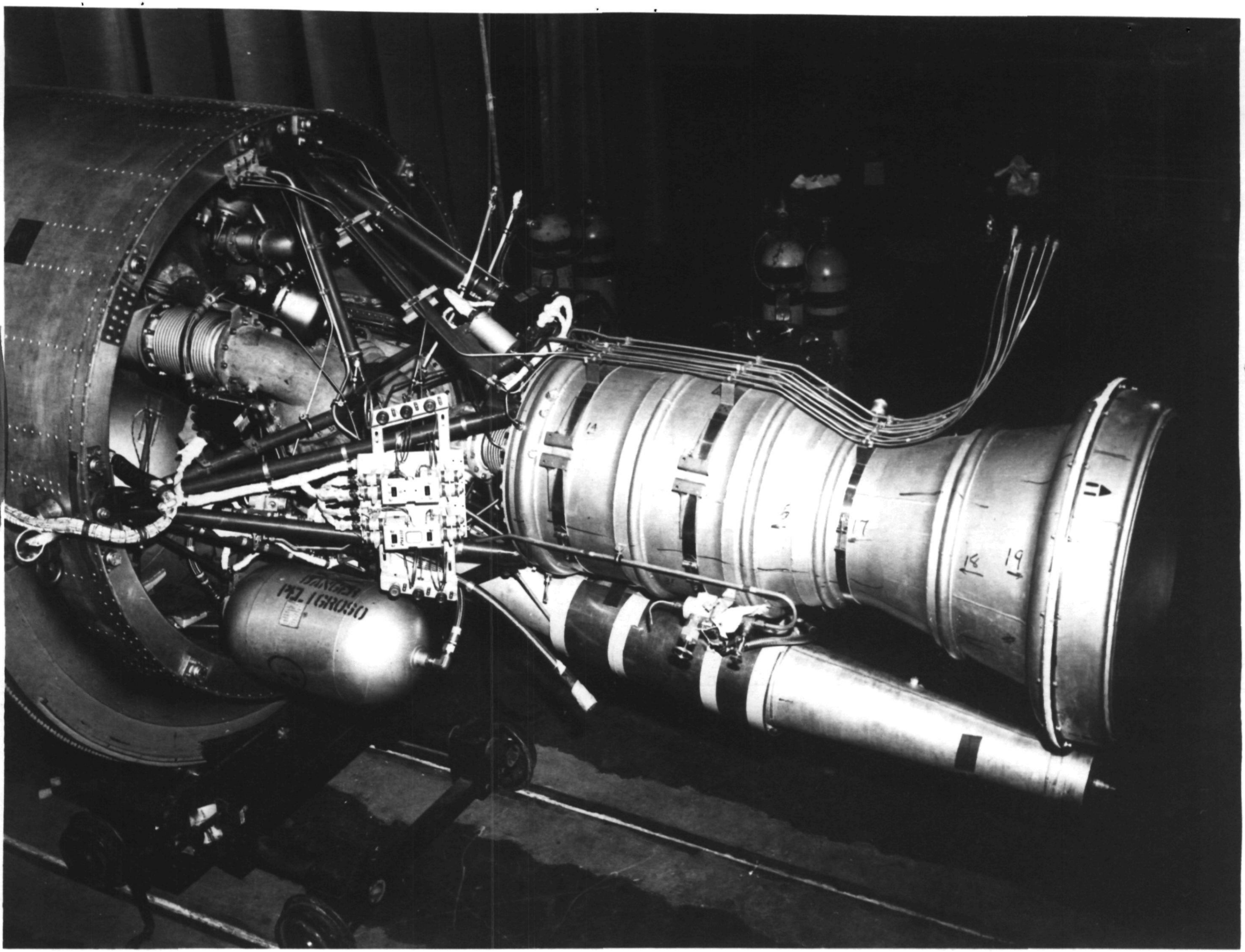

Figure 12.- View of A7 engine showing auxiliary H_2O_2 tank.

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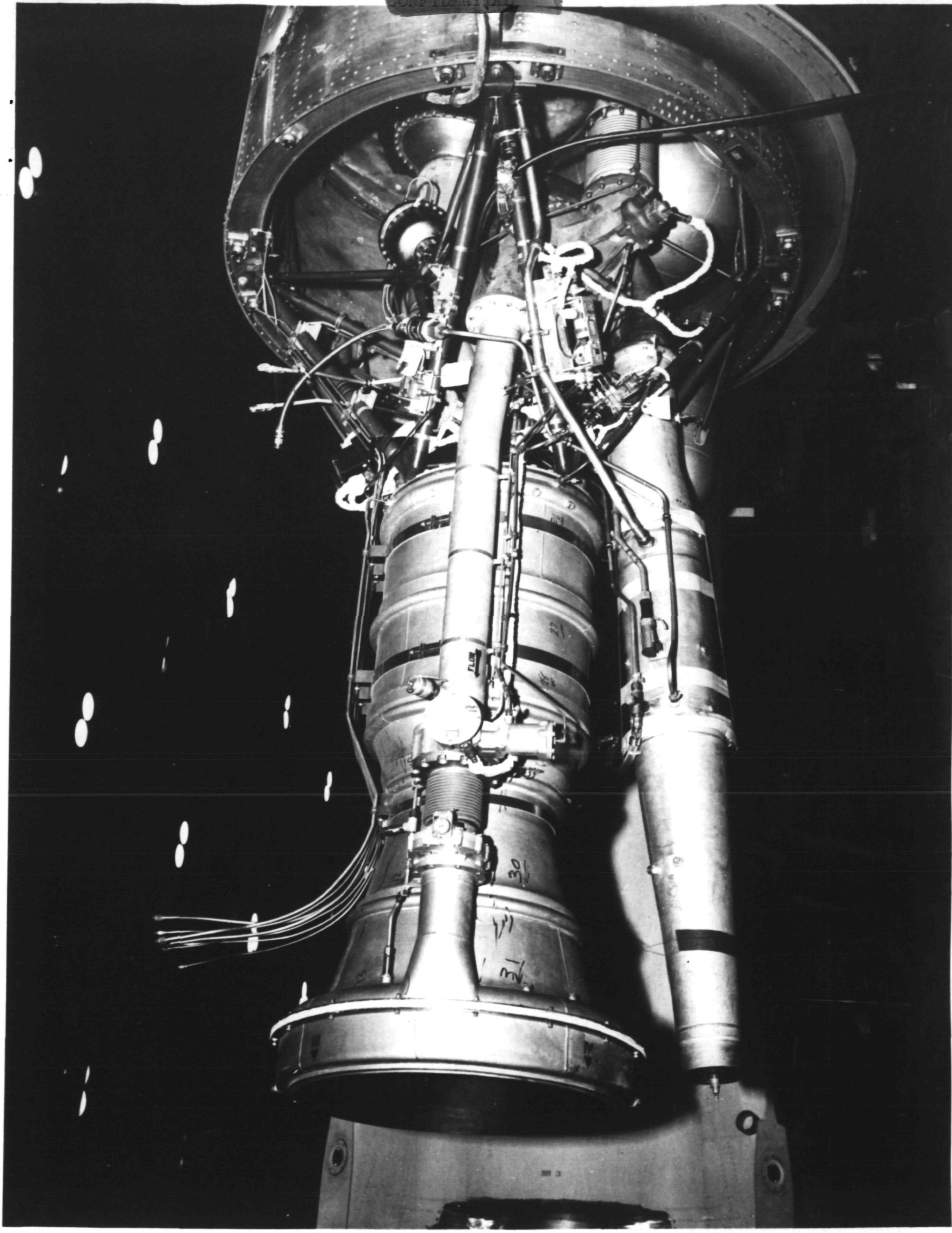

Figure 13- View of A7 Engine showing fuel feed lines.

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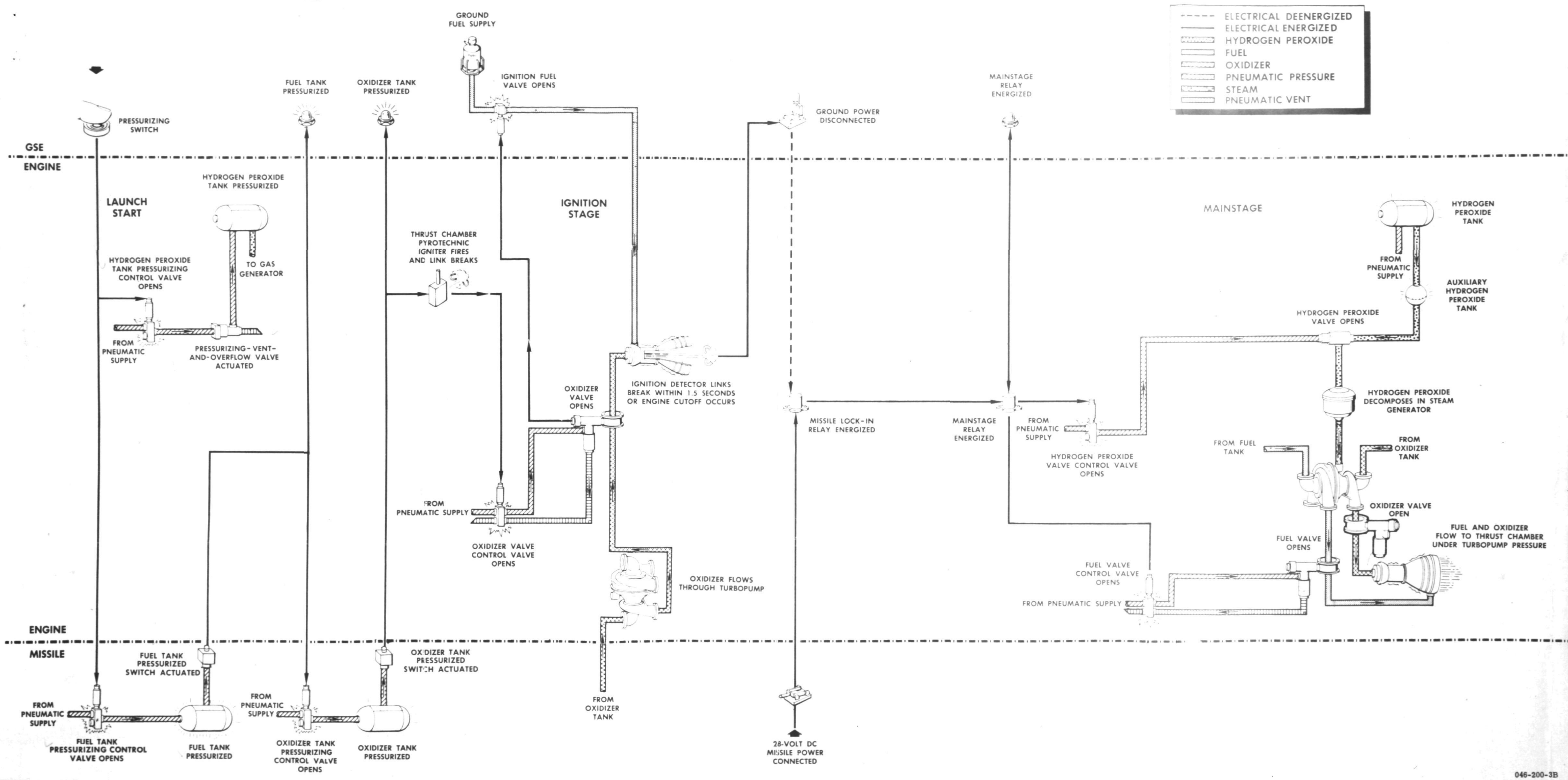

Figure 14.- Launch, Ignition, and Mainstage Combustion Schematic.

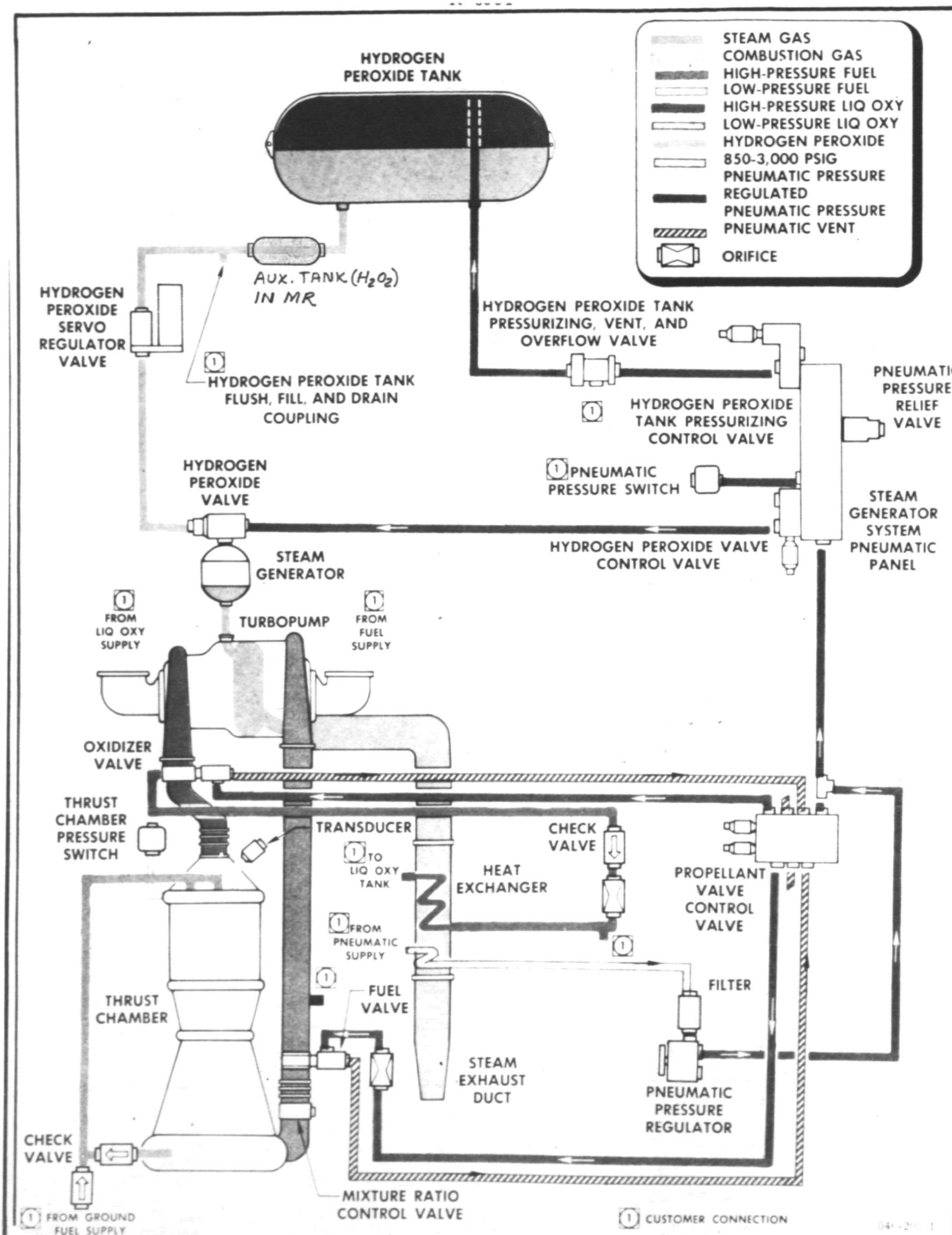

Figure 15.- Propulsion System Schematic

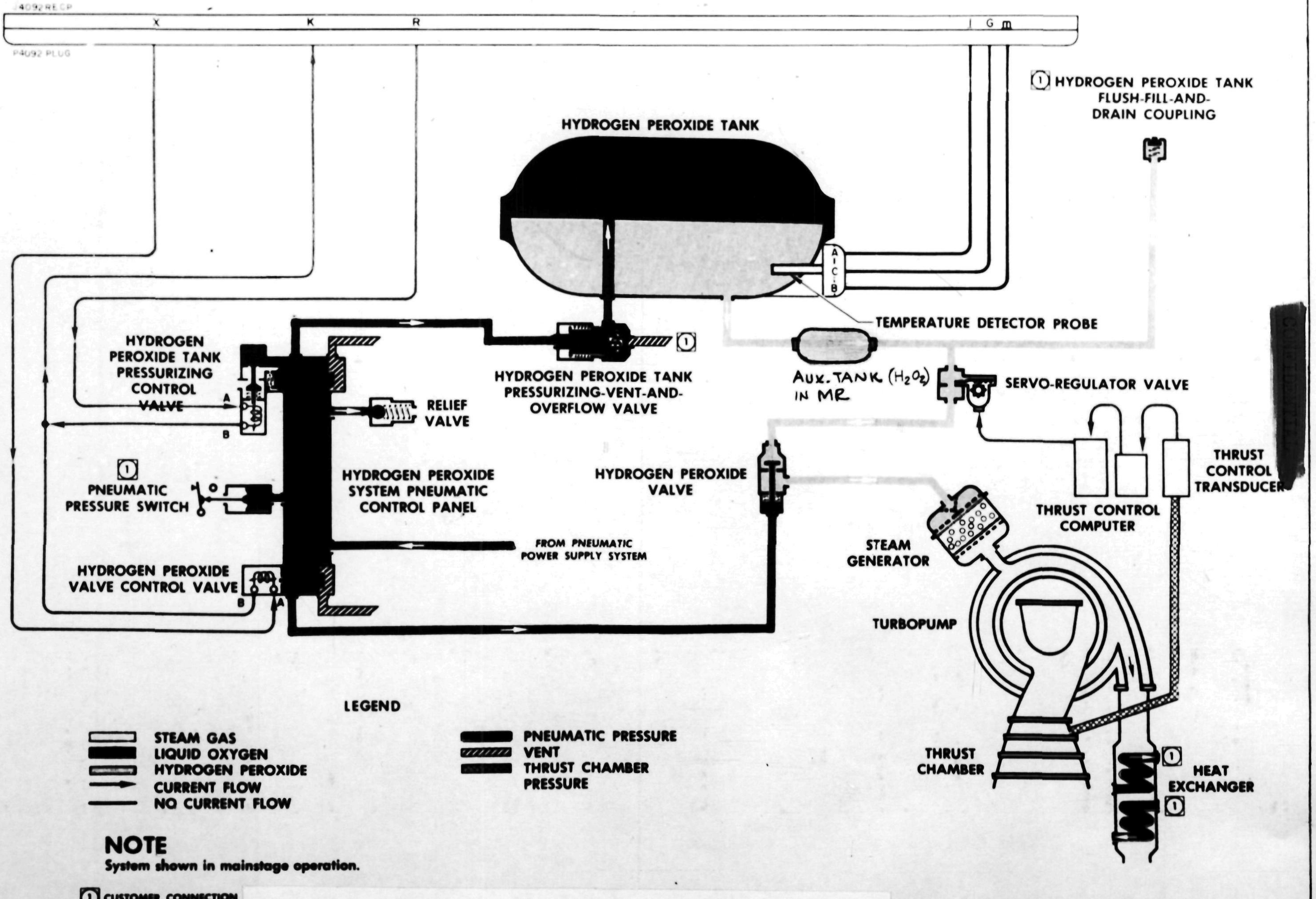

Figure 16.- Schematic showing steam generation.

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