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SATURN IB LIQUID HYDROGEN ORBITAL EXPERIMENT DEFINITION

by ADVANCED STUDIES OFFICE
Propulsion and Vehicle Engineering Laboratory

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

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ABSTRACT

A Liquid Hydrogen Orbital Experiment is defined, using Saturn IB launch vehicle SA-203, which will demonstrate the adequacy of the S-IVB/V continuous vent and propellant settling system prior to a Saturn V launch. The state-of-the-art knowledge of cryogenic propellant behaviour under weightless environment will be significantly advanced by this observation of transient effects on liquid hydrogen through two television cameras mounted on the manhole cover of the S-IVB stage LH_2 tank.

The experiment justification, objectives, and S-IVB stage instrumentation are presented in detail.

The liquid hydrogen experiment was proposed and defined by the Propulsion Division of Propulsion and Vehicle Engineering Laboratory. This report was compiled for R&D Operations with the assistance of Aero-Astrodynamics Laboratory, Astrionics Laboratory, and Quality and Reliability Assurance Laboratory and complements NASA TM X-53159, "Saturn IB Liquid Hydrogen Experiment Preliminary Launch Vehicle Design Definition."

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

TECHNICAL MEMORANDUM X-53158

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PROPULSION AND VEHICLE ENGINEERING LABORATORY

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SUMMARY

Data in the areas of fluid mechanics of cryogenic propellants and heat transfer in an orbital environment are almost non-existant. An orbital experiment is necessary to provide the data and assure a reliability for future manned efforts at the level required by NASA. The Liquid Hydrogen Orbital Experiment is planned to provide data on continuous orbital vent and settling as well as stage restart. The experiment will be of equal value whether it substantiates existing design assumptions or provides data indicating the need for corrective re-design.

The experiment will be conducted in a 100-N. M. circular orbit. The sequence of events for the experiment will be initiated by an on-board recorder or by ground commands. Two television cameras will be mounted in the manhole cover of the modified S-IVB stage of the Saturn IB launch vehicle, SA-203. These will observe the liquid/gas propellant interface during coast, orbit insertion, orbital maneuvers, and re-circulation and thrust chamber chilldown prior to re-ignition. Auxiliary instrumentation will transmit data on pressure, temperature, acceleration, etc. Data will be received for a minimum of three orbits and possibly for as long as four orbits. Control and payload considerations dictated the use of an aerodynamic nose cone envelope. The nose cone will be fabricated by MSFC. It will be of skin and skin-and-stringer type construction and will have a coat of ablative material on its exterior surface and will weigh about 3500 pounds. Nose cone instrumentation will provide data or acceleration, acoustics, pressure, and temperature.

Propellant loading will be controlled by the S-IVB propellant utilization system. With the planned loading levels of 100 per cent LH_2 and 65 per cent LOX it is estimated that a payload of approximately 18,000 pounds of LH_2 will be placed in orbit. The construction of the design trajectories will employ trajectory shaping to ensure structural integrities of the vehicle.

Stage flight will be accomplished with the PU system in the open loop mode. This requirement is imposed by the excessive tank mixture ratio inbalance caused by the hydrogen payload. Control considerations

dictated that the stage be shutdown by guidance on the attainment of the nominal Saturn V parking orbit. The desirability of eliminating residual LOX was overridden by the inability to cancel out the velocity increment the burnout would entail.

Hydrogen vented overboard through a continuous vent thrust system will be used to provide a positive axial acceleration of approximately 2×10^{-5} g on the stage during orbital coast to ensure propellant settling. The exact configuration of the continuous venting system is still under study. More than sufficient thrust to provide the required g load is available and alternative systems for cancelling out the required fraction of the thrust are under consideration.

The thrust of the S-IVB 70-pound ullage rockets will be simulated by ducting residual LOX ullage gas overboard two axially directed nozzles. An increase in auxiliary propulsion system requirements will necessitate some system modifications. Also, the Saturn V/S-IVB LH_2 tank repressurization system will be simulated during this experiment.

Sufficient airborne telemetry channel capacity exists to transmitt the acquired data. Existing ground facilities are capable of handling the transmitted data with two exceptions. The 30-foot dish antenna required by the high-rate TV camera is scheduled to be ready for use by the SA-203 launch date. Also, MSFC will be required to provide a special wide-band video recorder to the selected high-rate receiving stations.

The high-rate stations will make immediate film copies of the high-rate TV data. If the high-rate system should fail, low-rate data will be used as backup. DAC will provide linearized data from the telemetry types to MSFC for analysis.

Documentation, testing, and reliability practices will conform to NASA, MSFC, and Saturn V standards.

SECTION I. INTRODUCTION

A. GENERAL

The success of the Saturn V program requires many state-of-the-art advances. Representative of these are the behavior of cryogenic propellant in a low gravity field and heat transfer in an orbital environment. Data in these fields are noticeably sparse. The work simply has not been done before. Ground based stage testing cannot adequately simulate the critical orbital conditions. These conditions must be properly considered in designing to assure the success of the Saturn V mission. Some experimental data are available, but are limited to small diameter models and short-duration test times. With such limited data it is impossible to reliably predict the propellant behavior in a 260-inch-diameter cryogenic stage while it is subjected to unknown transient conditions and heat transfer problems.

B. CONTINUOUS VENT AND LIQUID SETTLING

An orbital experiment is necessary to demonstrate the adequacy of the Saturn V/S-IVB continuous orbital vent and settling system under a low gravity field. This same experiment would yield a significant amount of stage restart data which would help to assure a successful coast and second burn for the Saturn V/S-IVB configuration. Saturn IB launch vehicle SA-203 has been proposed for carrying liquid hydrogen into orbit to obtain the desired information prior to committment of Saturn V launch vehicle SA-503. The S-IVB stage is recommended to perform the tests. The technical approach is outlined in the following sections of this report. Instruments would be strategically located in the liquid hydrogen tank to provide temperature, pressure, liquid level, and acceleration data. A TV system would be located on the forward dome of the liquid hydrogen tank to observe the propellant behavior under low gravity environment. This approach would provide all of the data necessary to substantiate the present S-IVB design or permit corrective redesigns to be properly engineered.

C. FLUID MECHANICS AND HEAT TRANSFER

There are many uncertainties in the low gravity fluid mechanics and heat transfer phenomena associated with predicting the performance of the vent systems. Some of these uncertainties result from the extrapolation of available experimental data. The successful operation of a continuous venting or ullage system would be better assured with the knowledge gained by the orbital test proposed in this document.

SECTION II. EXPERIMENT JUSTIFICATION

A. BACKGROUND

At the present time, very little is known about the behavior of fluids in a weightless condition. The data available are confined to information on the equilibrium configuration of the liquid vapor interface without heat transfer. The models have been limited in size to 2 or 3 inches in diameter and test times have been on the order of only 2 or 3 seconds. With such limited data, it is impossible to reliably predict the propellant behavior of a 260-inch diameter cryogenic stage subject to transient conditions and heat transfer. Considering the enormity of the lack of data, the need for experimentation is obvious. Many methods of obtaining the needed data were investigated, including one-g tests, drop towers, the X-15, drops from high flying aircraft or balloons, and sounding rockets. None were completely satisfactory. The major limitations of each testing method are listed in Table 2-1. Those testing limitations coupled with the present lack of knowledge concerning transient scaling parameters necessitate a full-scale orbital experiment to prove conclusively the orbital performance of the Saturn V/S-IVB from a fluid mechanics standpoint.

B. S-IVB VENTING SYSTEM AND OPERATING SEQUENCE

In order to understand the problems and the need for an experiment one must first understand the S-IVB venting system and the operating sequence. The Saturn V/S-IVB must burn into orbit, perform an attitude controlled orbital coast of up to 4.5 hours, restart, and burn to escape. Following lift-off, no venting is required until after orbital injection. After orbital injection the J-2 engine shuts down and two 70-pound thrust Gemini engines (located in the APS modules) are ignited and burn for 50 seconds. This will ensure that the hydrogen is settled in the tank before the continuous vent, which is utilized for propellant bottoming during orbital operations, is opened. The S-IVB is injected into orbit with both the hydrogen tank and LOX tanks approximately two-thirds filled. During orbit, venting is required due to the heat input to the hydrogen and oxygen tanks. This venting must be accomplished with a minimum of propellant loss. The present concept is to vent H_2 continuously so as to provide a very small propulsive thrust which will maintain the propellants in an ullaged condition. This approach should reduce the hydrogen and oxygen boiloff and at the same time assure that the liquid will be bottomed for the engine restart.

Table 2-1. Limitations of Low Gravity Testing Facilities

Testing Method	Testing Time	Model Size	Remarks
One-g			Lack of knowledge of scaling laws governing transient phenomena. Cannot study all phenomena at one-g.
Drop Towers	2 to 3 sec 10 sec	Small	Very short test time Not operational until 4th quarter, 1965
Aircraft	Short 30 sec at best		Results not repeatable
X-15	200 sec	20 to 30 inches in dia.	Disturbances caused by operation of attitude control jets.
Drop from high flying aircraft or balloons	30 sec	several feet in diameter	Wind shear requires excessively large drag shield.
Sub-orbital rocket flights	7 to 11 minutes	30-in. dia.	Lack of knowledge of scaling laws governing transient phenomena. High cost per test.

C. POTENTIAL LOW-GRAVITY PROBLEMS

Some of the problems of immediate concern are as follows:

1. At J-2 engine shutdown, liquid transients may cause control disturbances and result in the premature opening of the hydrogen vent and subsequent loss of liquid. Shutdown transients result primarily from structural relaxation, closing of main propellant valves, the persistence of oscillating waves and sidewall convective boundary layers developed during boost.

2. During aerodynamic boost phases of the mission, heating has built up a boundary layer in the liquid near the tank wall, which has kinetic energy. The average velocity in the boundary layer is about one foot per second with a maximum velocity of about four feet per second. If this kinetic energy is converted into potential energy, then the liquid in the boundary layer could jump easily into the neighborhood of the inlet to the vent line. Also while burning into orbit the J-2 engine is consuming propellant and the liquid interface is draining at the rate of about 0.1 foot per second. This places momentum in the entire liquid body. At J-2 engine shutdown, the draining ceases and the energy must go somewhere. The question is, where?

3. During the boost of the vehicle, the propellant could be sloshing. If it is sloshing when thrust is terminated and the vehicle enters zero-g, the liquid will not continue to oscillate from side to side in the container. This has been shown in model tests. Rather than oscillating, the liquid will continue on around to the top of the tank and cover the vent line.

4. The attitude control system will induce propellant sloshing. The natural frequency of a liquid body is reduced when the force field is reduced. Therefore, the ratio of forcing frequency to natural frequency may be large, and the liquid may be sloshing at high frequency ratios. The behavior of liquid at very high frequency ratios is not completely understood, and the current slosh theories primarily assume sinusoidal forced excitation in translation; however, due to impulses from the Ausiliary Propulsion System, the motion induced by attitude control is rotational about the vehicle center of mass. The S-IVB center of mass is slightly below the LH_2 level which may represent an additional complication.

5. The critical venting rate is not known. If venting is too fast, bubbles formed in the liquid may be so large and occur so rapidly the liquid level will rise and eventually result in the loss of liquid through the vent system.

6. A screen over the LH_2 suction line is provided to prevent foreign matter from reaching the engine and turbopumps, and also to prevent vortexing. During coast the suction line boils dry and results in a vapor pocket being trapped below the screen. This vapor must be removed from the suction line before the turbopumps can be started. A fine-mesh screen can support a large column of liquid in low g, so it may be difficult to remove the vapor with the pressures and accelerations available prior to engine start.

D. LIMITATIONS OF PRESENT TEST FACILITIES

The available experimental information is only a beginning toward obtaining an understanding of low g fluid behavior and the acquisition of reliable design information, particularly concerning dynamic phenomena. The facilities for pursuing the necessary additional work are still relatively few and most have serious limitations. None of the operational drop towers will provide more than three seconds of low g test time. Several drop towers are either proposed or already under construction which will provide low g test periods of four to five seconds, and the two-pass system now being constructed at Lewis Research Center will provide about ten seconds of test time. However, these facilities will not be operational for some time, perhaps not before 1966. Most of the problems of real concern in low g design work are dynamic in nature; therefore, experiment time is an important factor in observing and correlating results. It is questionable whether these drop tower facilities will be completely adequate for studying dynamic response of liquids in low g.

Eventually aircraft and sounding rockets will increase the low g test time considerably; however, past experience with aircraft test has not been encouraging. Actual test times achieved are comparatively shorter than the theoretically obtainable times and the residual motions in the test fluid and random accelerations negate the collection of accurate data. The Aerobee and Wasp sounding rockets provide from three to five minutes and seven to eleven minutes of low g test time, respectively. A considerable amount of useful data has been obtained from flights of these vehicles, but varying the acceleration on the test container to provide predetermined test conditions (nondimensional scaling parameters) may pose a problem.

Two attempts to obtain data from experiments contained in pods on the side of the Atlas vehicle have failed. The pods are ejected from the side of the Atlas, after nose cone separation, and must be stabilized in angular rotation.

The X-15 attitude at high altitudes is pilot controlled by H_2O_2 rockets in the nose and wing tips. These attitude control rockets will impose significant tangential and centrifugal accelerations at the various experiment locations.

The Scout rocket has orbital capabilities and may merit further investigation as a test vehicle for orbital fluid mechanics experiments; however, the payload module is only 24.3 inches in diameter. So the experiment still does not approach full scale vehicle proportions.

The feasibility of drop experiments from high flying aircraft or balloons (100,000 ft) in order to obtain very long drop times has been investigated. The wind shear even at such altitudes dictates a drag shield of such proportions that further considerations seem fruitless.

E. VALUE OF PROPOSED ORBITAL EXPERIMENT

The value of this orbital experiment will be to either substantiate the present S-IVB design or permit corrective redesign to be engineered without loss of schedule. In addition, we will extend the state-of-the-art in low g fluid mechanics and heat transfer. The cost incurred by this experiment could result in a future savings by developing the S-IVB orbital capability on the Saturn IB rather than the Saturn V.

SECTION III. EXPERIMENT DESCRIPTION

A. GENERAL

The Saturn IB Liquid Hydrogen Experimental Vehicle will be composed of an S-IB first stage, an S-IVB second stage, an Instrument Unit and an aerodynamic nose fairing as shown in Figure 6-2. The S-IB stage will be propelled by eight Rocketdyne H-1 engines which will lift the launch vehicle to a height of approximately 33 N. M. The S-IVB stage will be propelled by one Rocketdyne J-2 engine which will boost the S-IVB stage, Instrument Unit, and nose fairing into a 100-N. M. circular earth orbit. The Instrument Unit will provide guidance, control, and sequence signals for operation of the total Saturn IB launch vehicle. The launch vehicle guidance will be accomplished by an inertial guidance system currently being developed for the Saturn IB and for the Saturn V launch vehicles.

B. EXPERIMENT CHARACTERISTICS

The Saturn IB/S-IVB stage for this experiment, will have the liquid hydrogen (LH_2) tank loaded to capacity. The liquid oxygen tank will be off-loaded to provide the optimum performance necessary to place the maximum amount of LH_2 into orbit with a minimum of LOX residual. Using this technique approximately 18,000 pounds of LH_2 should be available for the orbital experiment. This amount of LH_2 remaining in the S-IVB represents approximately 60 per cent of the LH_2 carried into orbit in a Saturn V/S-IVB stage.

C. TELEVISION SYSTEM

To obtain the needed visual data, a TV system will be required. The TV coverage consists of two completely independent camera systems. One system employs a low-rate camera which transmits one picture every two seconds. The low-rate camera has several advantages. The picture can be transmitted and received over standard telemetry links, thus it can be received at many existing ground stations. The second camera system uses a high-rate TV camera transmitting 30 pictures per second. This system provides motion continuity but has the disadvantage of requiring special ground receiving equipment.

The cameras will be mounted on the manhole cover of the LH_2 tank to avoid cutting holes in the LH_2 tank. The TV cameras will be pointed at the intersection of the liquid surface and the tank wall. The high-rate camera will use a wide-angle lens and the low-rate camera will use a medium angle lens. The field of view of the cameras will be overlapped in the area of the tank vent by about five degrees. With this arrangement, coverage of the vent area is assured. To illuminate the tank, a light is required for each camera. The lights are 50-watt GE lamps and are pointed in the same direction as the cameras.

Neither the lights nor the cameras are exposed directly to the tank environment. They are protected by 1.5-inch thick quartz windows. To prevent fogging of the windows, a helium or dry nitrogen gas purge will be employed prior to lift-off. Even though the cameras are not exposed directly to the tank environment, their temperatures could drop below the operating limits. Therefore, 100-watt electrical heaters have to be utilized continuously during the experiment.

The horizontal resolution was fixed at 200 lines so that the planned 30-foot antennas could be used to receive the signals. With this resulution, objects of one-inch diameter in the tank will appear approximately 1/16-inch diameter on the TV screen. It will not be possible to discern the shape of smaller objects. However, should smaller objects such as bubbles coalesce into larger groups, it will be possible to observe the area of the disturbance.

Since LH_2 is transparent, it will be difficult to visually observe anything when the liquid is quiescent. However, when there is fluid motion, boiling, or disturbances of the liquid vapor interface, the disturbance will be visible. To aid in depth perception, a grid system will be painted on the internal insulation surface and the instrumentation support probes will be graduated.

D. INSTRUMENTATION

Many important facts, such as the pressure rise rate in the tank, the success of the LH_2 chilldown system, etc., cannot be determined by the TV system. Therefore, additional instrumentation will be required for this experiment. Besides providing needed data, the instrumentation will serve as backup to the two independent TV systems.

E. DATA RETRIEVAL

Data will be received for at least three orbits and perhaps as many as four orbits at various points around the world. Besides recording the data as it is received, there is a requirement for real-time display of at least 15 channels of information at the Cape, Bermuda, and a location in Texas.

F. DATA REDUCTION

After the flight, the telemetry tapes will be sent to DAC where they will be linearized and returned to MSFC. At MSFC the Computation Laboratory will reduce the linearized tapes and provide SA 4020 plots and digitized data for initial analysis. Later, EAI plots will be required for reports. It is understood that the additional measurements and the increased transmission time will not significantly increase the work load of the MSFC Computation Laboratory.

It is desired that DAC analyze the data received only to determine that the system performed satisfactorily and to the extent necessary to explain and correct failures or inaugurate improvements for future flights. Detailed analysis of a research nature will be performed by MSFC.

SECTION IV. EXPERIMENT OBJECTIVES

A. SATURN V STUDIES

It should be noted that studies are presently being made on Saturn V to determine the necessity of using the zero g vent separator. It is possible that the results of these studies will conclude in the removal of the separator from the Saturn V and the employment of a constant pressure ullage system during the three-orbit coast period. If the results of these studies do dictate a Saturn V system change, then a similar change will be made for this experiment, i.e., no separator and constant pressure venting. Similarly, the experiment objectives will be altered as required.

B. TEST OBJECTIVES

The Saturn V system characteristics and orbital phenomena to be studied in this experiment are as follows:

1. Continuous Venting System

a. Adequacy of 6 pounds minimum thrust to maintain propellant in settled condition

b. Thrust split of the continuous vent ports to neutralize torque

c. Adequacy of APS to maintain ullage control during shutdown transients

d. Propellant settling time with continuous venting thrust

e. Entrainment of liquid hydrogen in vent gas at continuous venting flow rates

f. Mechanism of heat transfer at low g level

g. Liquid/vapor separator operation at low flow rate

h. Effect on settling of simulated orbital maneuver

i. Sloshing behavior of hydrogen on S-IVB tank

j. Heat transfer to APS modules

2. Restart Preparation Tests

a. Entrainment of liquid hydrogen in vent gas at fuel tank blowdown flow rate

b. Liquid/vapor separator performance at high flow rate

c. Recirculation chilldown characteristics

d. Anti-vortex screen bubble removal

e. Thrust chamber chilldown

f. Orbital storage characteristics of ambient helium bottle

g. Repressurization level achieved in hydrogen tank when using the ambient helium bottle

3. Pre-ignition Tests

a. Start bottle performance (and orbital storage characteristics)

b. General engine performance including pump characteristics

SECTION V. MISSION PROFILE

SEQUENCE OF ORBITAL EVENTS

The sequence of events in orbit is shown in Table 5-1. Each event will be initiated by an on-board recorder in a predetermined sequence or by ground commands. The major events are programmed to occur over ground stations where high speed TV data can be received. Also, as a safety measure, the more important events are scheduled to occur in the first orbit. However, to obtain all of the data desired, three orbits will be required. The orbit should continue even longer and telemetry information may be received for as many as four orbits. The limiting factor seems to be the availability of electrical power to operate the attitude control system (see Table 5-2).

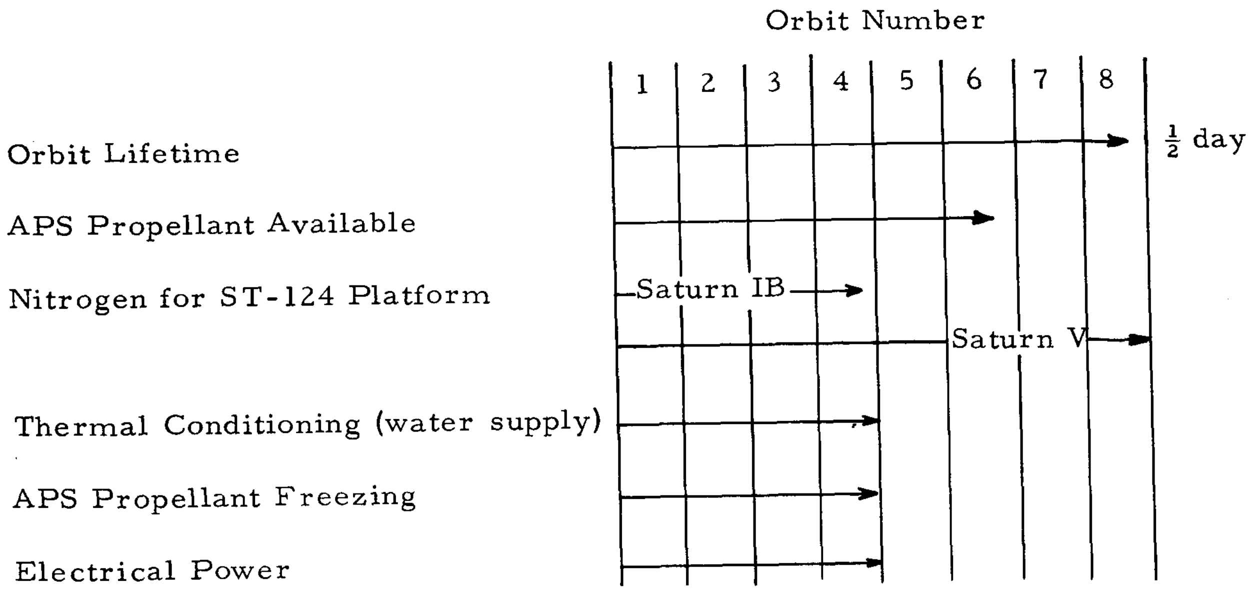
Table 5-1. Liquid Hydrogen Orbital Experiment Sequence of Events

Orbit	Duration	Event	Station	Comment
0	LO to 467 sec	(1) Launch - injection	KSC-Bermuda	High-rate TV coverage. Visual display and record. High-rate = 30 frames/sec; Low-rate = 1 frame/2 sec
1	Burnout + 0.1 to 75.1 sec	(2) Ullage thrusting using LOX tank gas	KSC-Bermuda	
1	Burnout + 72.1 sec	(3) Initiate continuous vent & attitude control limit cycling	KSC-Bermuda	
1	Burnout + 258 sec	(4) End of Bermuda data		
1	4.6 min over Canary Islands	(5) Continuous vent monitor	Canary Island	Start warm up of low-rate TV early enough to obtain full Canary coverage.
1	3.0 min over station	(6) Continuous vent monitor	Carnarvon	Low-rate TV
1		(7) First orbit data dump from recorder (number of tank vents, if any)	White Sands	
1	2.0 min	(8) Initiate blowdown of LH_2 tank (Approx. 2 min)	Texas & KSC	High-rate and low-rate TV visual and record start warmup early (10 min)
2	5.0 min	(9) Sequence restart, i.e., LH_2 repress., ullage thrusting, terminate continuous vent, recirculation, simulated vent	Texas & KSC	High-rate and low-rate TV

Table 5-1. (Concluded)

Orbit	Duration	Event	Station	Comment
2	1 min	(10) Ullage control after simulated restart (LOX vapor)	KSC-Bermuda	TV coverage (high- and low-rate) visual and record
2	-	(11) Resume continuous venting	KSC-Bermuda	TV coverage (high- and low-rate) visual and record
2	-	(12) Continuous vent for second orbit		
2	-	(13) Same as step 7 from first orbit	White Sands	
3	2 min	(14) Same as step 8	Texas	High- and low-rate TV visual and record
3	1 min	(15) Recirculate without repressurization	Texas-KSC	High- and low-rate TV visual and record
3	5 min	(16) Terminate continuous vent	KSC	High- and low-rate TV visual and record
3	2 min	(17) Resettle with continuous vent	KSC-Bermuda	High- and low-rate TV visual and record
3	1 min	(18) Ullage thrusting		
3		(19) Third orbit heating		

Table 5-2. Factors Influencing Experiment Lifetime



SECTION VI. NOSE CONE CONFIGURATION

A. CONFIGURATION SELECTION

Two nose cone configurations were considered for use in the Liquid Hydrogen Orbital Experiment. Configuration 1 (Figure 6-1) consists of an Apollo payload shell. Configuration 2 (Figure 6-2) consists of an aerodynamic nose cone envelope. If the Apollo configuration were used instead of the aerodynamic nose cone, the available hydrogen in orbit would be reduced by 1500 to 2000 pounds. This is due to approximately a 2800-pound increase in S-IVB jettison weight in orbit and different aerodynamic drag losses.

Other studies have shown that control cannot be maintained using Configuration 1 when parameter variations are considered in conjunction with a 95 per cent wind speed profile. Reduction of the wind speed to the 90 per cent wind speed profile reduces the required gimbal angle sufficiently to maintain control. Configuration 2 was able to maintain control through the 95 per cent wind speed. The recommendation to use Configuration 2 is a result of these studies.

B. DESIGN

The nose cone will be fabricated by MSFC. The cone will be a skin- and stringer-type construction and will have a coat of ablative material on the exterior surface. It will be bolted to the Instrument Unit and will not be separated in orbit. The weight will be approximately 3500 pounds.

C. INSTRUMENTATION

The following measurements will be needed in the nose cone:

1. Pitch and yaw accelerations
2. Longitudinal acceleration (0-30 cps)
3. Internal acoustics (one pickup)
4. External acoustics (one pickup)
5. Eight static pressure measurements
6. Four unsteady pressure measurements
7. Twelve external temperature measurements (providing no additional telemetry is required)

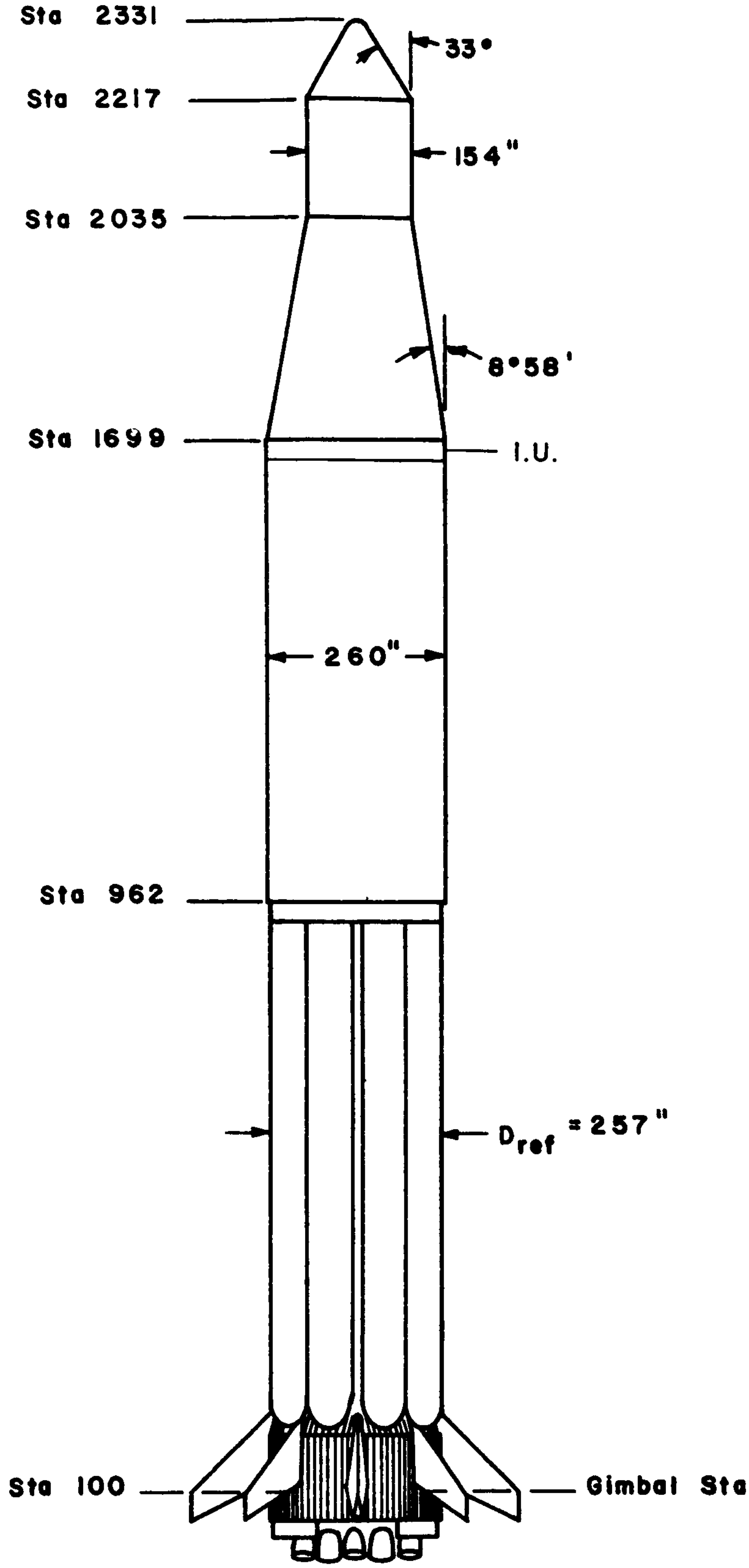


Figure 6-1 Configuration I

The above measurements must be transmitted by the Instrument Unit telemetry system and are second priority to the television equipment in the Instrument Unit. The exact locations, accuracies, range, etc., of the measurements within the nose cone will be specified after the design is frozen.

SECTION VII. VEHICLE PERFORMANCE

A. PROPELLANT LOADING

The S-IVB propellant utilization system will be used to control propellant loading of the orbital cryogenic experiment stage thus maintaining continuity with the loading procedure used for other S-IVB stages at Kennedy Space Center. Other loading methods (point level sensors, ΔP, etc.) were not considered because of the required hardware modifications. The approximate loading values will be 100 percent for the hydrogen tank and approximately 65 percent (125, 500 lbs) for the oxygen tank.

B. TRAJECTORY DESIGN

A design trajectory similar to that shown in Figure 7-1 must be constructed in order to satisfy the stated mission without objectionable vehicle compromise. Since maximum payload capability trajectories are characterized by excessive aerodynamic loads, trajectory shaping is believed to be necessary in order to insure the structural integrity of the vehicle. Increases in aerodynamic loads are attributed to trajectories marked by higher accelerations which in turn result from reduced configuration weight. The principal system weight differences, as compared to the operational Saturn IB mission, are a liquid oxygen off-load of approximately 60, 000 pounds, deletion of the Launch Escape System, replacement of the Saturn IB Apollo payload with a 3, 500-pound aerodynamic nose fairing, and the addition of approximately 18, 000 pounds of liquid hydrogen.

C. DYNAMIC RESPONSE STUDY FOR STRENGTH ANALYSIS

In order to assess the structural integrity of Saturn IB vehicle SA-203, the dynamic response of the vehicle with respect to winds and gusts must be determined. This information will result in defining maximum angle-of-attack histories that might be encountered.

D. VEHICLE STABILITY

It is necessary to insure that stability margins are maintained during powered flight. The basic parameters which are changed for this mission are vehicle moment of inertia, location of center-of-gravity and possibly center-of-pressure, and vehicle mass distribution. These

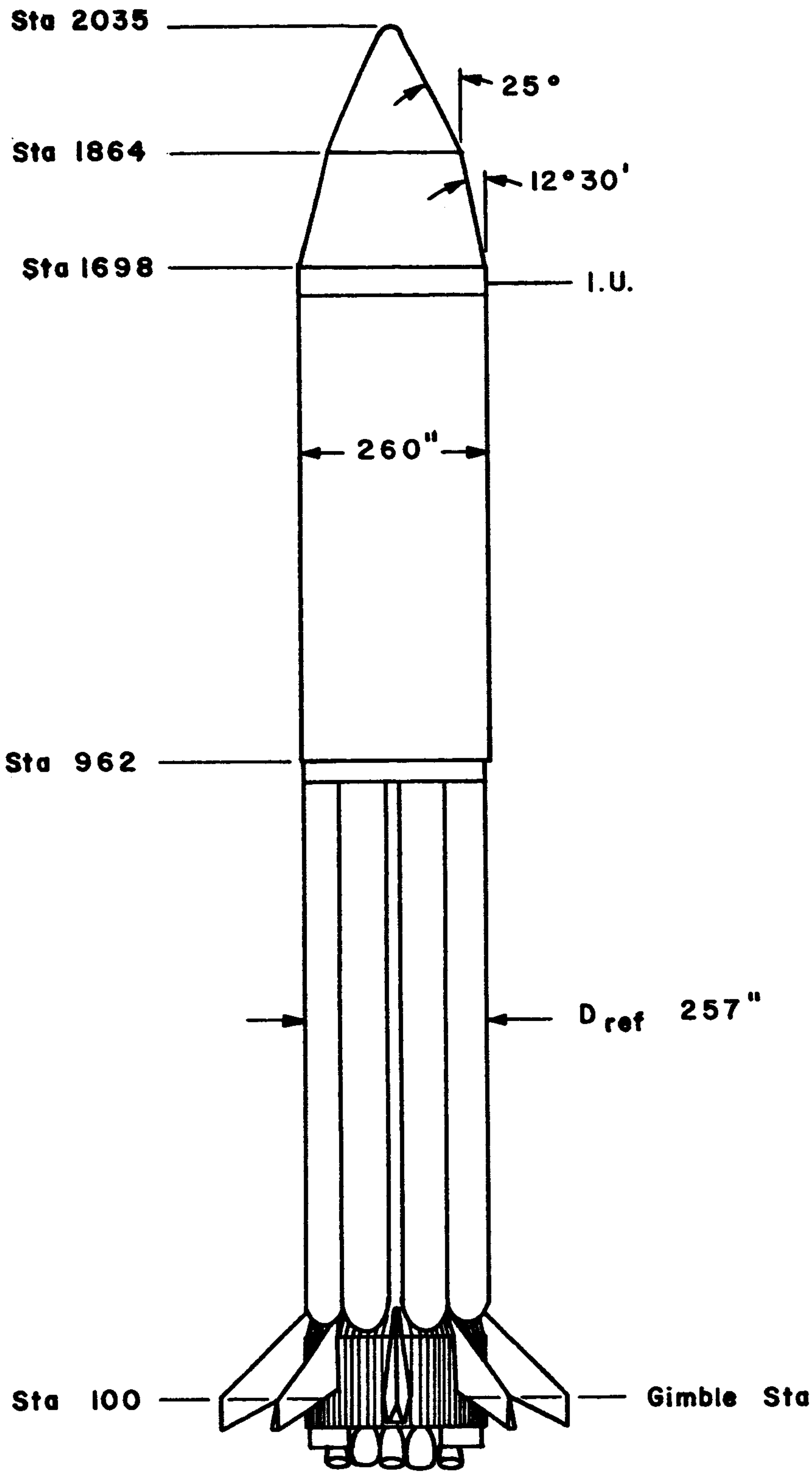


Figure 6-2 Configuration 2

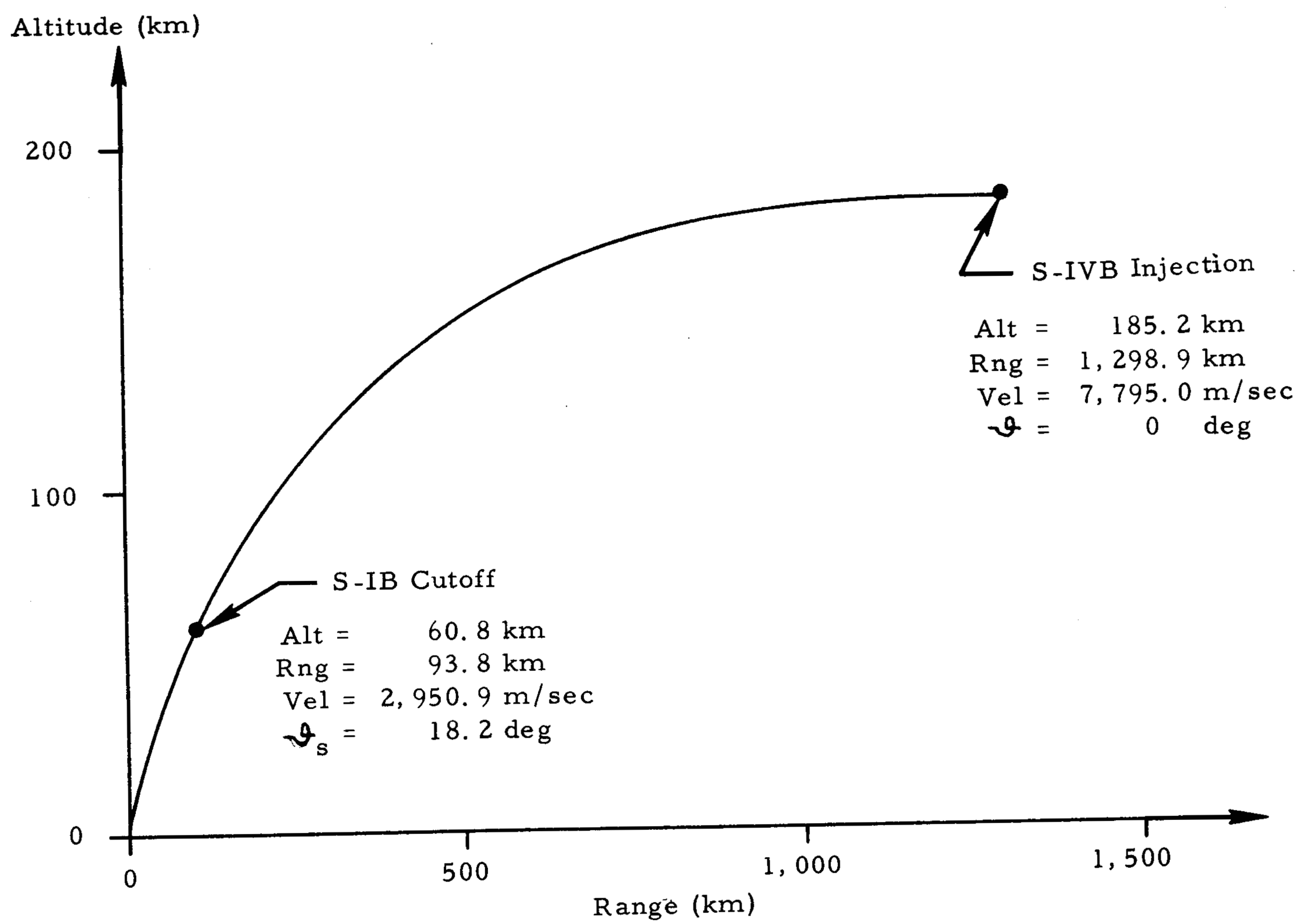


FIGURE 7-1. SATURN IB SA-203 ALTITUDE AS A FUNCTION OF RANGE FOR A 100-N.M. CIRCULAR ORBIT

in turn result in new rigid body response and bending modes. Using these values, the vehicle stability must be examined at the appropriate burn times to determine the necessary changes in gains and shaping networks to insure maintaining the desired stability margins. In addition, new propellant sloshing parameters will have to be determined to conform to the propellant loading and acceleration histories peculiar to this mission.

E. LOX TANK SLOSH BAFFLE

Due to the low oxidizer fluid levels required for this mission (approximately 60,000 pounds less than the Saturn IB operational mission) a new LOX tank anti-slosh baffle must be designed to insure three per cent damping effectiveness. At this time, no slosh testing is envisioned. Therefore, a conservative design will be used to guarantee the required damping without test verification. The resulting baffle design will probably be either a horizontal ring or a circular diaphragm with holes. The existing baffle will be left in place as it supports the propellant utilization (PU) probe.

F. PROPELLANT UTILIZATION SYSTEM

Stage flight will be accomplished with the propellant utilization system operating in the open loop mode. This can be accomplished with negligible P.U. system hardware changes. The control valve will remain in the nominal position and will not be governed by tank propellant quantities. This is necessary because of the excessive tank mixture ratio unbalance caused by the hydrogen payload. Closed loop operation is not possible with the existing P.U. system because of excessive hydrogen bias requirements. The entire payload mass would have to be biased out of the probe signal or the P.U. system would see the payload as an apparent error and would attempt to eliminate it by operating the engine at a low engine mixture ratio (EMR).

The present maximum bias capability of the P.U. system is conservatively sized at 5000 lbs of hydrogen based on Saturn V orbital boiloff. This is well below the 17-18,000 pounds of liquid hydrogen payload presently planned for the mission. Increasing the bias capability to 18,000 pounds would require an increased voltage supply to the biased network and subsequent modification to the P.U. system.

acceleration level ullage control for fifty seconds after engine cutoff, during the shutdown transient, and to assist settling for a portion of the simulated Saturn V/S-IVB orbital restart sequencing.

Because of the relatively low orbiting weight of the experiment, only 28 lb total thrust will be necessary to simulate Saturn V/S-IVB orbital acceleration during burn of the 70-pound engines.

Basically the system will require two 3-inch lines routed around the thrust cone to two nozzles located diametrically opposite each other in an axial direction from an S-IV or S-IVB type fill and drain valve mounted on the side of an existing vent and relief valve tee. A control module must also be added to actuate the added fill and drain valve.

A LOX residual will exist on the S-IVB stage due to tolerance in open loop flowrate predictions, flight performance reserves, and the possibility of a high performance engine. The energy in the GOX-helium ullage thrusting system should not be affected by this residual, because the reduction in ullage volume caused by liquid residuals is negligible with respect to the total ullage volume.

Other possible areas that could possibly be affected as a result of having liquid residuals are being analyzed to insure system integrity, although no problems are apparent at this time.

J. CONTINUOUS VENT THRUST LEVEL

The continuous vent thrust will be sized to maintain a positive axial acceleration of approximately 2×10^{-5} g's on the stage during orbital coast, thus keeping the propellants bottomed. The exact thrust level will depend on the vehicle weight and the orbital drag. The maximum orbital drag was calculated for zero angle-of-attack and six-degree angle-of-attack. The six-degree angle-of-attack could occur as a result of the tolerances in the guidance system horizontal reference plane.

K. AUXILIARY PROPULSION SYSTEM

The auxiliary propulsion system requirements are similar to those of the Saturn IB mission with the possible elimination of all or at least a portion of the Saturn V type simulated maneuver exercises and attitude control operations. There will be an increase in the hydrogen

G. REQUIREMENTS FOR A ΔV CUT-OFF-SYSTEM

It was originally planned to operate the J-2 engine in the open-loop mode until LOX depletion occurs, thereby minimizing the amount of liquid oxygen onboard the stage during shutdown. Further investigation has determined that a significant amount of liquid oxygen could remain in the tank at orbital injection due to:

1. Tolerances on open loop flow rate predictions

2. Unused flight performance reserves

3. Unused main-stage propellants which might not be consumed due to 3σ high engine performance.

Burning this residual LOX by operating to depletion would not significantly affect the experiment with respect to the total liquid hydrogen mass in orbit since the LOX will be consumed at an engine mixture ratio of 5/1. However, depletion of these residuals would impart a significant velocity increment to the stage and it would be impossible to hold the vehicle to the nominal Saturn V parking orbit and the vehicle would be injected into an elliptical orbit. This would tend to decrease the over-all validity of the experiment. Consequently, the stage will be shut down by guidance on the attainment of the nominal Saturn V parking orbit with the attendant possibility of the higher liquid oxygen residuals.

H. S-IVB STAGE SEPARATION DYNAMICS

An analysis of the S-IB and S-IVB stage separation will be required in order to determine transient responses and the probability of collision. The magnitude of these separation transients will be analyzed in order to demonstrate the range of separation conditions wherein control can be maintained.

I. ULLAGE THRUST SYSTEM

In order to simulate the thrust of the two Saturn V/S-IVB 70 pound thrust hypergolic engines, residual ullage gas from the LOX tank (oxygen-helium mixture) will be ducted overboard and directed axially through a pair of nozzles. The system will be used to maintain high vent impulse which will result in additional APS propellant usage to counteract any vent induced disturbances. Additional APS propellant will also be required for (1) the cancellation of any ullage nozzle unbalance and (2) the production of a desired pitch or yaw angular acceleration to determine its influence on continuous venting. Neither of these two requirements is included in the present APS design.

Based on preliminary analyses, the present Saturn IB APS design appears to be capable of satisfying the mission requirements although at the expense of at least a portion of the maneuver and attitude control exercises. However, the effect on the APS propellant requirements of lower inertia values, changed CG location, and I_{sp} variation as a function of pulse width will have to be evaluated in detail before the adequacy of the present APS propellant loading can be completely ascertained. Should the present loading prove inadequate, it is felt that a system parameter optimization (increased deadband, optimum minimum pulse bit, etc.) and/or a small reduction in the allowable coast time for which attitude control is available could be used in lieu of a change in APS tankage.

L. HYDROGEN TANK REPRESSURIZATION SYSTEM

A hydrogen tank repressurization system consisting of a Saturn V ambient helium bottle with minimum liftoff and pad safety switches, actuation control module, approximately 20 feet of 1/4-inch tubing, and two normally closed shutoff valves will be required to complete the system simulation. The system will be used to determine the pressure level that can be achieved by using a single ambient helium bottle and also to determine the orbital storage characteristics of the bottle. These parameters are needed to verify the design integrity of the Saturn V repressurization system.

SECTION VIII. S-IVB VENTING SYSTEM

A. CONTINUOUS VENTING SYSTEM

The present Saturn V/S-IVB orbital vent system is based on a low flow rate of vaporized hydrogen continuously vented from the hydrogen tank during the coast period. Gaseous hydrogen is bled from the tank at rates of 0.05 to 0.2 pound/second and ducted overboard through dual and parallel ports. The vent exits, located 180 degrees apart, are directed aft to provide a continuous low level axial thrust. At first-burn shutdown of the J-2 engine, two 70-pound-thrust engines located in the Auxiliary Propulsion System (APS) modules burn for 50 seconds to insure that the hydrogen tank is settled before the continuous venting is initiated. Near the end of the 50-second ullage engine burn period, continuous venting is initiated and continues until engine restart. The thrust from the continuous vent system provides approximately 10^{-5} g forward acceleration to keep both the fuel and oxidizer settled. Relief venting and tank blowdown at restart are accomplished through a non-propulsive system using larger diameter ducts. The blowdown at restart involves the venting of a large mass of gas at a relatively high flowrate. The successful operation of both vent systems under low gravity conditions is of critical importance to the overall success. Also significant to the low gravity operating conditions are the engine propellant feed, turbomachinery and engine bell chilldowns. Chilldown times and system hardware designs are highly dependent upon the heat flow into the propellant tanks during the launch and coast periods. The liquid hydrogen orbital experiment will require the complete Saturn V/S-IVB vent system. The main non-propulsive vent system, including the vent and relief valve is part of the normal Saturn IB/S-IVB hardware. However, a continuous vent system and a liquid/vapor separator for liquid hydrogen must be added to obtain the required configuration. The continuous venting system will require two 1-inch lines routed around the inside of the forward interstage to two nozzles located diametrically opposite each other in an axial direction (located as shown in Figures 8-1 and 8-2). The continuous vent system is shown schematically in Figure 8-3.

B. REQUIREMENTS AND PROBLEMS OF THE CONTINUOUS VENT SYSTEM

Analytical problems associated with using the Saturn V continuous vent system on the Saturn IB SA-203 vehicle are minor. The only area of concern is finding a means to simulate the Saturn V g levels

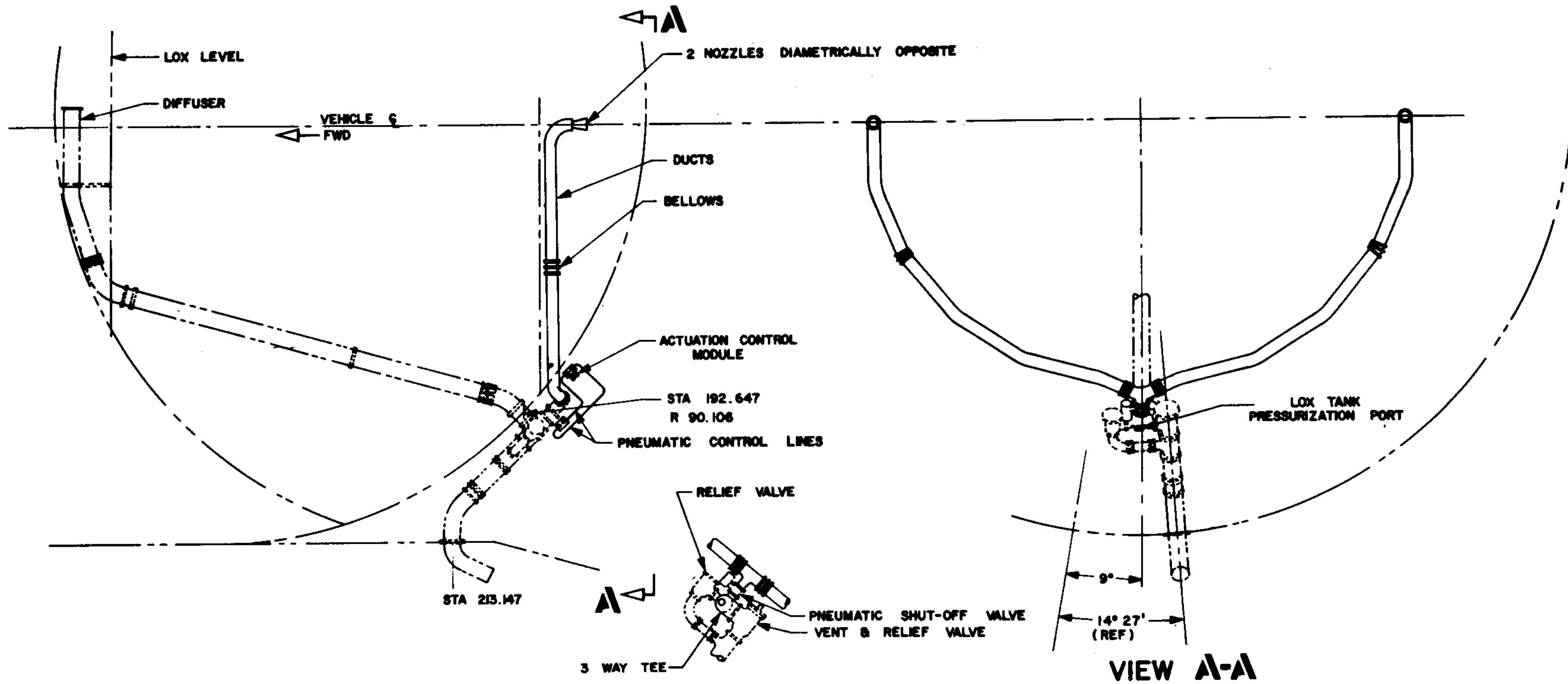


FIGURE 8-1. ULLAGE THRUSTER OXIDIZER TANK

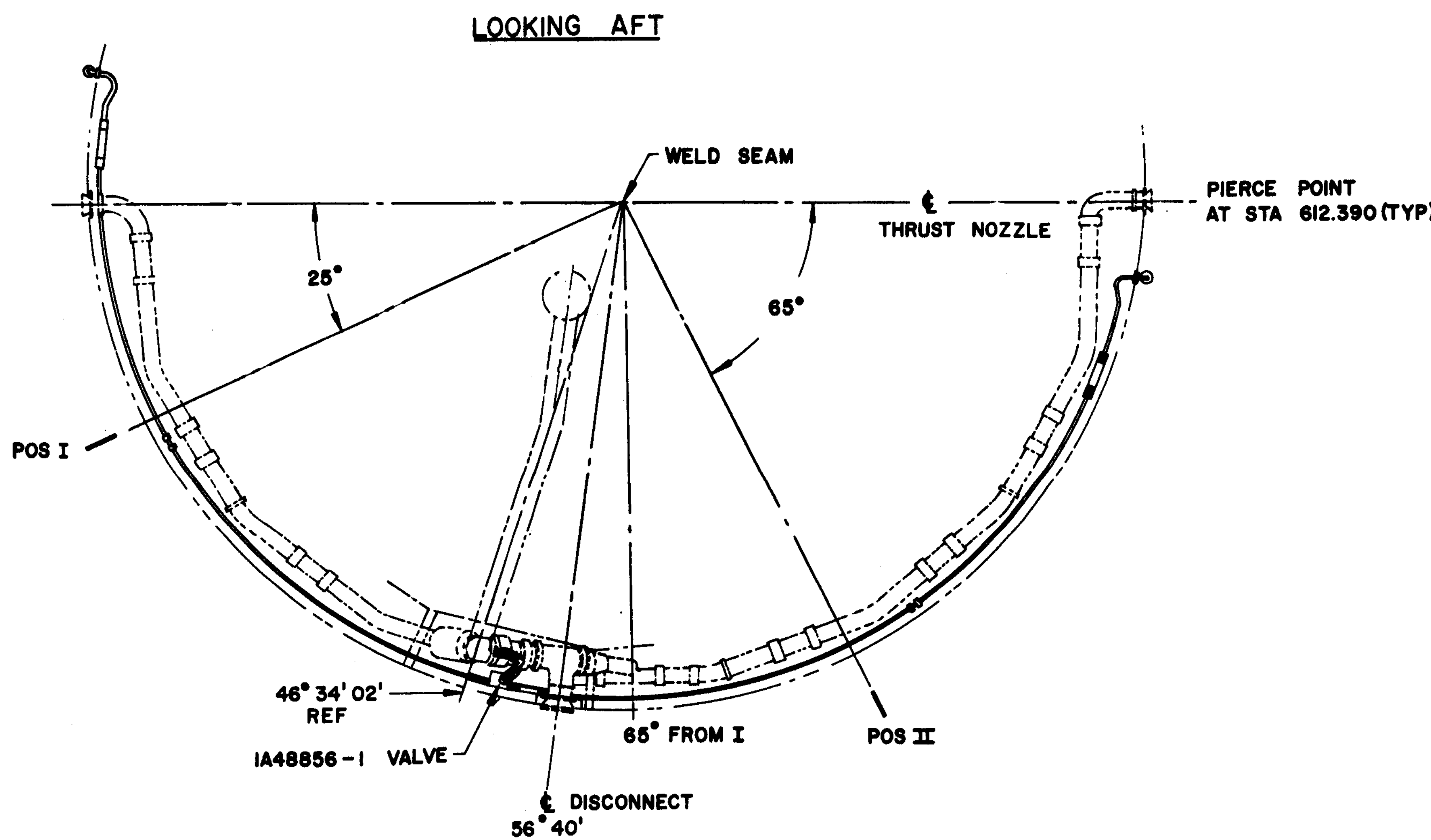


FIGURE 8-2. FUEL TANK VENT SYSTEM

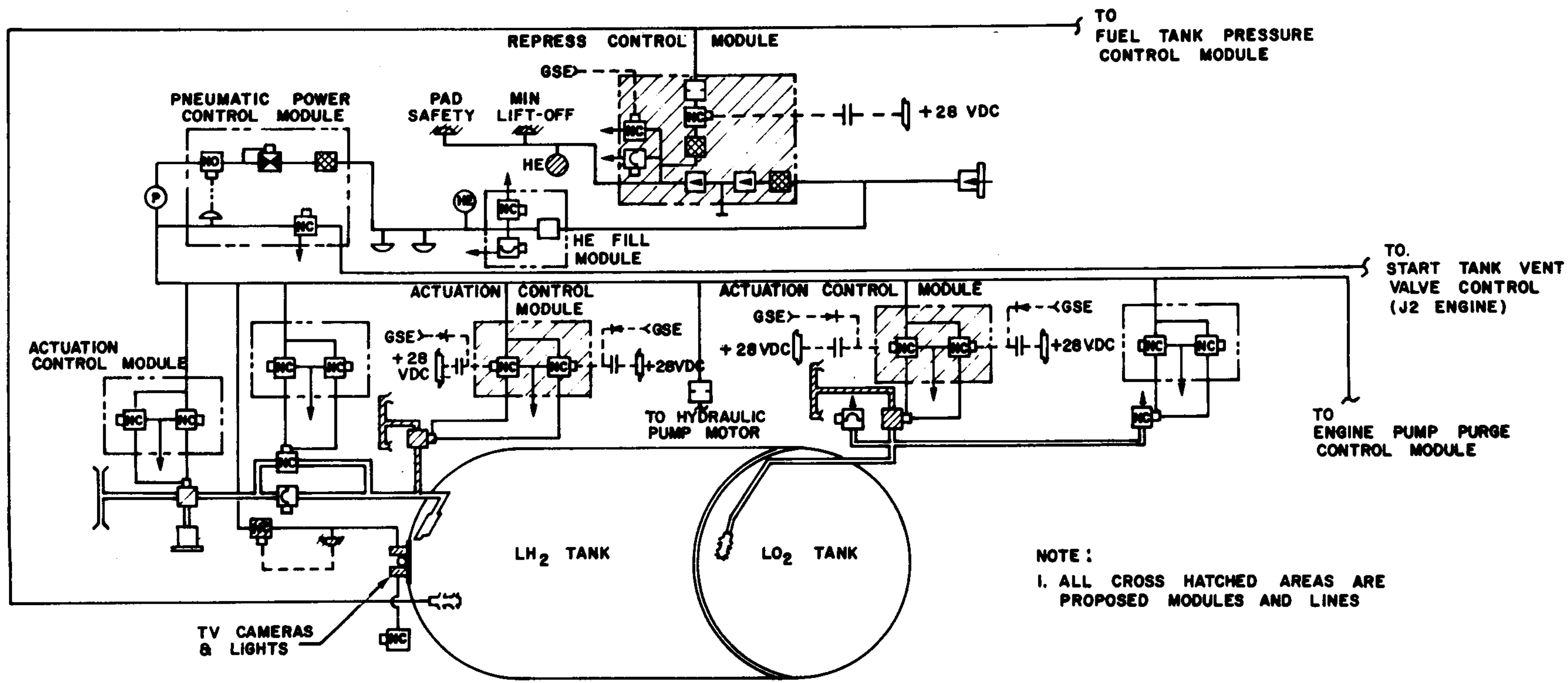


FIGURE 8-3. SCHEMATIC, LO_2 AND LH_2 ULLAGE THRUSTING

on SA-203. This problem exists because the Saturn IB/SA-203 vehicle is considerably lighter than the Saturn V; thus, it is necessary to reduce the thrust from the continuous vent system to achieve acceleration simulation. The apparent solution to this problem is to reduce the gaseous hydrogen flowrate from the ullage accordingly. The reduction in flowrate is so significant (factor of 5), however, that the resulting hydrogen tank pressure levels would differ drastically for the two vehicles. Therefore, this apparent solution is not acceptable. Two alternate solutions, which appear feasible, are shown below. Configuration A of Figure 8-4 shows a second set of smaller nozzles opposite to the first pair. This would serve to cancel part of the thrust produced by the larger nozzles, thus simulating the desired Saturn V g level. Configuration B of Figure 8-4 shows the two nozzles canted at an angle such that the excessive thrust components in the axial direction are reduced to the desired level and the resulting horizontal components cancel each other.

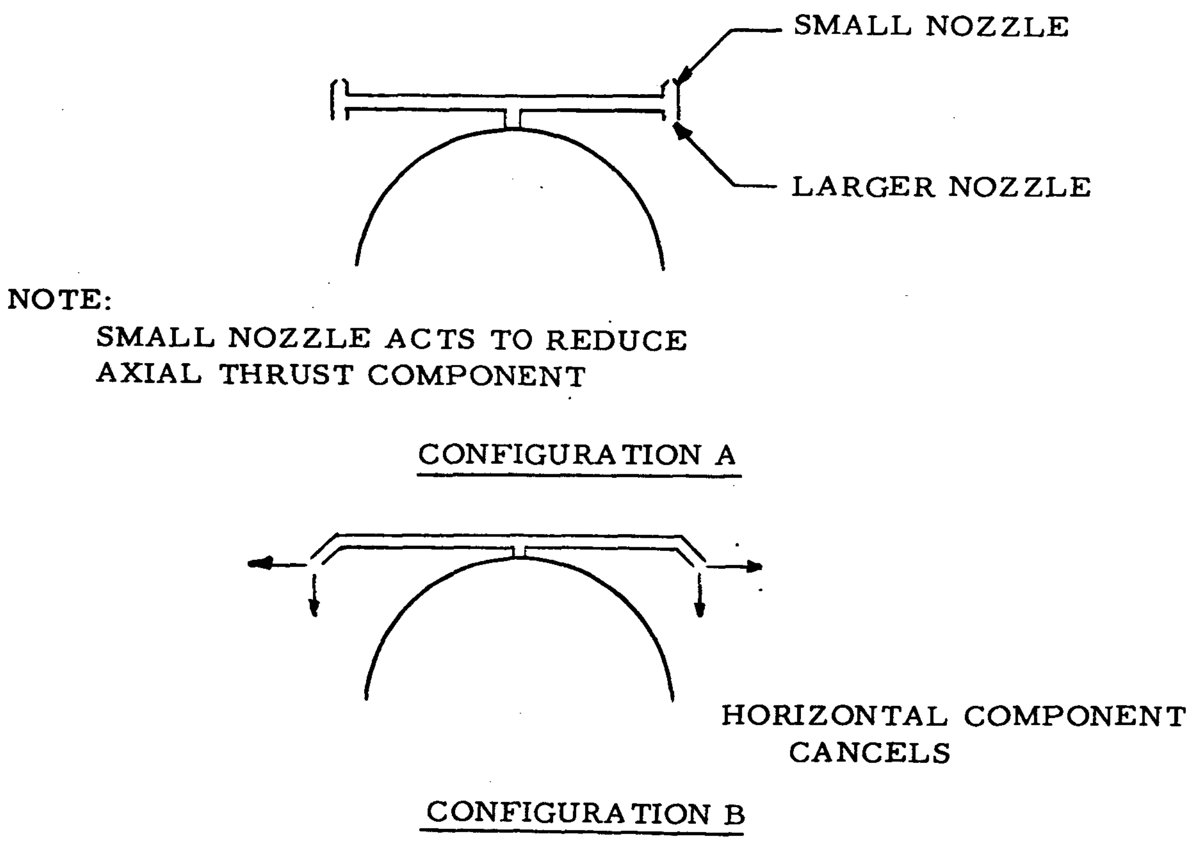


FIGURE 8-4. CONTINUOUS VENT SYSTEM CONFIGURATIONS

1. Rate of motion of subject matter

2. Field of view of subject matter

3. Minimum particle size to be distinguished

An experimental test was made to determine the ability of the TV system to meet the requirements stated above. Both black and white and color motion pictures were made inside a LH_2 tank during filling, pressurization and draining. The pictures showed that any surface motion, turbulence, or bubbling was clearly visible. It was decided to employ a high rate (30 frames per second) system to observe the turbulance during injection into orbit and during high speed venting.

A low rate TV system will be used as a back-up to the high rate system and also to provide visual observations whenever the experiment is within range of receiving stations having only telemetry capability. The use of a high-rate system for the entire orbital coverage would be economically impractical, since it would necessitate the installation of additional high-rate receiving stations. The low-rate system can use the existing on-board single-side-band transmitter and existing telemetry ground stations to receive and record the information. This system will make pictures every two seconds, which will permit a good analysis of the equilibrium condition in the tank. An analysis of signal strength and signal to noise ratio of the received picture was made. These are tabulated on Table 9-1. Two other frequencies were checked as possible alternates and are shown here for comparison. An acceptable minimum detected S_{pp}/N_{rms} was taken as 26 db for this experiment. While all four frequencies were acceptable from the 26 db point; overall system complexity and problems involved with 870 mc and 1700 mc systems eliminated them from consideration. In the process of arriving at the results given in Table 9-1, the time the vehicle would be over each of three high rate stations on each orbit was checked to ensure that the desired functions in the vehicle could be viewed. One of the high rate (30 frames per second) stations will be located at Guaymas, Mexico or Hawii dependent on chosen vehicle and station operational dates. The other two stations will be located at Kennedy Space Center, Florida, and Bermuda. Conservation of battery power plus three high-rate stations limitations predicated that the high-rate camera be turned on as the vehicle in orbit approached the most westerly station, and be turned off as it left the most easterly station of the three-station group. It has been recommended that ground commands be used to activate the high-rate

Table 9-1 System Parameters At Given Frequencies
For Liquid Hydrogen Orbital Experiment

20W (+43 dbm) Transmitter Power, 960-Mile Slant Range

SYSTEM

PARAMETER	2200 mc	250 mc	1700 mc	870 mc
Free Space Attenuation	-162.0 db	-144.0 db	-160.0 db	-155.0 db
GND AND Gain (30-ft. dish)	+ 43.8 db		+ 41.5 db	+ 36.0 db
Cable Losses	- 2.0 db	- 2.0 db	- 2.0 db	- 2.0 db
Polarization Loss	- 3.0 db	- 3.0 db	- 3.0 db	- 3.0 db
On-board ANT Gain	+ 3.0 db	+ 3.0 db	+ 3.0 db	+ 3.0 db
Received Signal Strength:		- 84.0 db		
30-ft. dish	- 79.2 db		- 79.2 db	- 78.0 db
GND ANT Gain (TM antenna)		+ 18.0 db		
Assuming NF	3 db	4 db	3 db	3 db
Bandwidth	10 mc	500 kc	10 mc	10 mc
IF S_{rms}/N_{rms}	22.5 db	30 db	22.5 db	21.3 db
Detected	31.5 db	39 db	31.5 db	30.3 db

system, since predictions are inadequate to determine the times at which the vehicle would cross the high-rate stations. All the high-rate stations will have ground command facilities available by launch date.

For a listing of the time over each station within the 5-degree elevation angle of the station for each orbit, see Table 9-2.

The low rate television information may be recorded by telemetry stations located at the following sites:

Orbit I	Orbit II	Orbit III
Canarv Island	KSC	KSC
Carnarvon	Bermuda	Bermuda
Guaymas	Canary Island	Antigua
Corpus Christi	Madagascar	Ascension
	Carnarvon	Madagascar
	Hawaii	Carnarvon
	Guaymus	Hawaii
	Corpus Christi	Guaymas
		Corpus Christi

Table 9-2 Time Over High Rate Stations

(Orbital Coverage Above 5° Elevation)

Station	Post Insertion		Orbit 1		Orbit 2		Orbit 3	
	Maximum Elevation (degrees)	Viewing Time (minutes)	Maximum Elevation (degrees)	Viewing Time (minutes)	Maximum Elevation (degrees)	Viewing Time (minutes)	Maximum Elevation (degrees)	Viewing Time (minutes)
CAPE	82	4.3	22.	4.6	51.	5.0	15.	4.2
BERMUDA			52.	5.0	11.	3.7		
HAWAII					22.	4.5	17.	4.3
GUAYMAS			77.	5.0	21.	4.6	26.	4.7

C. IMPLEMENTATION OF TELEVISION SYSTEM

The development of the television system will be the responsibility of the Astrionics Laboratory. Testing and minor changes of the supporting electronics will be performed by contractors and IBM will integrate the systems into the IU.

A hydrogen tank manhole cover containing one low-rate camera. one high-rate camera and two 28-volt lights in separate housings will by provided by MSFC for installation in the S-IVB stage at Sacramento. The necessary equipment for ground checkout of the TV system will be sent along with an MSFC test engineer to the test site. During static firing DAC will provide a purge for the cameras and lights. On the flight vehicle there will be only a ground purge supplied by MSFC.

The airborne stages of the television system are shown in block diagram form in Figure 9-1 and the viewing angles are shown in Figure 9-2. The system will use the following equipment:

1. 2200-mc transmitter including driver and power amplifier (high-rate) - 10-mc bandwidth, 20 watts output power

2. Minature TV camera with camera control unit - 30 frames per second interlaced 2:1

3. Antenna - 2200 mc

4. Light (two required to serve both cameras)

5. TV camera with camera control unit (Ranger VII type) - 1/2 frame per second

6. 250-mc telemetry transmitter (SSB) - already included in vehicle

7. Antenna - 250 mc already included in vehicle

For the purposes of this experiment, the power amplifier portion of the 2200-mc transmitter will require the installation of a 28-vdc power supply to replace the existing 115-volt, 400-cycle 3-phase supply. The driver portion of this transmitter is built but will require qualification to MSFC environmental specifications.

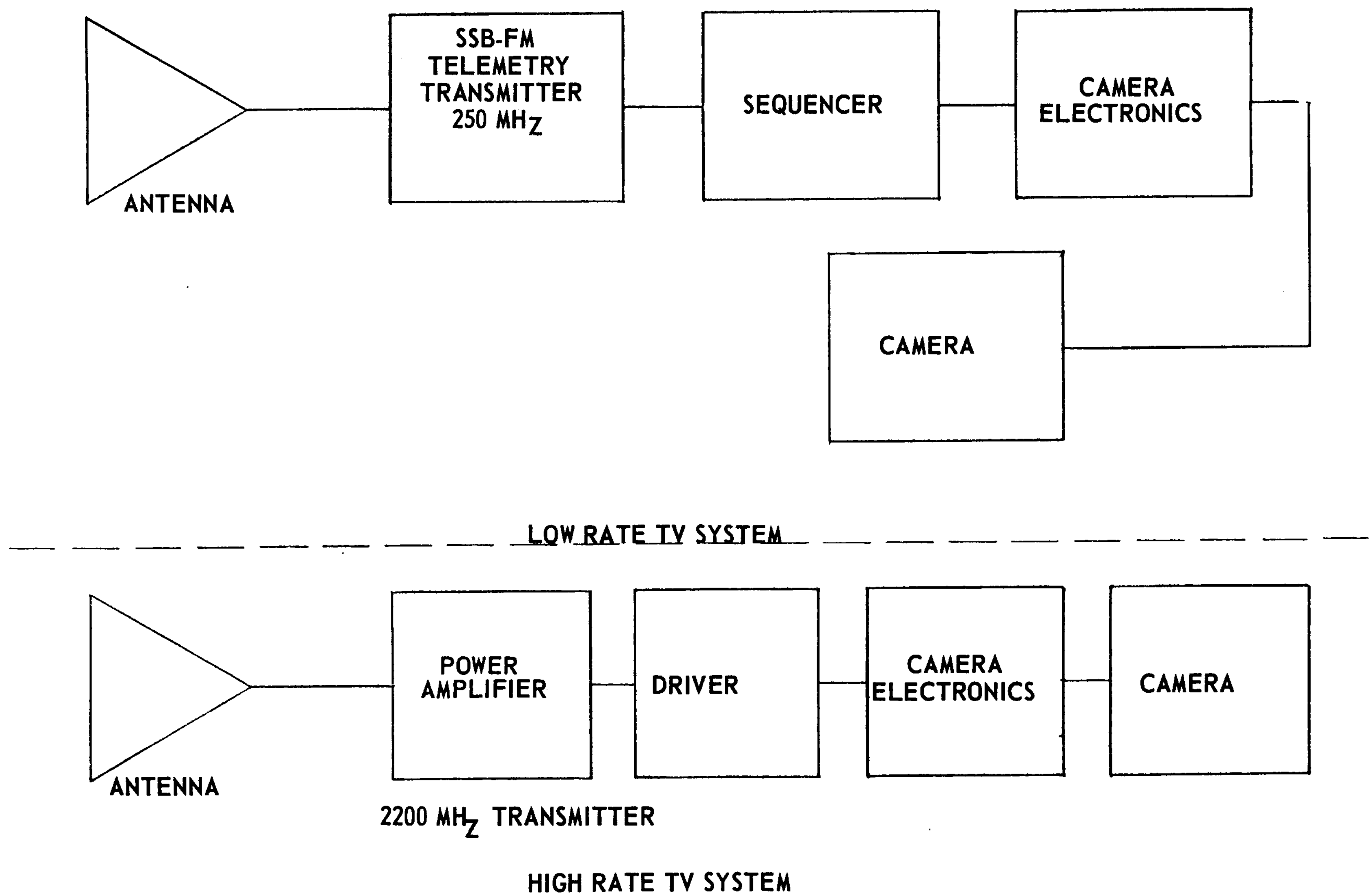


FIGURE 9-1 AIRBORNE TELEVISION SYSTEMS BLOCK DIAGRAM

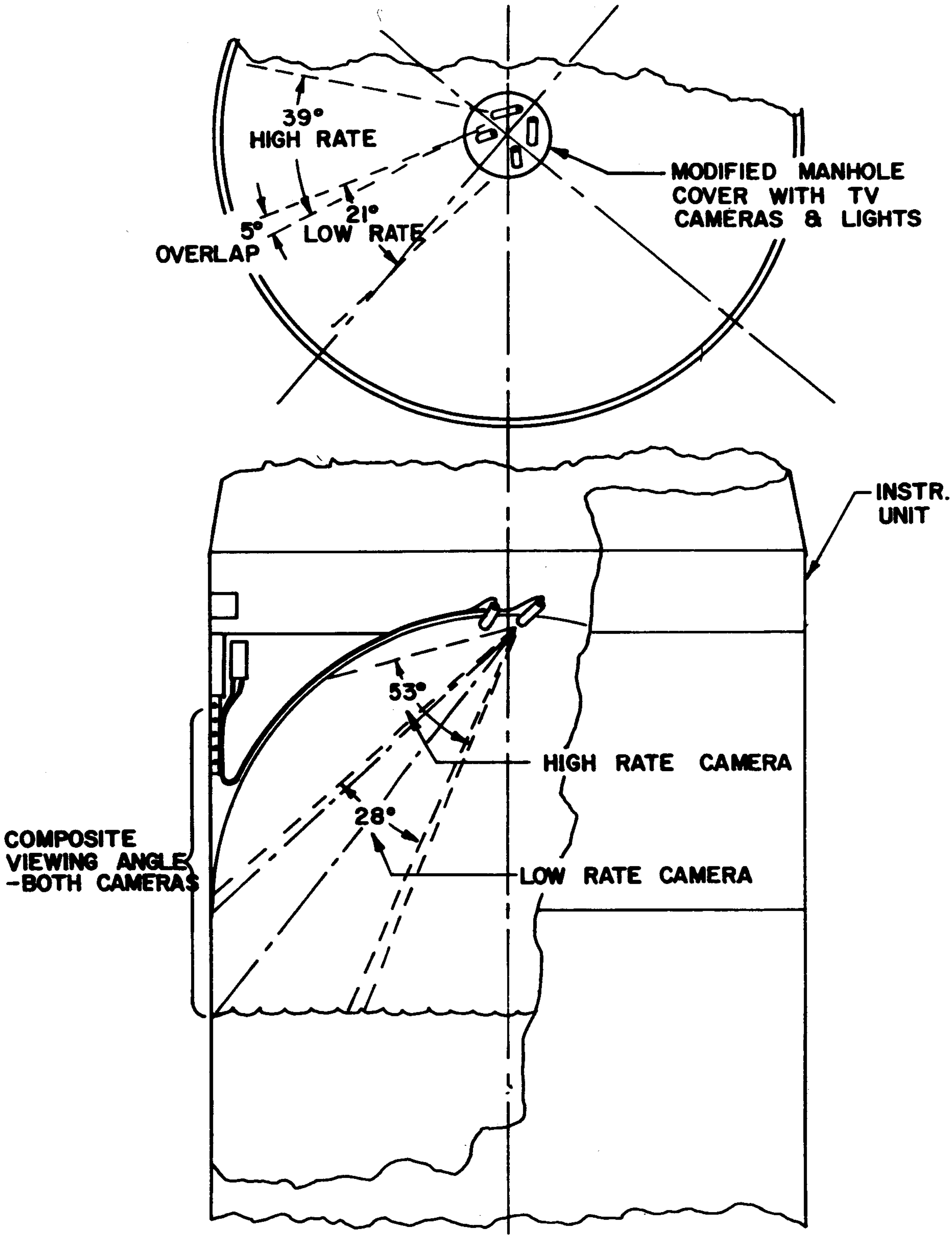


FIGURE 9-2. TV CAMERA AND LIGHT INSTALLATION

The ground television stations are shown in block diagram form in Figure 9-3.

The 250-mc stations required to receive the low-rate TV pictures are in existence. The 2200-mc stations required by the high rate TV system are planned and the 100% operational dates are given below:

Bermuda	November 1966
Hawaii	January 1967
KSC	February 1967
Guaymas	March 1967

For the purpose of this experiment, the entire station does not have to be operational. However, the 30-foot dish antenna and the receiver must be operational, and it may be necessary to speed-up the installation of these two items at each of the required tracking stations.

MSFC will supply a standard video tape recorder to record the receiver output of these stations. A real-time presentation of the 2200-mc receiver information will be available. The 250-mc system will use existing tracking stations used for receiving standard wideband telemetry. The receiver output will be recorded on standard wide-band telemetry recorders. No real-time presentation will be available for the 250-mc channels.

A tape-to-file converter will be used for data reduction. It will be located at MSFC. The low-rate video telemetry tapes from each station will be played into it. All synchronizing and photographic operations will be done by the converter. The output from the converter will be unprocessed 35 mm film roll. There will be no visual real-time low-rate display, but a Polaroid camera will be available to provide immediate hard copy when required. The high-rate video tapes will be made into 16mm, 30 frames-per-second movie films at MSFC for evaluation.

D. EXPERIMENT INSTRUMENTATION

Most of the present Saturn IB/S-IVB pressure and temperature instrumentation will be used to obtain data for the experiments; however supplemental liquid-vapor interface and temperature sensors in addition to the television systems will be required. Table 9-3 is a list of the required instrumentation and their priority. Locations of this

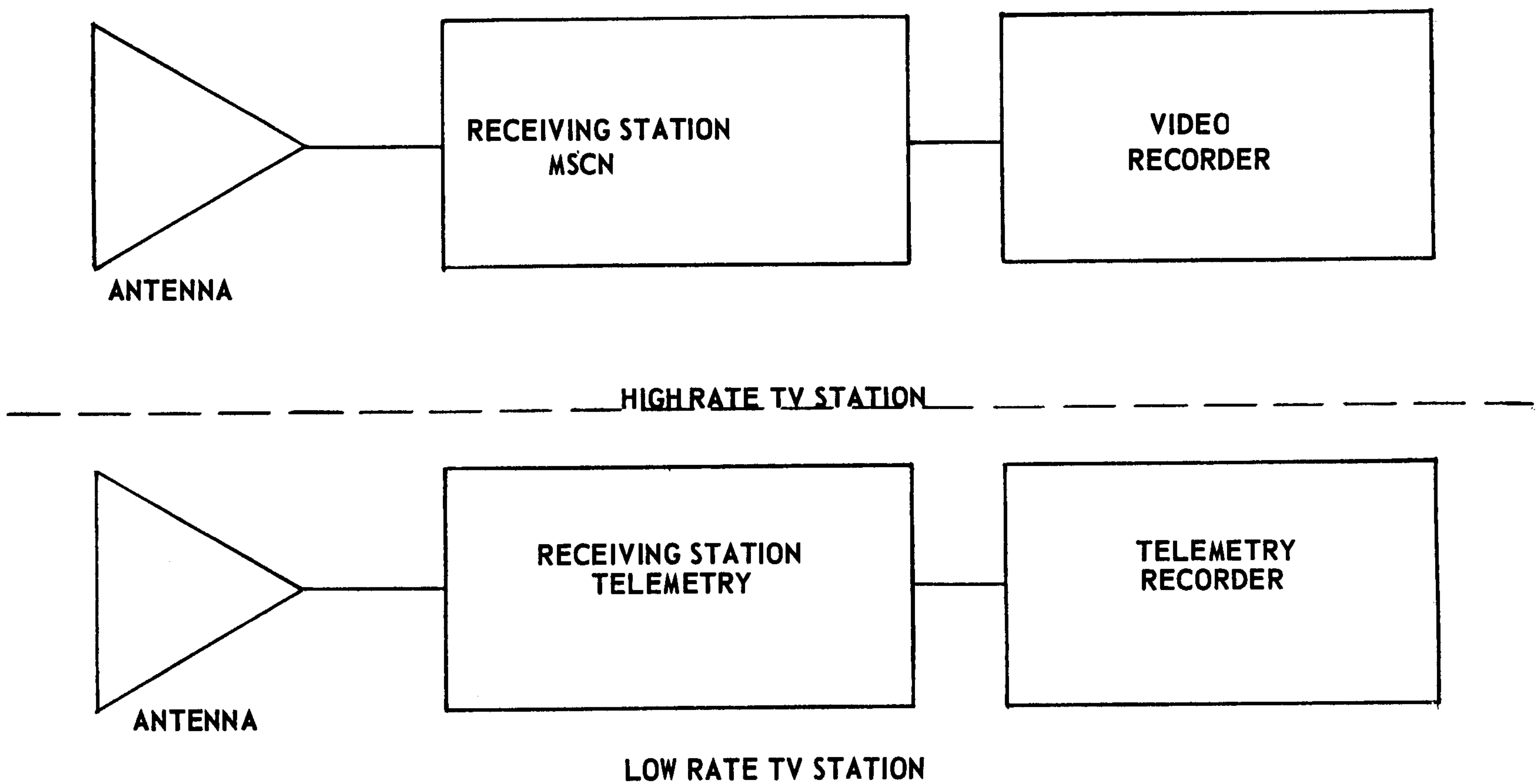


FIGURE 9-3 GROUND TELEVISION STATIONS BLOCK DIAGRAM

Table 9-3. Priority of Additional Installed Instrumentation

Priority	Objective	Instrumentation	Total
1	Verification of continuous vent system capability	Valve talkback	3
		Anti-vortex screen vapor removal	
		Liquid vapor sensor	1
		Temperature	1
		Liquid vapor separator RPM	1
		Main vent	
		Pressure	2
		Temperature	1
		Count of vent opening and closing	1
		Continuous vent	
		Pressure	2
		Temperature	1
		GOX ullage system	
		Pressure	2
		Temperature	2
		LH_2 ullage pressure	1
		Accelerometers (during orbital coast phase)	
		Longitudinal 10^{-5} g's	1
		Pitch, Yaw, Roll $\approx 10^{-2}$ g's	3
		Liquid vapor sensors (mounted on probe B)	4
		Helium repressurization bottle (ambient) performance	
		Pressure	1
		Temperature	1
		Total First Priority	28

Table 9-3 (Continued)

Priority	Objective	Instrumentation	Total
2	Recirculation system Performance	Temperature (located in engine area)	3
3	Observe tank fluid motions including shutdown transients	Ullage temperature	
		One on probe B and one on probe C	2
		Mounted internally in ullage shown at typical B-B cross section	2
		Mounted on forward dome opposite existing measurements CO 85-410 CO 86-410	2
4	Determine heat leak into liquid through sidewall and information concerning propellant thermodynamic model	Temperature	
		Mounted internally and externally at three stations shown as typical cross section A-A	18
		Stratification measurement mounted on probe B	6
		Boundary layer measurement mounted at two stations on probe B	8
		Total Through Priority 4	69

SECTION IX. EXPERIMENT INSTRUMENTATION

A. PURPOSE

The purpose of this experiment is to confirm the low gravity S-IVB stage venting system on the Saturn V/S-IVB, and to confirm chill-down of the J-2 engine. This entails observing the reaction of LH_2 during:

1. Engine shutdown at insertion
2. S-IVB stage ullage engine firing
3. S-IVB stage continuous venting
4. S-IVB stage high speed venting
5. J-2 engine chilldown
6. Second firing of S-IVB ullage engines for fuel settling
7. Second high rate S-IVB venting
8. Propellant sloshing due to attitude control motors.

These observations should show action of liquid/vapor separator, wall creep of LH_2 and turbulance of LH_2 when vents are operated.

B. TELEVISION REQUIREMENTS

The television camera will observe the liquid vapor interface during the experiment. Specific operations to be observed are engine shutdown at orbital injection, ullage engine firing, continuous venting, high speed venting, and liquid sloshing induced by attitude control motors. A test was conducted to determine the minimum satisfactory image resolution. Television pictures, with resolutions of both five hundred horizontal lines and two hundred horizontal lines were shown. A minimum resolution of two hundred lines was chosen for the television system outputs. The requirements of the TV portion of the experiment yielded three major points for consideration:

Table 9-3 (Concluded)

Priority	Objective	Instrumentation	Total
5	Common bulkhead heat leak and aft structural joint heat leak	Temperature	
		Internal and external shown as typical cross section A-A	6
		Common bulkhead in LOX and LH_2 tank shown as typical cross section B-B	4
		Center of common bulkhead - one in LOX and one in LH_2 tank	2
6	Other heat leak data	Temperature	
		Mounted externally opposite other temperature measurements given priority 3 and shown as typical cross section B-B'	2
		Mounted internally and externally on forward dome below structural joint and shown as typical B-B	4
		Total Additional Proposed Measurements	87*

* Additional Instrumentation Limited to Total of 75

instrumentation are shown in Figures 9-4 through 9-8. For the experiment to be meaningful all of the instrumentation listed through priority four should be installed. The other measurements are highly desirable but not mandatory. The exact type of accelerometer, liquid-vapor sensor, etc. is not specified but will be determined later by mutual agreement between MSFC and DAC. It will be necessary to evaluate each transducer (even the temps.) to determine their usefulness in a low gravity environment. The main problem anticipated is the entrapment of liquid in small crevices in the instrument thus giving false indications of liquid level.

A quality meter is under development by MSFC but the data needed for its consideration for inclusion in the experiment is not presently available. However, the quality meter has #1 priority and it will be installed later even if other, lower priority measurements must be deleted. Also, a device to determine whether or not vapor is entrapped in the anti-vortex screen is under consideration. Everything stated about the quality meter applies to this device.

Since no particular functions involving the LOX tank are planned, LOX tank instrumentation will consist only of the existing measurement program.

The additional measurements, with the exception of the TV system, will be handled in the same manner as existing measurements, regarding implementation and automatic checkout.

The electrical leads for measurements inside the liquid hydrogen tank will be brought out through an existing instrumentation feedthrough. DAC will have to change the pin connector configuration but will not have to perform any structural modifications.

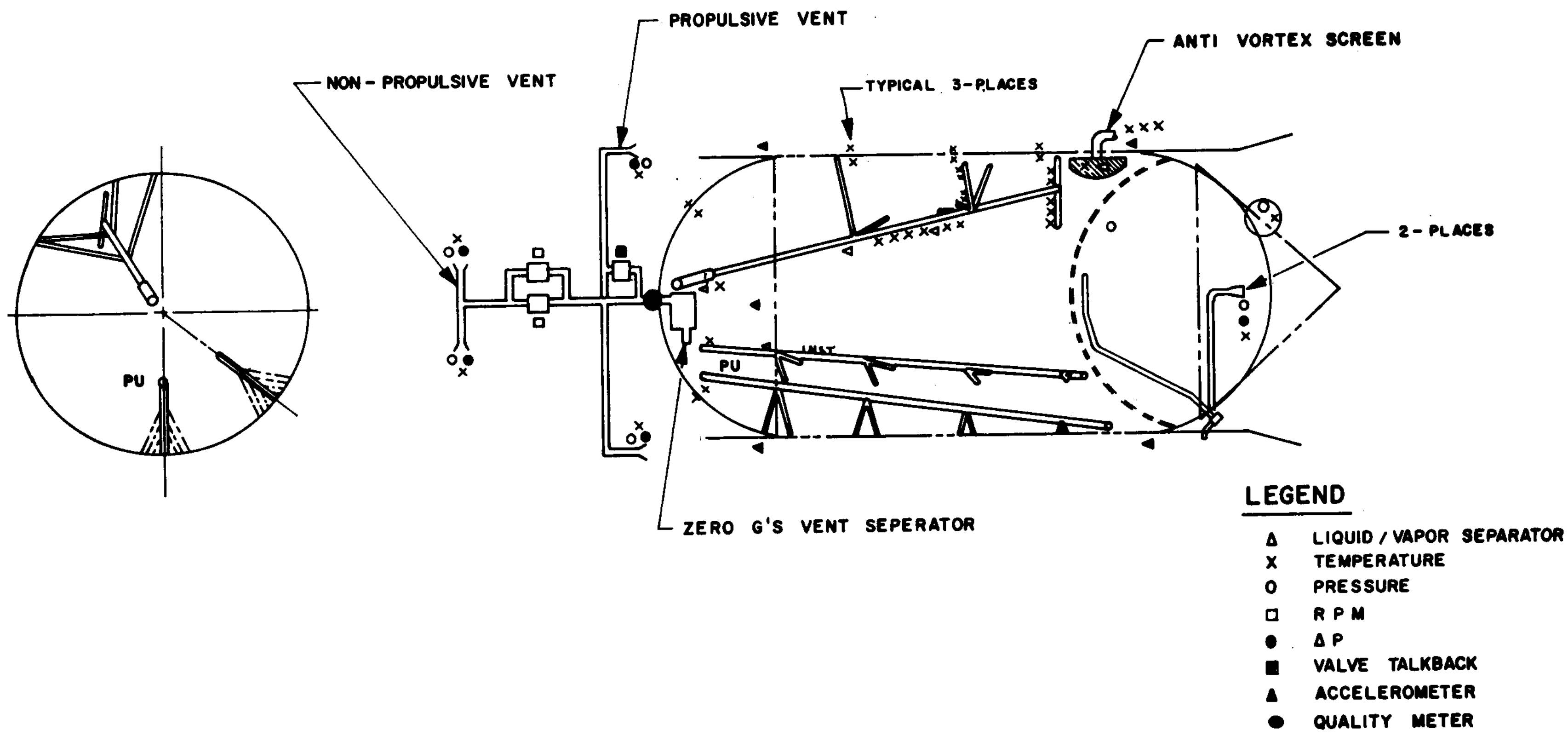


FIGURE 9-4. HYDROGEN TANK INSTRUMENTATION

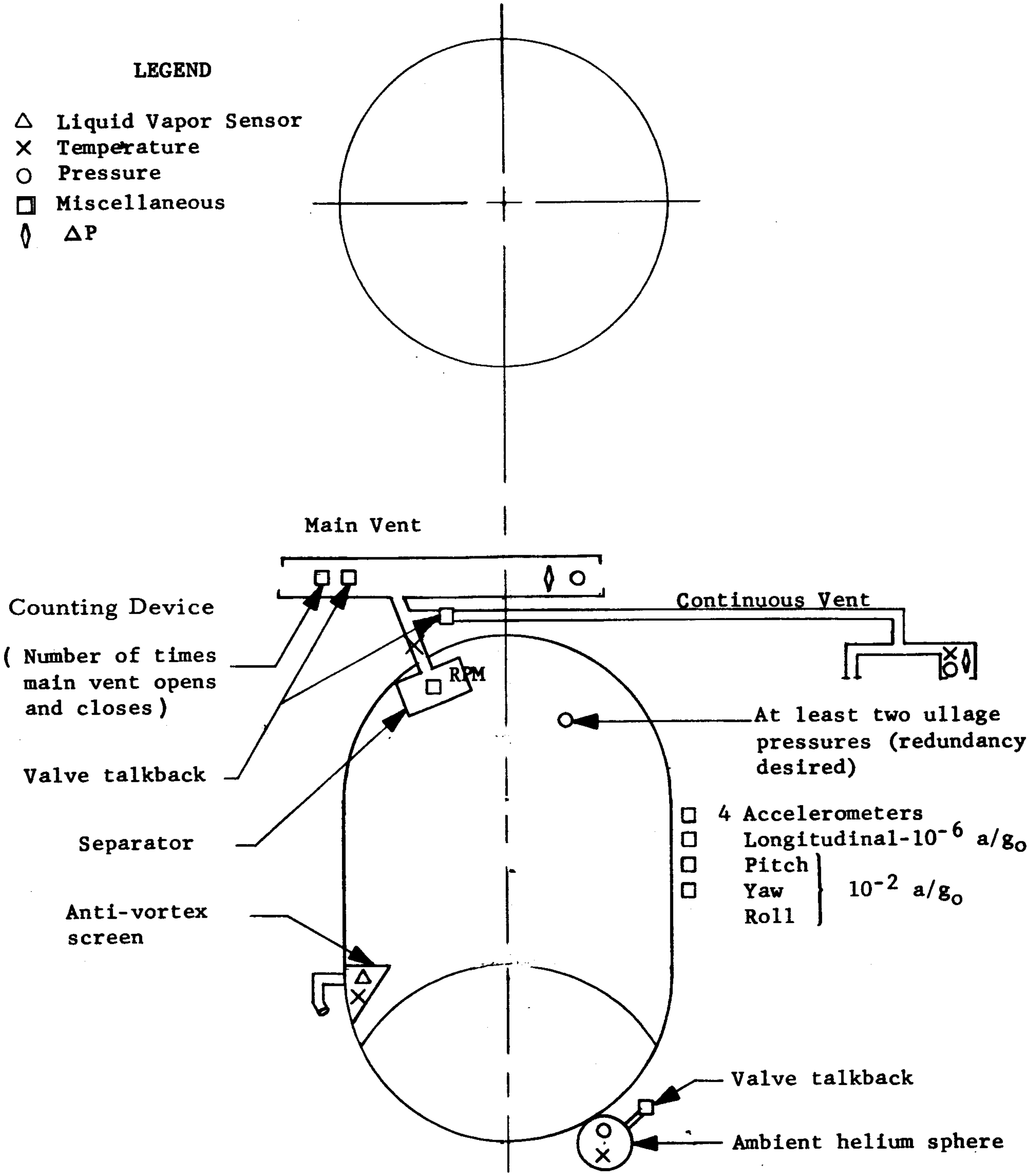


FIGURE 9-5. ADDITIONAL INSTRUMENTATION REQUIRED FOR SATURN IB ORBITAL HYDROGEN EXPERIMENT

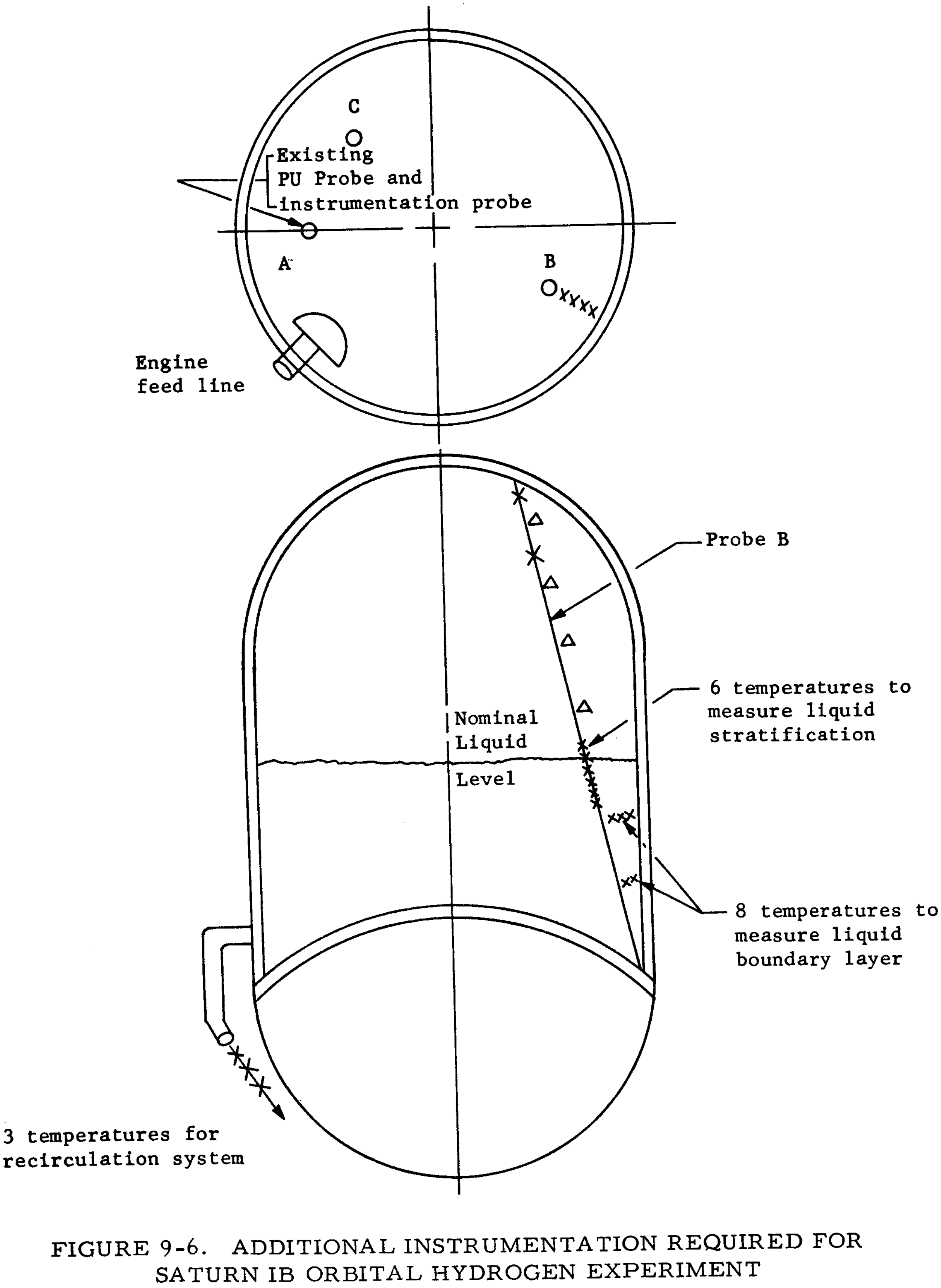


FIGURE 9-6. ADDITIONAL INSTRUMENTATION REQUIRED FOR SATURN IB ORBITAL HYDROGEN EXPERIMENT

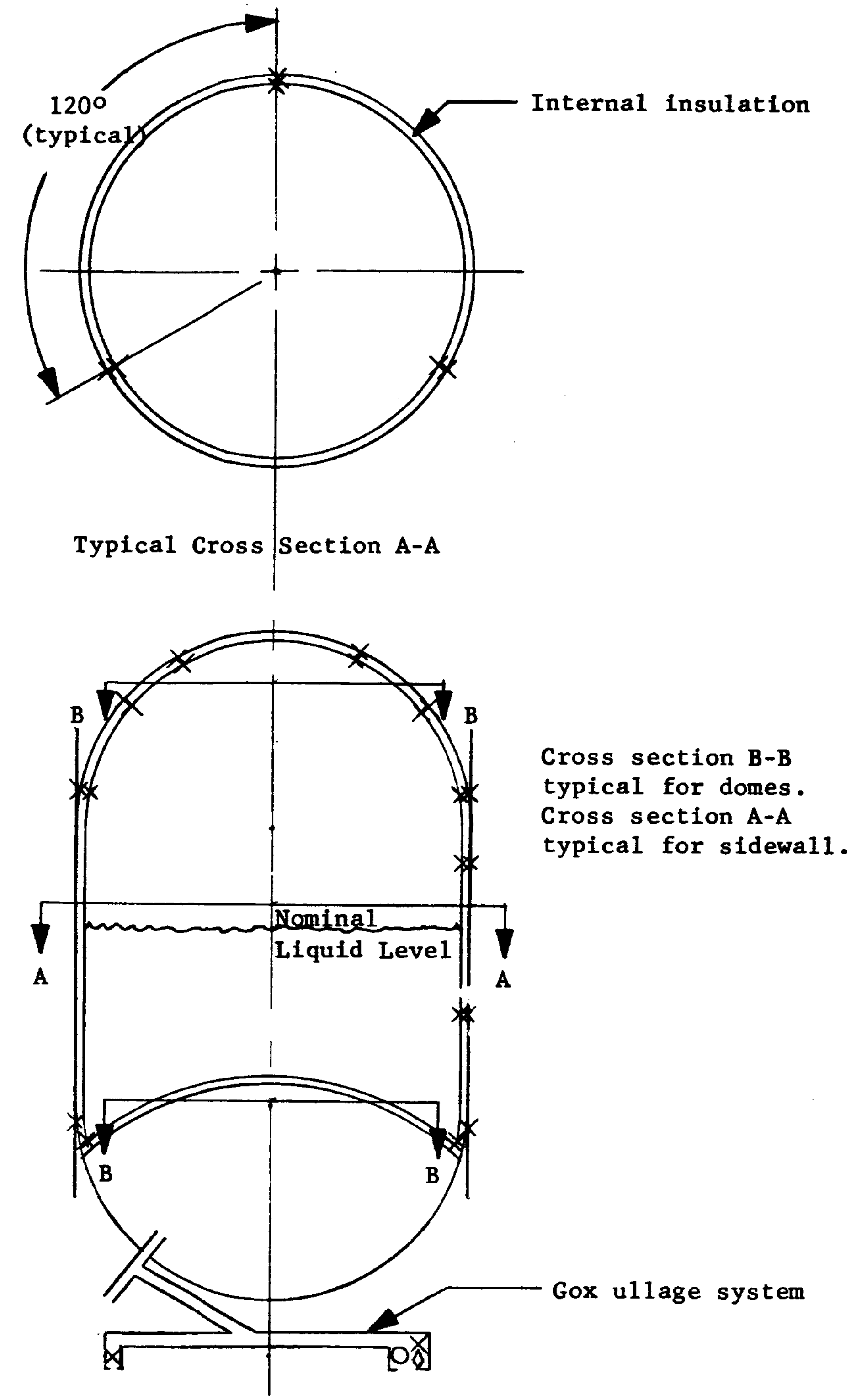
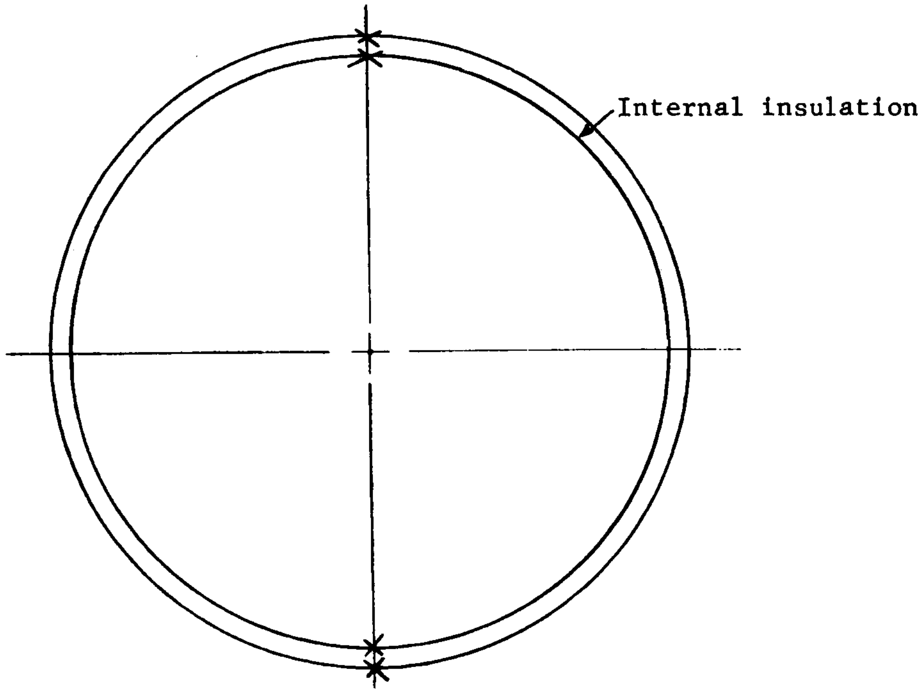


FIGURE 9-7. ADDITIONAL INSTRUMENTATION REQUIRED FOR SATURN IB ORBITAL HYDROGEN EXPERIMENT



Typical Cross Section B-B (See Figure 9-7)

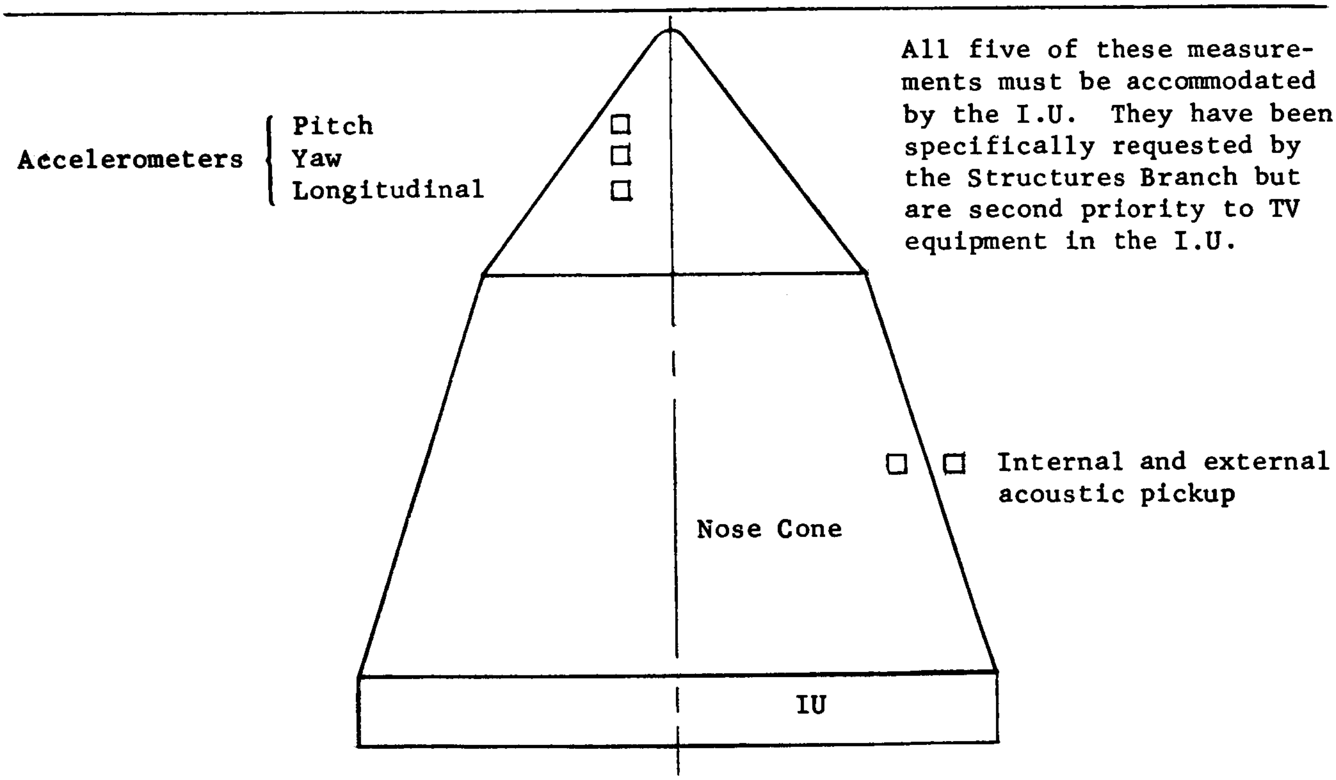


FIGURE 9-8. ADDITIONAL INSTRUMENTATION REQUIRED FOR SATURN IB ORBITAL HYDROGEN EXPERIMENT

E. TELEMETRY SYSTEM

Figures 9-9 through 9-12 contain the present channel loading information for S-IVB stage . They indicate that the forward multiplexer on link No. 1, as programmed, may accept fifty additional 12 samples-per-second measurements and five measurements sampled at 120 samples-per-second. It may be reprogrammed for 100 additional measurements at 12 samples-per-second. The "Checkout Only" multiplixer as indicated by Figure 9-9 is relatively empty and could accomodate many channels at 4 samples-per-second (not presently turned on during flight). Figure 9-11 and 9-12 show the aft mounted multiplexer loading. The unit on PAM link No. 2 has 4 open 12 samples-per-second channels. The unit on PAM link No. 3 has one prime 120 samples-per-second channel open, but may be reprogrammed and the channel assignment changed to provide 10 additional 12 samples-per-second channels. There is, therefore, more than adequate channel capacity forward and a total of 14 possible openings aft.

Figure 9-13 details the module space and decoder lines remaining on the various racks in all Saturn IB stages. Capacity at this point is limited by either space or line availability for automatic checkout. If we assume two spaces for temperature measurement (bridge module and amplifier) and a requirement for two decoder lines per measurement (20 and 80 per cent calibration), an approximate capacity figure per rack may be determined by using the smaller resulting figure. Following this procedure, it appears possible to mount 61 modules forward and 41 aft.

The composite capacity of the present telemetry system, considering both channel and space availability, is 75 measurements. This allows 61 measurements forward and 14 measurements aft. Measurements in addition to the 75 will require additional cold plates for the mounting of signal conditioning, amplifiers, etc. Additional measurements may be handled forward, without additional cold plates, if they are of a type not requiring signal conditioning or decoder lines for checkout i.e., potentiometer type transducers.

Telemetry system modifications are relatively few in number, primarily consisting of multiplexer programming to handle the eighty-eight new measurements and the possible activation of the "Check Out" or A3 multiplexer at liftoff.

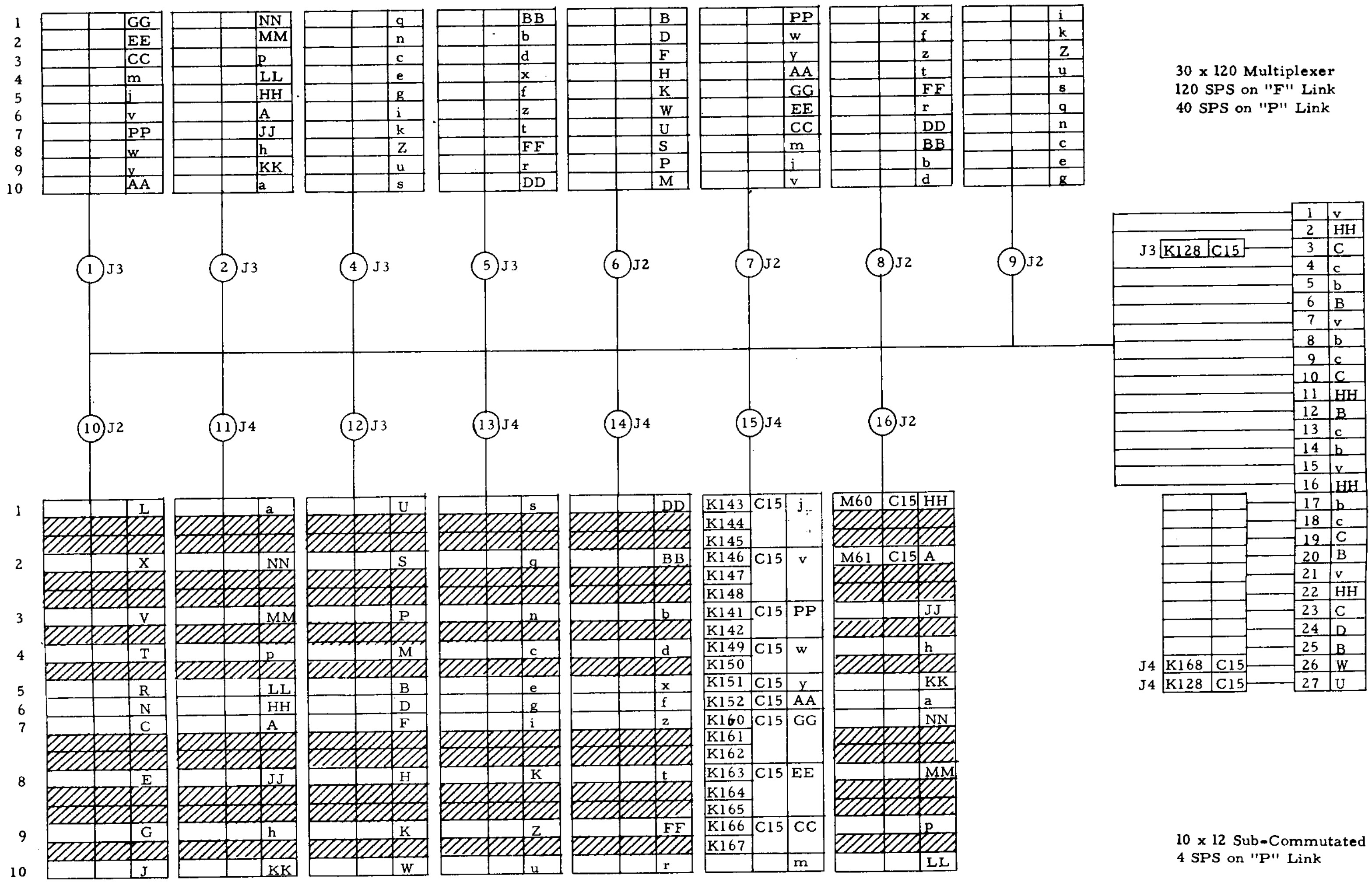


FIGURE 9-9. "CHECKOUT ONLY" MULTIPLEXER

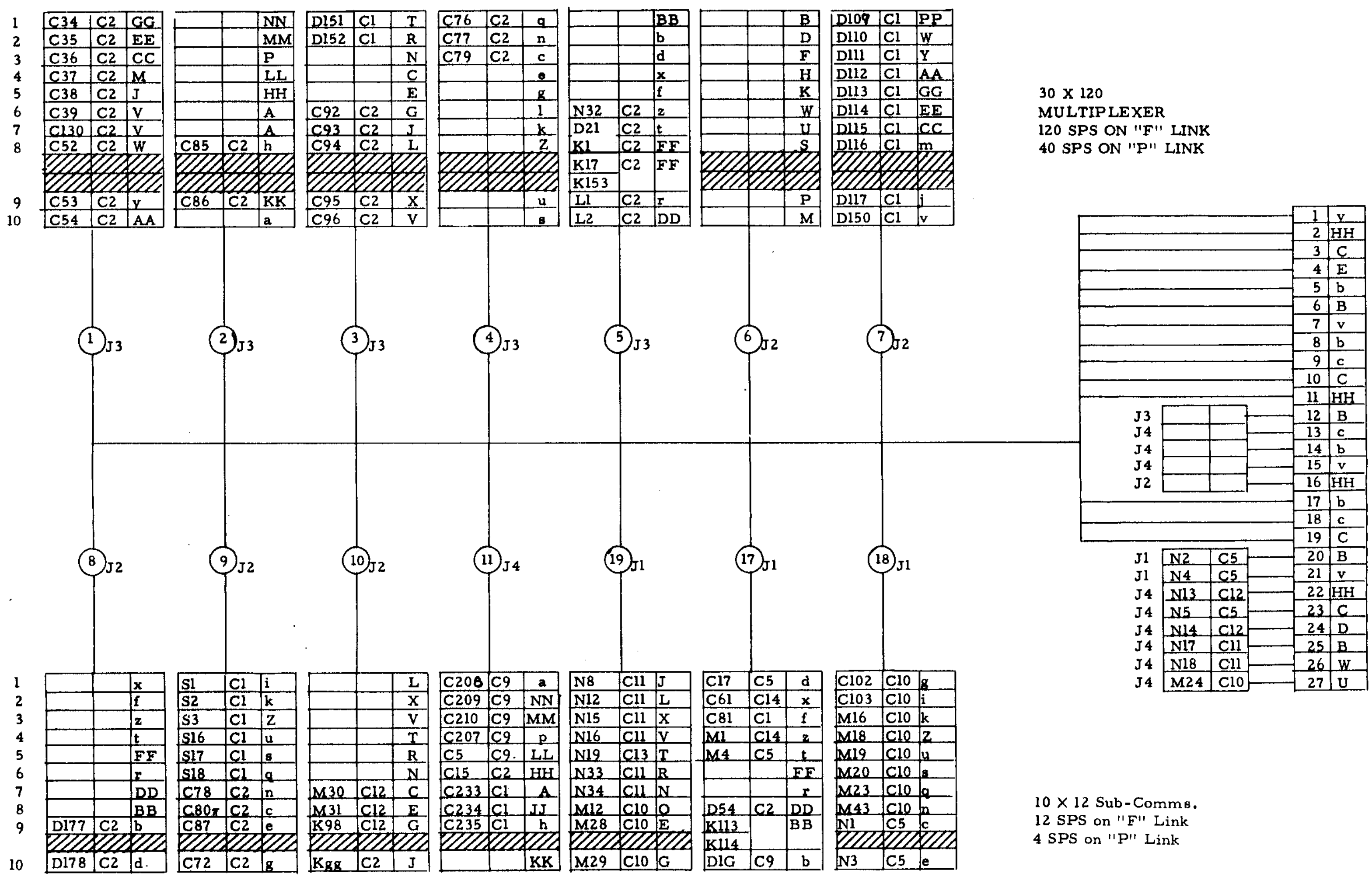
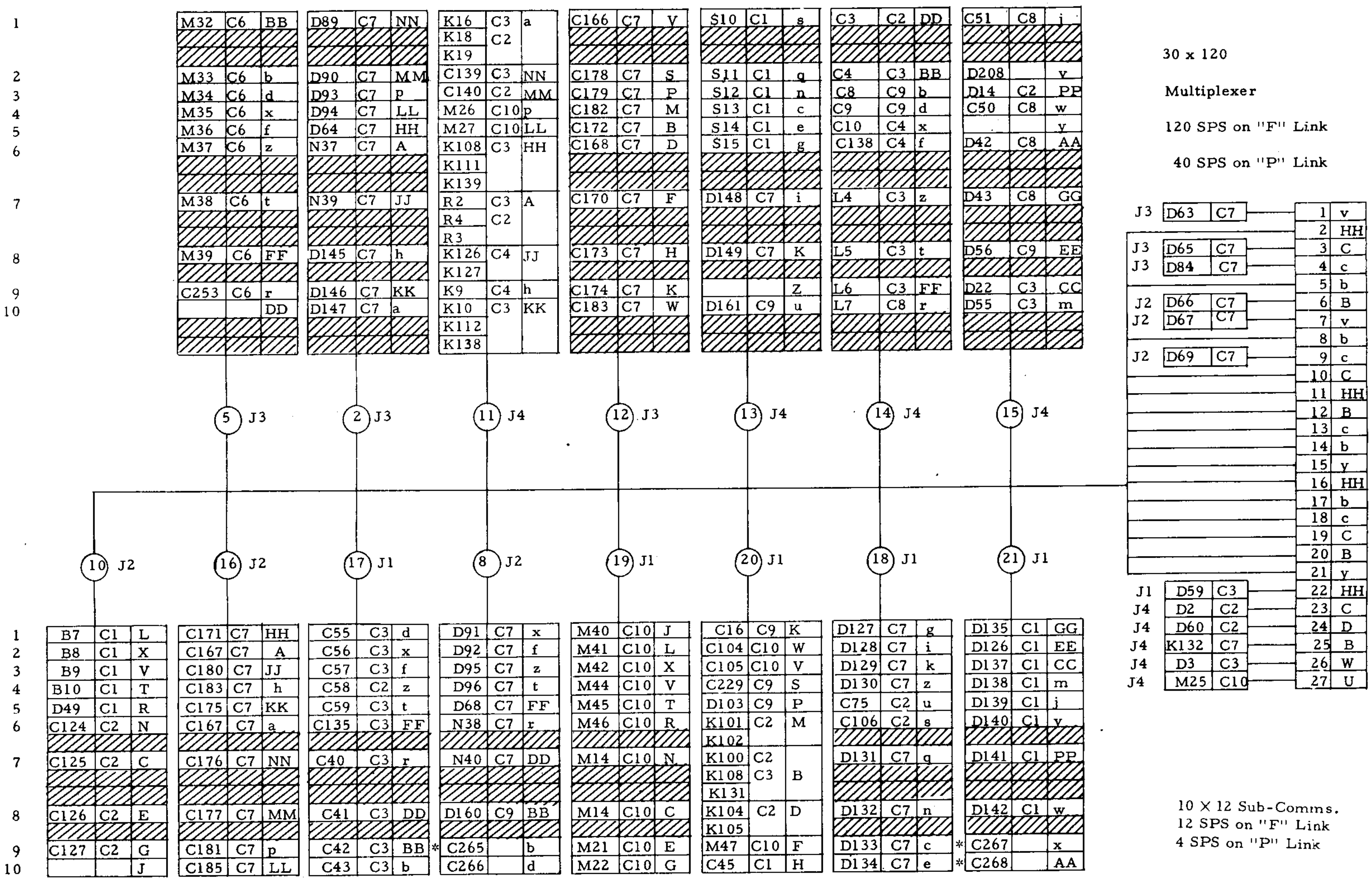


FIGURE 9-10. PAM LINK NO. 1 - LOCATED FORWARD



*Reserved

FIGURE 9-11. PAM LINK NO. 2 - LOCATED AFT

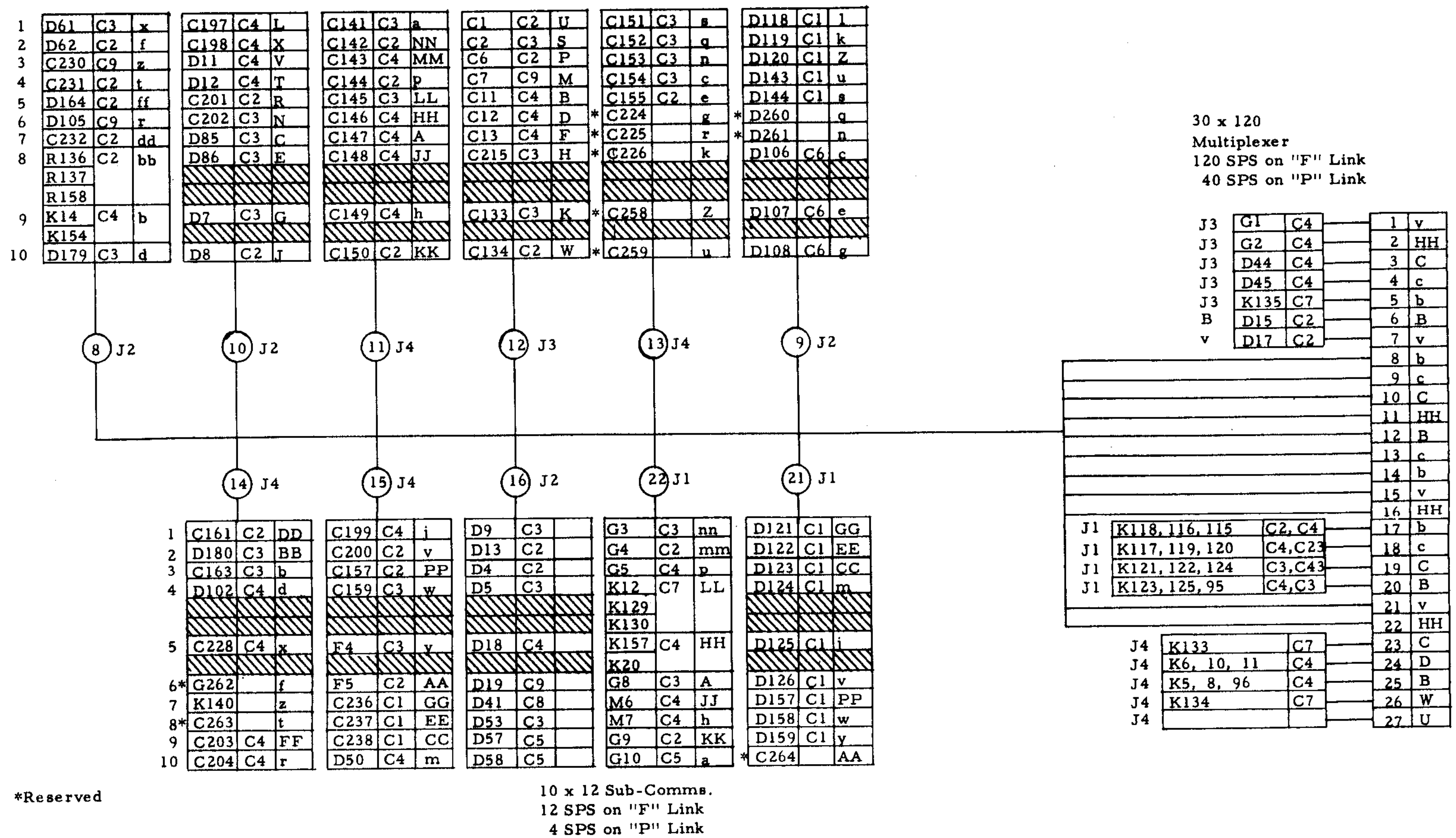


FIGURE 9-12. PAM LINK NO. 3 - LOCATED AFT

Aft Rack	Module Spaces				Decoder Lines			
	2001	2002	2003	2004	2001	2002	2003	2004
A	26	26	6	6	22	22	/	/
B	11	11	21	25	4	4	16	20
C	14	14	16	18	14	14	16	18
D	/	/	6	14	/	/	6	14
E	/	/	12	14	/	/	12	14
F	5	5	13	15	3	3	11	13
G	/	/	/	20	/	/	/	20
H	/	/	6	10	/	/	6	10
J	19	19	17	17	4	4	2	2
K	14	14	14	14	17	17	17	17

FWD Rack	Module Spaces				Decoder Lines			
	2001	2002	2003	2004	2001	2002	2003	2004
A	/	/	24	24	40	38	24	24
B	2	2	2	2	8	8	8	8
C	14	14	26	32	16	16	28	32
D	20	20	20	20	20	20	20	20
E	4	4	15	19	4	4	12	14
F	24	24	24	24	19	19	19	19
G	28	28	30	30	18	18	18	18

FIGURE 9-13. MODULE SPACE AND DECODER LINES AVAILABLE ON SIGNAL CONDITIONING RACKS

F. HYDROGEN EXPERIMENT - GENERAL COMMENTS

1. Space is available in the Instrument Unit to mount related electronic equipment for the TV System.

2. Ground commands will be required to perform the experiment. The Command System and the switch selector presently planned have the capacity to meet this requirement. All recommended ground stations have the command capability.

3. The Instrument Unit Telemetry System can meet the requirement to telemeter five measurements from the nose fairing. No impact on schedule, manpower, or cost is anticipated for work other than TV.

4. Tape recording in orbit is not a requirements but data is required on the number of vents that occur. This can be accomplished using a counting device.

5. The DAC feed-thru must be redesigned to accomodate the additional measurement requirements in the LH_2 tank. This will eliminate a requirement for a feed-thru in the manhole cover.

SECTION X. S-IVB STAGE MODIFICATIONS

A. PROGRAM PLAN

Douglas Aircraft Company will design, fabricate and supply MSFC a S-IVB stage modified to incorporate a Liquid Hydrogen Orbital Experiment. Figure 10-1 shows a schematic of the modified stage. The modifications and/or additions will consist of:

1. Continuous Vent System
2. Gaseous Oxygen/Helium Thrusting System
3. Liquid/Vapor Separator
4. Helium Sphere and Associated Plumbing
5. Liquid Hydrogen Tank Instrumentation Support Structure
6. Instrumentation (LH_2 Tank)
7. Battery
8. LOX Tank Baffle Modifications
9. Telemetry Modifications
10. Insulation on Forward Dome (LH_2 Tank)
11. Sequencer Modifications

These modifications and/or additions will require the following engineering effort:

1. Prepare specifications for the following:
   a. Liquid/vapor detectors
   b. Accelerometer to measure 10^{-5} g
   c. Instrumentation feed-thru (new configuration)

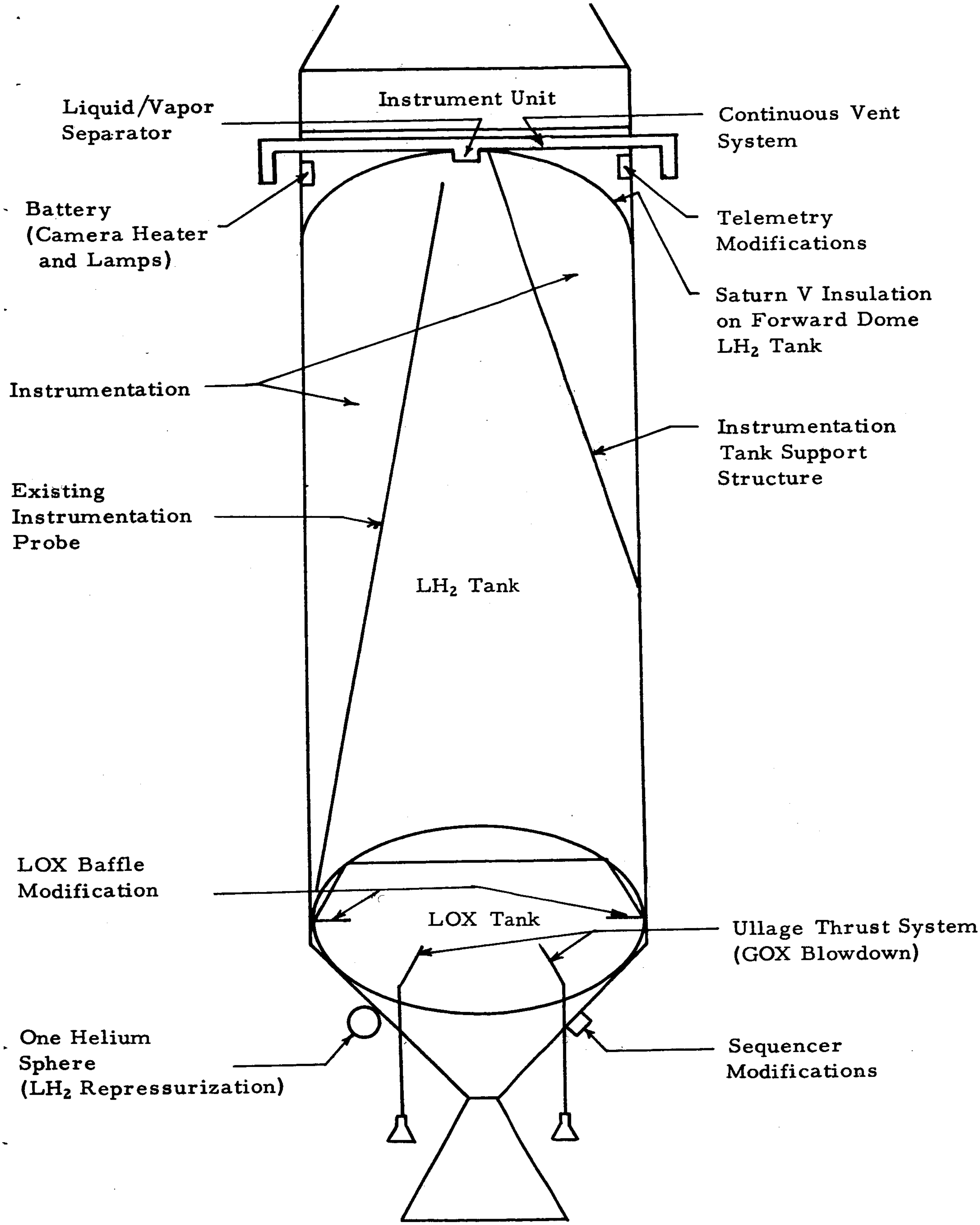


FIGURE 10-1. MODIFICATIONS TO S-IVB FOR LIQUID HYDROGEN ORBITAL EXPERIMENT

2. Prepare layout, installation and detail drawings for:

a. Propellant Tank Repressurization System

b. Hydrogen Tank Instrumentation Support Structure

c. LOX Tank Ullage thrusting system

d. LH_2 continuous vent system

e. LH_2 Tank Instrumentation Routing and Feed-thru

f. Ullage Thrust Nozzle Support

3. Prepare layout, installation and rework drawing for:

a. Forward Dome Ring (Support Clip Attach)

b. Battery Installation

c. LOX Tank Baffle

d. Continuous Vent Support Structure

4. Prepare rework drawing for insulation on forward dome and aft dome

5. Prepare installation drawing for insulation on forward dome - LH_2 tank

6. Modify drawing 1A39322 (Tank Components Installation, Main Fuel (Saturn V) - Installation Drawings and Detail Drawings) to add liquid/vapor separator, continuous vent lines, thrust nozzle (resized) and support shut-off valve (pneumatic), actuation control module, pneumatic control plumbing and support

7. Prepare Network Control Drawing (top schematic book, cable network diagram, advance functional schematics) for:

a. Continuous vent system

b. LOX tank ullage system

c. LH_2 tank repressurization system

d. Camera/light purge

8. Prepare instrumentation drawings for the connection of transducers within an external to the LH_2 tank, suction line inlet, vent system, recirculation system to their signal conditioning and/or telemetry system. This will consist of:

a. Electrical Schematics - Control System

b. Cable Networks

c. Sequence Diagram

d. Advanced Functional Schematics

e. Test Requirements Drawings

f. Power Distribution Design Requirements Drawings

9. Prepare Mechanical Installation Drawings for:

a. Temperature and pressure transducer installation on helium sphere and for repressurization system

b. Transducer installation - continuous vent system

c. Transducer installation - main vent

d. Accelerometer installation - LH_2 experiment

e. Harness installation - signal conditioning racks, forward

f. Harness installation - signal conditioning racks, aft

10. Modify existing electrical and mechanical installation drawings

a. Wiring installation - patch external

b. Wiring installation - probe internal (LH_2 tank)

c. Battery installation - forward

d. Hole installation - forward skirt

e. Instrumentation installation - panel mounted forward

f. Instrumentation installation - panel mounted aft

g. Ground plane installation - forward

h. Ground plane installation - aft

i. Electrical equipment installation - panel mounted forward

j. Electrical equipment installation - panel mounted aft

k. Rack assembly forward signal conditioning

l. Rack assembly aft signal conditioning

m. Sequencer assembly

n. Control distribution, forward

o. Control distribution, aft

p. Power distribution, 28 volts, aft

q. Power distribution, 28 volts, forward

r. Harness installation - forward skirt

s. Harness installation - aft skirt

t. Harness installation - tanks

u. Harness installation - sequencer

v. Harness installation - forward control distribution

w. Harness installation - aft control distribution

x. Harness installation - 28-volt aft power distribution

y. Harness installation - forward power distribution

11. Design and construct one piece of additional electrical ground support equipment (LH_2 tank TV monitor) to utilize DAC and GFE items. This will require the following engineering effort:

a. Prepare design requirements drawing

b. Prepare cable drawing

c. Prepare top assembly drawing, schematics, and wire diagrams

d. Prepare detail drawings of DAC items

e. Generate functional and EMC test documents

f. Prepare new GSE drawings required to install GFE items

12. Perform programming and patching changes to the automatic checkout equipment to provide:

a. Command and monitor response of gaseous oxygen ullage thrusting system valve

b. Command and monitor response of continuous vents

c. Ground power and monitoring for camera heater and lamps

d. Battery load tests

e. Command for forward buss 3 internal-external switch

f. Monitoring for forward buss 3 (DDAS or hardwire)

g. Strip out and programming of additional instrumentation

h. Camera control power during checkout and static firing

i. Checkout procedure for additional harness and equipment installed at Huntington Beach

13. Provide checkout procedure to checkout experiment-peculiar hardware

14. Generate drawing release schedules, task plans and job drawing list

15. Prepare and issue procurement instructions for slow delivery items including:

a. Liquid/vapor detectors

b. Pressure transducers

c. Accelerometers

d. Instrumentation feed-thru

e. Battery

f. Liquid/vapor separator

g. Ambient helium sphere

16. Prepare and issue memo releases for:

a. Saturn V insulation for LH_2 dome

b. Feed-thru port (instrumentation)

17. Prepare measurement request drawings for additional instrumentation

18. Perform required test planning and requirement evaluation of experiment-peculiar hardware

19. Perform design evaluation testing on experiment peculiar hardware

20. Perform electrical load analysis for battery sizing

21. Analyze the effect of higher "g" loading on cylinder walls, common bulkhead, aft dome, and thrust structure

22. Perform design analysis on ullage thrust simulation system

a. Simulate 70-pound Gemini ullage engine "g" levels at orbiting weight of Saturn IB using LOX tank ullage gas as an energy source

b. Determine optimum system control and thrust histories

c. Determine mass flow rates and LOX tank ullage pressure histories that are consistent with required simulation of Saturn V duration, yet do not deplete LOX tank ullage pressure so as to endanger the common bulkhead

d. Perform design analysis to size necessary system hardware

e. Determine probable vent thrust unbalance

23. Perform design analysis on hydrogen tank blowdown system

a. Check line and orifice sizes to insure that Saturn V pressure histories are accurately represented

b. Determine need for aft facing exit nozzles to replace thrust lost from continuous venting system as a result of being partially starved out during blowdown process

c. Determine probable vent thrust unbalance

24. Perform design analysis on hydrogen tank continuous venting system:

a. Check line and orifice sizes to insure that Saturn V pressure histories are accurately represented

b. Check item 23. a. above with respect to simulation of Saturn V orbital acceleration levels during continuous venting. Determine need for necessary system modification to satisfy both requirements, i.e., correct pressure levels and acceleration levels

c. Determine probable vent thrust unbalance

25. Perform design analysis on hydrogen tank repressurization system

a. Determine pressure level that will be obtained during hydrogen tank repressurization from one 4.5 $ft.^3$ helium bottle

b. Perform design analysis on system to determine hardware requirements, line sizes, etc.

26. Determine optimum instrumentation locations and number of measurements required to obtain maximum useful system performance information relative to orbital venting blowdown, repressurization, restart, shutdown impulse control, settling time, recirculation chilldown, and thrust levels

27. Provide necessary design analysis coordination with MSFC on design analytical items

28. Perform design analysis on auxiliary propulsion system

a. Determine APS adequacy for this experiment, including required impulse to obtain desired maneuvering, attitude control, and control of various impulse unbalances from the various vent system

29. Provide analytical support of propellant loadings by analyzing open loop EMR and flow rate variations to determine hydrogen residual in orbit

30. Perform design analysis to insure that the experiment will adequately simulate the Saturn V mission with respect to flight behavior, pressure histories and effect of heating on propellants when considering differences in orbiting weight, hydrogen liquid levels, accelerations due to APS control, e.g., shifts and differences in LOX boiloff rates

31. Perform Aerodynamic analysis

a. Analysis of protuberance airloads

b. Analysis of vehicle aerodynamic loads

c. Analysis of forward and aft interstage venting requirements

32. Perform structural heating analysis

a. Analysis of aerodynamic heating effects on basic structure

b. Analysis of protuberance heating effects on fairings and in the surrounding regions

c. Analysis of plume heating effects based on hotter structural temperatures established in 3. a. and 3. b.

d. Determination of insulation requirements based on 3. a., 3. b., and 3. c.

33. Perform propellant heating analysis

a. Determination of the boost phase heat input into propellant tank through tank walls, forward and aft bulkhead and heat shorts

b. APS propellant temperature analysis

c. Analysis of ullage rocket propellant grain temperatures and temperature gradients during ground hold and boost

d. Determination of propellant conditioning requirements (active ground conditioning, fairing external surface coatings, insulation, etc.) based on 32. c.

34. Perform component heating analysis

a. Analysis of selected components such as the antennas during boost and orbit

35. Perform LOX sloshing analysis in order to insure 3 per cent damping effectiveness through LOX tank baffle modification

36. Construct or simulate the trajectory required to achieve the mission conditions

37. Provide assessment of the vehicle dynamic response characteristics in order to insure adequate control, to obtain angle-of-attack histories for inputs to airload calculation, analyze zero - g sloshing and to insure satisfactory performance of the APS system for this mission

38. Perform an evaluation of the S-IVB performance characteristics as affected by the employment of employing an open loop P.U. system

39. Perform S-IVB stage separation dynamics

40. Perform stage bending and sloshing analysis

41. Perform a stress analysis on the main propellant tank, ambient helium bottle installation, rework for additional battery in forward skirt, LOX tank baffle rework, forward skirt rework for continuous vent

42. Perform weight estimates for evaluation of weight effects on performance and cost

43. Maintain detailed weight records on experiment peculiar hardware

44. Conduct a Quality Control effort in accordance with the applicable portions of SM-41891, as defined in Section XIV

45. Conduct a Reliability effort in accordance with the applicable portions of SM-46644, Formal Reliability Program Plan, as defined in Section XIV

46. Provide the technical documentation specified in Section XI

47. Perform postflight data evaluation and correlation

The modification to the S-IVB stage and the electrical ground support equipment will require the following manufacturing effort:

1. <u>Planning</u>

a. Prepare and issue Planning paper for detail parts, subassemblies, assemblies, installations, production acceptance testing and checkout procedures

b. Issue the orders per detail and installation tools, production data sheets and production test equipment

c. Maintain support effort

2. <u>Manufacturing Engineering and Design</u>

a. Provide support for Planning, MR&PM, Plant Engineering for tooling and facility requirements

b. Prepare sketches, flow charts

c. Provide expeditious handling of tools and equipment

d. Prepare tool design, tool data sheets and production data sheets

3. <u>Production Test Engineering</u>

a. Provide Support Planning, MR&PM, Plant Engineering for tooling and facility requirements

b. Provide production data sheets and production test equipment design for checkout of wiring, components and systems electrical/ electronic components requiring receiving functional testing includes wire harnesses modules, pressure transducers and wire feed thru fitting. Structure details which require testing or calibration include nozzles, tubing, helium sphere and valves

4. <u>Tool Fabrication</u>

Fabricate, assemble, and inspect tooling and production test equipment. Installation tools for battery brackets and probe support brackets will require use of single installation tools

5. <u>Manufacturing</u>

a. Fabricate, assemble and inspect metal components. These items include probe structures, vent and ducts, and miscellaneous sheet metal parts

b. Fabricate, assemble and/or modify and check out electrical and electronic assemblies, such as signal conditioning modules with welded modules and printed circuit boards

c. Install metal details and assemblies, and electronic and electrical assemblies

d. Fabricate details, assemble and/or modify and check out GSE required

e. Modify existing structure and electrical and electronic components of vehicle to conform to new configuration

f. Check out modified vehicle

B. MODIFICATION INSTALLATIONS

The installation of details and assemblies for the modification will take place, schedule permitting, at the Santa Monica and Huntington Beach facilities. Those components which cannot be manufactured or provided in time for installation on the line or at Huntington Beach will be installed at Sacramento Test Area. Major installations to be made for this modification program are discussed below:

The Probe installation, for instrumentation, consists of one main tube, braces to support, and fittings for attachment to tank walls, and manhole cover flange. The side fittings are attached to the tank walls with welded studs, on the helium bottle support pads. The stud locations are determined by use of an installation fixture. The upper fitting on the manhole flange is located dimensionally. The clips and fittings for the probe installation are installed prior to cleaning of tank. The internal insulation will require modification to provide clearance for these installations. After installation of insulation, the probe and its braces are installed, in the LH_2 tank, concurrently with the propellant utilization and instrumentation probes at the Huntington Beach facility.

The helium bottle support is installed on the thrust structure assembly using an installation fixture. This work is accomplished at the Huntington Beach facility prior to the thrust structures installation on the tank.

The manhole cover assembly is the responsibility of Marshall Space Flight Center for fabrication, assembly, testing, and shipment to Sacramento Test Operations (SACTO). The Missile and Space System Division at Huntington Beach will use an existing tool as a dummy cover for hydrostatic testing of tank and an interim cover will have to be provided until the MSFC supplied cover is installed at SACTO.

The new battery brackets will be installed by use of a simple installation fixture and is accomplished at Huntington Beach after completion of forward skirt structure assembly and prior to structure installation on tank.

The anti-slosh baffle installation consists of miscellaneous clips and formed sheet metal baffles and is installed in the LOX tank at Huntington Beach. This structure can be located dimensionally and is accomplished prior to LOX tank being joined to cylindrical and forward dome sections.

The aluminized mylar insulation is installed on the forward dome at Huntington Beach and requires only layout templates. This insulation is bonded to the forward dome and is cured at room temperature. Special tools or facilities are not required. This insulation is installed while tanks are in tower prior to forward skirt installation.

The modification of the forward skirt for installation of vent system is accomplished at the Sacramento facility. Existing vent holes in the skirt structure are utilized and new nozzles and fairings are installed. The propulsion subsystem details and components will be installed at Huntington Beach as final assembly modification type work. These systems will be given final tests and checkout prior to shipment of vehicle to the Sacramento facility.

C. STRUCTURAL MODIFICATIONS

The structural modifications for the LH_2 experiment consist of a probe assembly, additional baffle ring and miscellaneous clips and bracketry for mounting the added battery and helium bottle. These components are manufactured using a "no tool" philosophy due to the quantity of articles being produced.

The probe assembly consists of approximately one 40-foot length of standard 3-inch aluminum tubing. This provides the main support to which are attached brackets which locate and hold the sensing units. Also, attached to the tube are four arms that provide a lower end support. These four arms are fastened to a bracket which is located on the tube and to the tank by bolting in the area of the helium bottle pads. The upper end of the support is secured to the manhole attach flange by pinning through the bracket and tube. The above items will be manufactured using standard shop equipment as table saw, power brake, standard punch press dies, a lathe and a mill in conjunction with common shop techniques. Subsequently, a continuity check, visual inspection, and LOX cleaning are performed prior to installation.

The added baffle assembly is manufactured similar to the existing baffle. It is made of sheet metal using shears, rolls, and standard punch press tooling. In addition a contour template will be required. After a visual inspection, the baffle is shipped to the LOX Tank Assembly area for installation.

The battery brackets and helium bottle brackets will be made from standard extruded stock or formed sheet metal. Standard sheet metal shop equipment as a shears and saw, power brake, and a drill press will be used to manufacture these components. After inspection, primer and paint, the brackets are shipped to final assembly area. A layout template for each set of brackets will be required.

The mylar insulation is hand cut and fitted to the forward end of the LH_2 tank. After the prefitting operation, a room temperature curing adhesive is applied to the mylar and it is located on the tank. A layout template is used for cutting the mylar section.

D. LOX BAFFLE MODIFICATION

The LOX tank will be off-loaded to meet the mission requirements, the present baffle rings will be ineffective. An additional anti-slosh ring will be installed at DAC station 254.000 and will be approximately 24 inches in width (see Figure 10-2). The ring will be reinforced with gussets as required to support the expected 0.3 psi slosh loading. To maintain present installation schedules, the additional baffle ring must be added by reworking the present baffle after installation in the LOX tank. The ring must necessarily consist of many small segments spliced together inside the tank in order to allow passage of the pieces through the thrust structure access door and the LOX sump jamb (28 inches in diameter).

E. LH_2 TANK INSTRUMENTATION SUPPORT STRUCTURE

A LH_2 tank instrumentation support structure is required to provide the required locations for mounting the liquid/vapor detectors

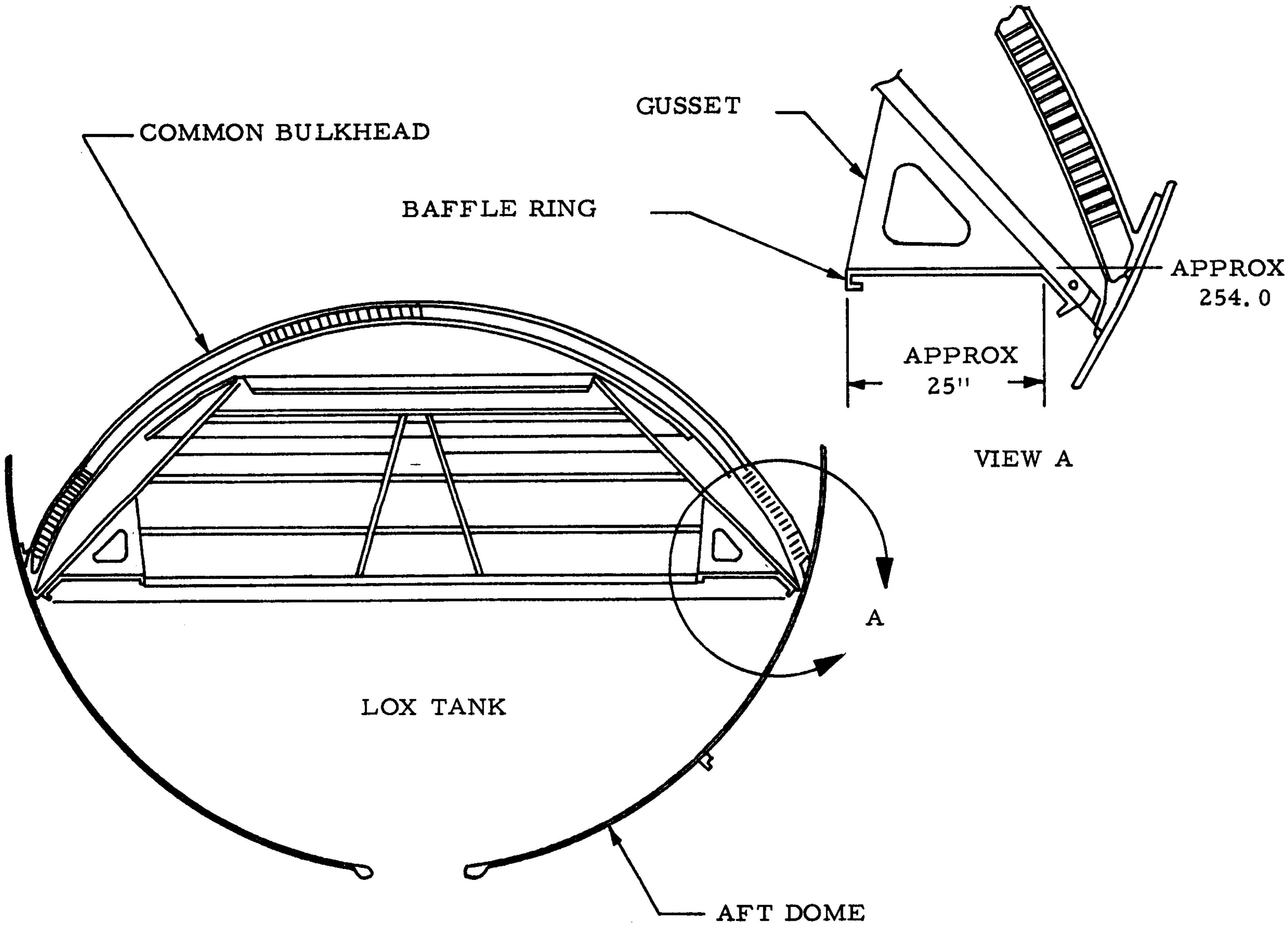


FIGURE 10-2. MODIFIED BAFFLE FOR LIQUID HYDROGEN ORBITAL EXPERIMENT

and pressure transducers. A third probe similar to the existing instrumentation probe will be installed approximately 180 degrees from the existing instrumentation and propellant utilization probes (see Figure 10-3).

One fitting with a monoball to support the forward end of the probe will be bolted to the forward manhole cover jamb using inserts. Two to four holes will be drilled and tapped into the aft side of the jamb for the installation of the inserts. The installation of the internal insulation will be trimmed to clear the fitting. Also at the heavy area at the intersection of forward dome and the LH_2 cylinder, two clips will be installed by means of percussive welded studs. The insulation will be modified to fit around the fittings. These fittings will be required to provide intermediate support of the probe. The aft probe support mount will be a tripod arrangement anchored to the tank by welded brackets similar to those provided for the cold H_e bottle strap clevises. These anchor brackets will be welded to raised pad areas existing presently as spare cold H_e bottle mount provisions. The internal insulation will be redesigned around the brackets.

F. MISCELLANEOUS STRUCTURAL MODIFICATIONS

Support structure for a 25 1/4-inch-diameter ambient helium bottle will be provided on the thrust structure. The support will be identical to one of those being designed for the Saturn V/S-IVB vehicle.

The support for the additional battery in the forward skirt will be provided. The support will be located near the forward skirt umbilical panel and is similar to other existing battery supports. The forward skirt will be reworked to provide attachment of the continuous vent system. A fairing will be provided for each vent nozzle.

Aluminized mylar external insulation will be installed over the forward LH_2 dome. The mylar installation will be identical to that being designed for the Saturn V/S-IVB vehicle.

A grid system, to be determined later, will be painted on the LH_2 tank insulation. Because of the reduced payload weight, the vehicle will have a much higher burn-out axial acceleration resulting in loads on the tankage and other components greater than those for which the vehicle was originally designed. These higher loads must be investigated to determine to what extent the factor of safety has been reduced.

2. <u>Camera Heater - 450-watt total.</u> The low temperature limit of the cameras is 0°F which would dictate an 80 to 100 per cent duty cycle on the heater. Based on the 4.8-hour mission time this is a requirement of approximately 60 to 80 ampere hours.

3. <u>Battery Heater (large capacity battery).</u> A battery heater will be required to maintain the battery at the proper operating temperature. It is estimated that this will require approximately 20 ampere hours.

4. <u>Measurements.</u> It has been estimated that there will be 70 temperature, at 40 milliampere each, and 20 pressure and miscellaneous measurements, at 60 milliampere each. This requires 20 ampere hours of power. This would be slightly less if 75 measurements are used.

The total additional power required by this experiment is then 170 ampere hours. To this must be added a design reserve of 30 per cent for laboratory testing and internal power tests during countdown. This is then a total requirement of 220 ampere hours. This requirement can be most easily satisfied by using a presently designed S-IVB/S-V battery which is capable of delivering approximately 470 ampere hours and weighs 170 pounds in two boxes.

This makes the second alternative for the telemetry battery the more attractive. The 20 ampere hours required for the forward No. 1 battery heater can be obtained from the new forward No. 2 battery and the 20 ampere hours of telemetry substituted in its place.

The forward power system for the LH_2 experiment then takes the following form:

1. Use existing battery P/N 1A83468-501 for the forward No. 1 bus

2. Move the forward battery heaters from the forward No. 1 bus to the new forward No. 2 bus

3. Remove the present forward No. 2 battery P/N 1A83469-1 from the vehicle

4. Install a new forward No. 2 battery P/N 1A59741-1

5. Modify the forward No. 2 power distributor to accept the larger battery and supply the heater loads

G. POWER SYSTEM MODIFICATIONS

MSFC will be responsible for the electrical power for the TV cameras, electronics and switching of that power. MSFC will be responsible for the cabling and integration into the I. U. of the TV electronics, TV Antenna, and new measurements for the TV. Also MSFC will be responsible for the electrical interfaces between the S-IVB stage and the I. U.

DAC will be responsible for the electrical power needed for the TV lights, heaters and switching of that power. DAC will be responsible for the electrical modifications, if required, to the following systems: LOX chilldown, LH_2 chilldown, J-2 engine restart, P. U. and cables and circuits required for the instrumentation to be added. DAC will be responsible for new electrical circuit design for the control of helium bottles for ullage thrust and purges for the camera lens.

The maximum electrical load added to the I. U. for total experiment will be 200 watts and for the S-IVB stage will be 750 watts.

Several modifications to the Saturn IB/S-IVB power system are required to accomplish the LH_2 experiment. A large capacity battery will have to be added to the forward interstage to power the camera heater and lights. Since the propellant utilization system will not be used during flight for this experiment, it appears feasible to substitute the new large capacity battery for the present forward No. 2 battery. This direct substitution would allow the use of the majority of the present forward No. 2 power distribution system.

A second modification is required by the addition of a maximum of 90 measurements (75 required) to the telemetry system. This addition may be accommodated by one of two alternatives. The first alternative is to increase the capacity of the present telemetry battery (Forward No. 1). The second alternative is to transfer some non-telemetry loads to the large capacity battery now in the Forward No. 2 position and use the existing telemetry battery.

The following load analysis will aid in determining which of the above approaches is more practical.

1. <u>Lights - 100 watts.</u> The lights will require approximately 52 ampere hours based on a 4.8-hour power transfer to end of experiment interval.

Several modifications to the aft power systems are also required. The increased number of sequence functions and valve operations associated with this experiment will require an increase in the capacity of the aft No. 1 battery. Provisions will also be necessary to allow the aft No. 2 battery heater to remain on during the experiment. The increased load requirements on the aft No. 1 bus can be satisfied by substituting a forward No. 1 battery P/N 1A83468-501 for the present aft No. 1 battery P/N 1A83470-1.

The present aft No. 2 battery P/N 1A83471-1 is capable of supplying the LH_2 chilldown system for an additional five minutes of running time if maintained at the proper temperature.

H. NETWORKS

Networks changes will be extensive as power distribution is revised to handle the increased telemetry and control loading. New wiring will be required for the battery, dead-face relay, internal-external switching, and load switching. New schematics and harnesses will be necessary for the instrumentation of the fuel system, ullage system, helium system, oxidizer system, and structure.

I. CAMERA AND EQUIPMENT

Two TV cameras and two 50-watt lamps will be mounted on a modified LH_2 dome manhole cover. Neither the lights nor the cameras are exposed directly to the tank environment. They are protected by 1-1/2 inch thick quartz windows. To prevent fogging on the windows a helium or dry nitrogen gas purge will be employed prior to lift-off. Even though the cameras are not exposed directly to the tank environment, if their temperatures drop below the operating limits, 100-watt electrical heaters will be utilized continuously during the experiment. See Figures 10-4, 10-5, and 9-2.

J. PROPULSION SUBSYSTEM MODIFICATION

The modification of the propulsion subsystem is in three major areas, which include main fuel tank component installation, main oxidizer tank installation of ullage thrusting system, and propellant tank repressurization and helium purge system for TV camera and incandescent lamp.

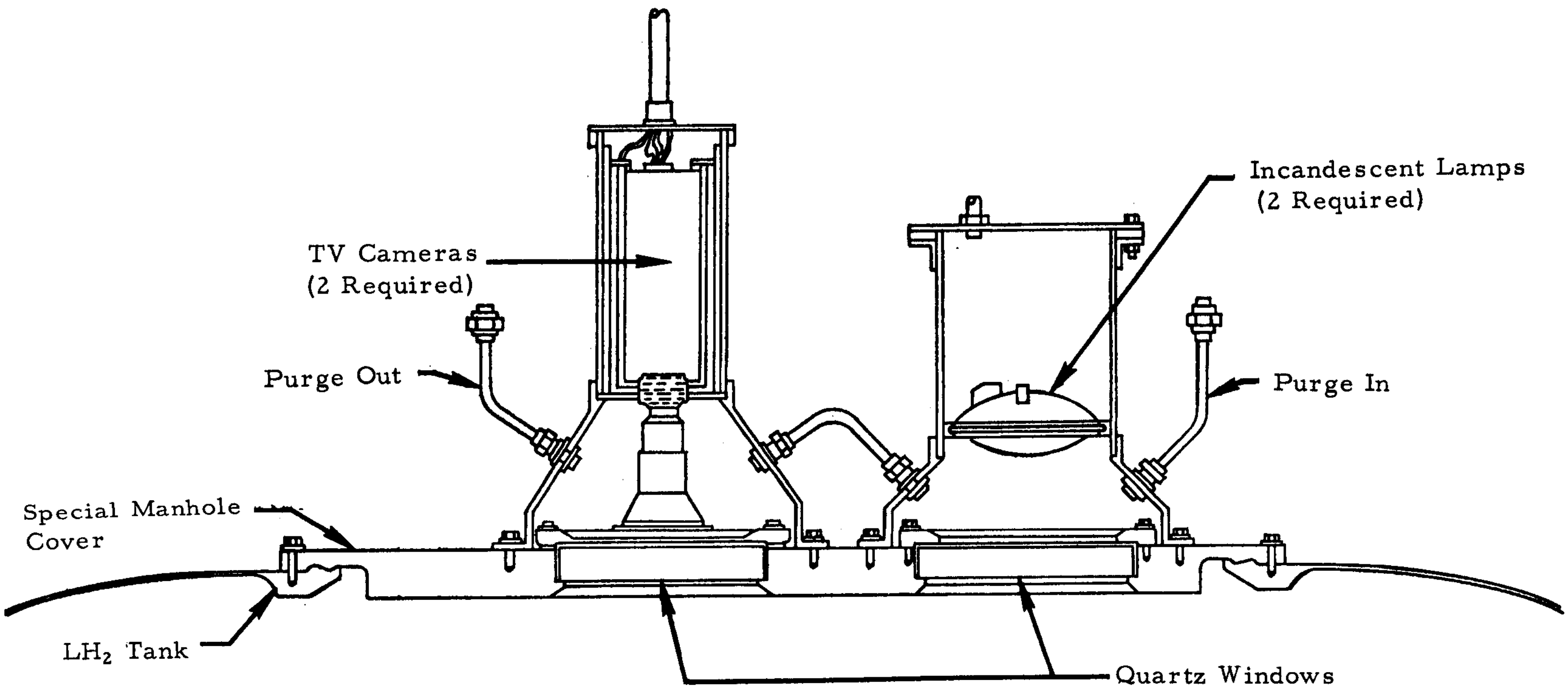


FIGURE 10-4. LIQUID HYDROGEN TANK TV CAMERA MANHOLE INSTALLATION

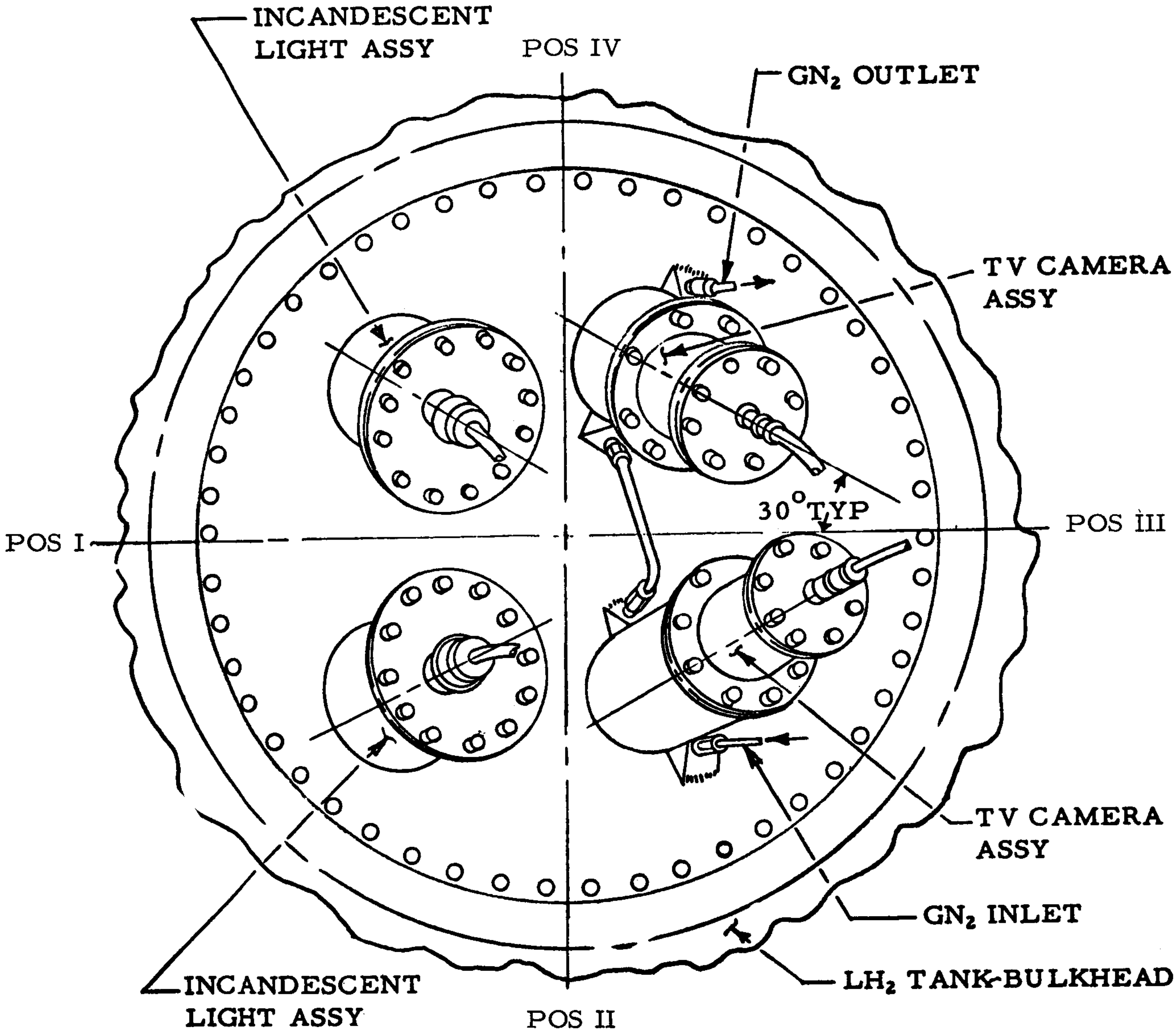


FIGURE 10-5. MANHOLE COVER ASSEMBLY, TOP VIEW

Purchased parts for this modification include the following:

1. Liquid/Vapor Separator

2. Pneumatic Shut-off Valves

3. Actuation Control Modules

4. Flex Joints and Bellows

5. Tees

6. Helium Storable Sphere

7. LH_2 Tank Repressurization Control Module

8. Purge Control Module or Shut-off Valve and Pressure Switch

9. Purge Valve

10. Check Valve

Parts which will require fabrication and/or assembly are:

1. Lines and Ducts (pressure and vent)

2. Thrust Nozzles

3. Orifices

4. Line and Duct Supports

5. Helium Tank Supports

Fabrication of the above noted parts will be at the Santa Monica Missile and Space Systems Division facility.

The lines and ducts will be fabricated using standard dies with existing facilities. Assembly and/or welding of lines and ducts will be accomplished in the development shops using a "no tool" or minimum tooling approach with existing facilities.

The thrust nozzles and orifices will be fabricated in the development shop on a "no tool" basis.

Line and ducts supports, helium tank supports, and miscellaneous sheet metal components will be fabricated on a "minimum" or "no tool" basis in the development sheet metal shops. Tooling which is required such as layout templates, contour templates, and form blocks will be in the "shop aid" category. Adequate existing facilities, including hydropress, punch press, saws, brake, etc., are available for use in this type of fabrication.

Details and/or assemblies for all systems will be tested, LOX cleaned, packaged, and transported to assembly areas.

K. VENT SYSTEM MODIFICATION

The Saturn IB/S-IVB hydrogen and oxygen vent systems should be modified to the Saturn V configuration. For the hydrogen system, the modifications will consist of the addition of a continuous venting system and perhaps a liquid-vapor separator. It has not definitely been established that the Saturn V/S-IVB will have a liquid/vapor separator in the hydrogen tank. If it does, then the same type of separator must be available for the hydrogen experiment. Should the separator be dropped then its replacement will have to be evaluated to determine whether or not it must be included in the experiment. To make the oxygen venting systems identical will not require additional hardware, but it will require realigning the vent line so that the thrust will be directed through the c.g. of the vehicle.

L. SEQUENCER MODIFICATIONS

On the S-IVB stage, functions previously handled exclusively in a sequencer relay box may be controlled by individual relays located in power distribution units. There will, therefore, be required now (10 amp) mag-latch relays, three located forward and three aft. These, in turn, will require twelve switch selector channels.

Two vent actuation control modules will be added for the LOX vent (ullage thrust system) and for the continuous vent system. GSE control of these modules will be furnished through four umbilical pins with four more used for talkback indications.

The new ambient helium sphere will require replacement of the ambient helium fill module by a Saturn V LH_2 Repressurization Control Module.

The purge control of the camera, light/tank cover interface will also require a new module.

The camera heaters and lights will utilize a separate GSE power supply while on the ground switching to the new Forward Battery No. 3 by means of an Internal-External switch at time of launch. Preload of the battery will be accomplished by a separate motor-driven switch.

M. WEIGHTS

The weight breakdown of the equipment must be added to the S-IVB Stage as presented in Table 10-1. As a result of these modifications, the center of gravity of the dry stage will shift 6.5 inches forward. The effect of the stage center of gravity due to the off loading of propellants will be investigated.

Table 10-1. S-IVB Weight Breakdown

Item	Weight (lb)
Modification to Feed and Pressurization System (continuous vent system, LOX ullage system and liquid/vapor separator)	74
Addition of Ambient H_e Bottle and Mount	151
High Performance Insulation of Forward LH_2 Dome	89
Sensors and Required Wiring (signal conditioning)	237
Batteries and Mounts	205
Instrumentation Mount	33
LOX Baffle	50
Camera and Light Installation (includes 40 pounds for MSFC Manhole)	102
Miscellaneous Fittings for Wiring	48
Total Increase to Dry Stage Weight	989

N. MANHOLE COVER

A manhole cover for the LH_2 container, S-IVB stage configuration, will be manufactured by Manufacturing Engineering Laboratory and equipped by Astrionics Laboratory with all Government Furnished Equipment items required for the experiment, such as TV camera, lights, wiring, switch device, etc.

O. INSTRUMENTATION FEEDTHROUGH

The instrumentation feedthrough design on the LH_2 tank consists of seven connectors of two types mounted on a flange. Six of the connectors contain nineteen pins, six of these being coaxial. The seventh connector contains thirty-seven pins.

It is proposed that a new configuration with three or four of the nineteen pin connectors replaced by the thirty-seven pin variety be called out and that a spare "controls" feedthrough be utilized if additional capacity is needed.

P. SCHEDULE

Figure 10-6 shows the schedule for the S-IVB LH_2 experiment. This schedule reflects a two-week delay in shipping the S-IVB stage from Huntington Beach, as a result of incorporating the LOX tank baffle rework, the addition of probe support brackets in the hydrogen tank and other miscellaneous structural changes. This two-week delay necessitates a two-week reduction to the S-IVB/V static test checkout.

The schedule/assembly status for this vehicle dictates that the major portion of the installation changes must be incorporated at Sacramento Test Center. This will cause an additional two-week delay for a total slippage of four weeks in the delivery of the stage.

Q. UNRESOLVED PROBLEMS

The following problems are presently unresolved and will require further discussions between MSFC and DAC:

1. Whether ground command or prerecorded sequencer on-board will be used to initiate experiment events

2. Whether PU will be flown open-loop or closed-loop

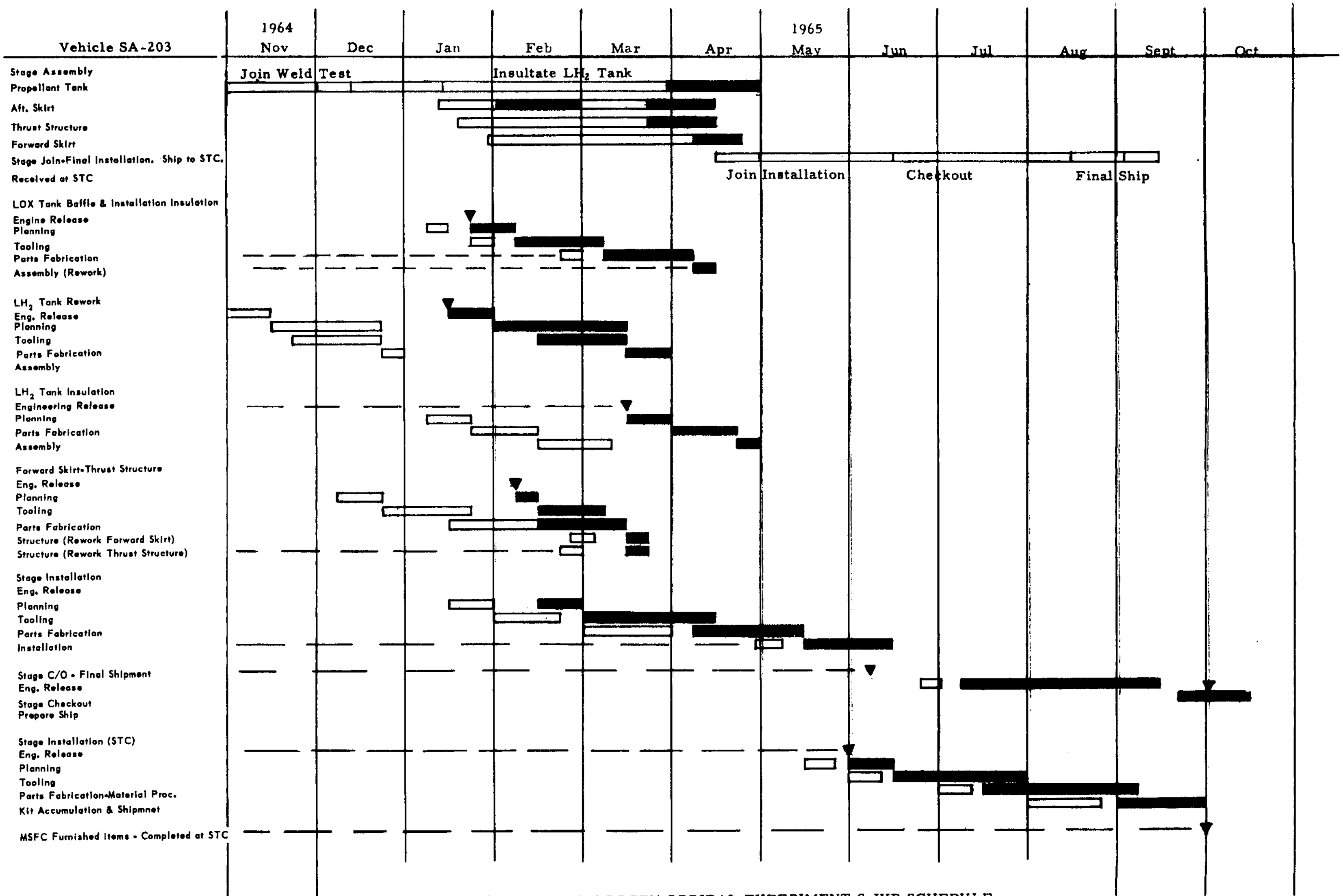


FIGURE 10-6. LIQUID HYDROGEN ORBITAL EXPERIMENT S-IVB SCHEDULE

3. How far to proceed in engine start sequence

4. Whether to add the 15 or 20 additional temperature measurements needed to determine total heat input

5. Minor differences in temperature measurements in tank and pressure in vent lines

6. Whether to use higher thrust J-2 engines

SECTION XI. DOCUMENTATION

REQUIREMENTS

Documentation peculiar to the S-IVB stage LH_2 experiment will be prepared in accordance with best engineering practices. The following minimum documentation will be provided by DAC:

1. Handling and Checkout Drawings

2. Maintenance and Calibration Drawings

3. Installation and Removal Drawings

4. Schematics and/or Wiring Diagrams

5. Assembly Drawing showing location and size of experiment peculiar items

6. Sequence of Events Diagram

7. Instrumentation List

8. Addendum to Model Specification, Program Plan and General Test Plan to cover experiment

The following documentation will be provided by MSFC:

1. Vehicle Assembly Drawings

2. Payload Assembly Drawings

3. Structural Payload Assembly Drawings

4. Camera Package Assembly Drawings

Figure 11-1 shows the required documentation responsibility.

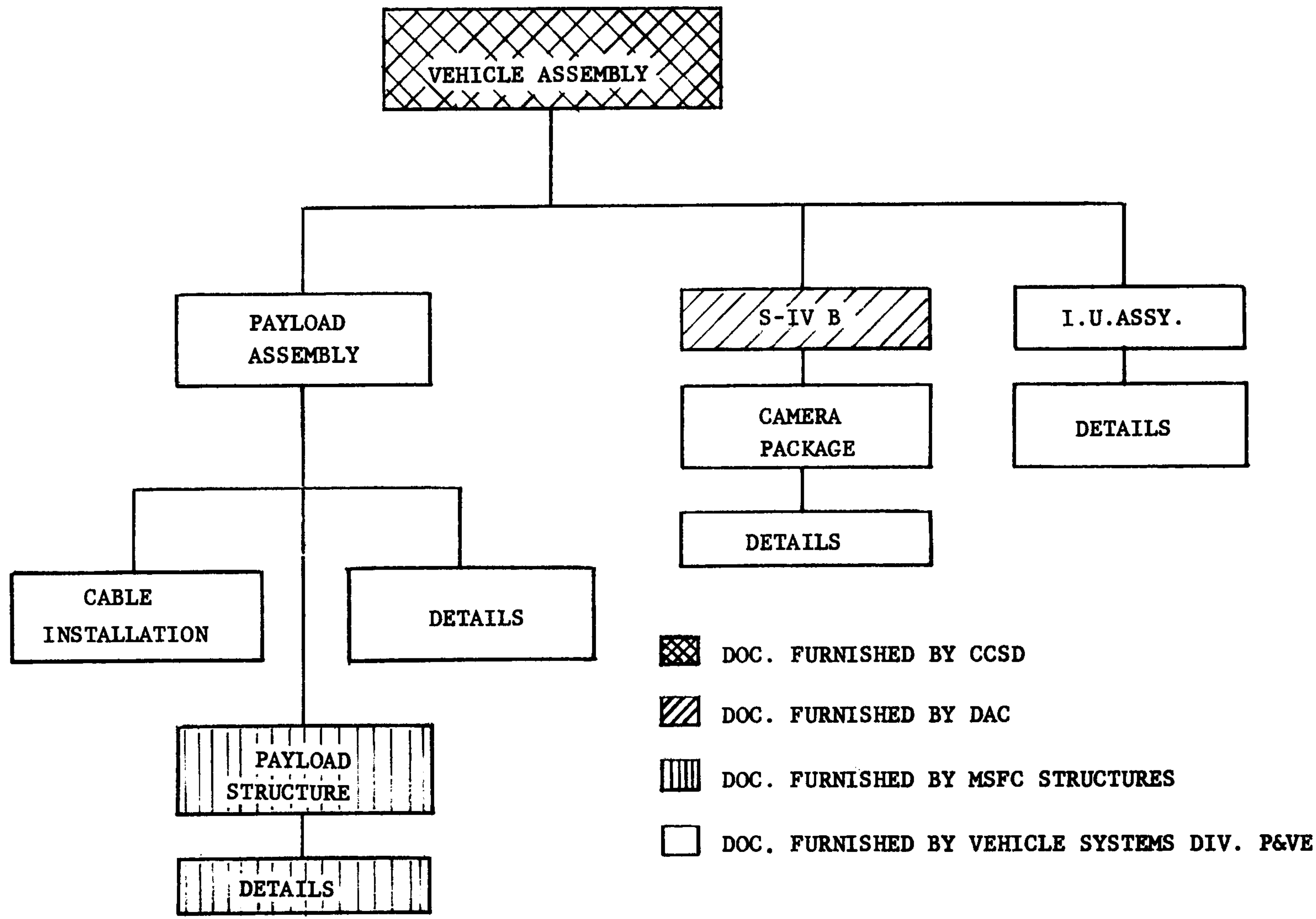


FIGURE 11-1. LIQUID HYDROGEN ORBITAL EXPERIMENT DOCUMENTATION RESPONSIBILITY

SECTION XII. TESTING

A. TESTING REQUIREMENTS

Testing of the S-IVB stage of the Saturn IB vehicle, SA-203, will be in accordance with the Saturn S-IVB General Test Plan, SM-41412, with the exception of experiment-peculiar hardware. Experiment-peculiar hardware will be tested as follows:

1. The following items will be qualified under the Saturn V Program:

   a. Battery for camera heater and lamps

   b. Ambient helium storage sphere

   c. Ambient helium storage sphere support structure

   d. Continuous vent system - the qualification test for adapting the S-V vent system to S-IVB stage will consist of resizing orifices and configurating the qualification test set up to a continuous vent system. This can be completed prior to S-IVB stage delivery.

2. The following items require modification and requalification as a result of the addition of already qualified parts:

   a. Sequencer

   b. Telemetry equipment

3. The following new items, made up of already qualified parts, will require qualification:

   a. Ullage thrust system - (actuation control module)

   b. Ullage thrust system (shut-off valve) (either a S-IV or S-IVB part)

4. The following items require no qualification test:

   a. LOX tank baffle

   b. LH_2 tank forward dome insulation

5. Due to schedule limitations, new items that would normally require qualification test will undergo a limited qualification test, possibly by the vendor. These include:

a. Instrumentation probe

b. Liquid/vapor separator tachometer

c. Liquid/vapor detectors

d. Accelerometers

e. Ullage thrust system

(1) flexible bellows (joint)

(2) thrust nozzles

(3) three-way tee

6. MSFC will perform all the necessary tests on the manhole cover and associated electronic equipment and mounting bracketry.

7. Stage checkout at Huntington Beach will be identical to a typical flight stage, with experiment-peculiar subsystems being checked out to the extent that hardware installation permits, the stage will then be shipped to the Sacramento Test Center (STC).

B. PROPULSION ACCEPTANCE TESTING

The propulsion subsystem ducts and tubing are proof and leak tested to meet engineering specification. Test adapters will be fabricated but in all instances tooling will be kept to a minimum or "no tool" approach.

The propulsion modules and valves are proof tested and internal and external leakage tests conducted. Functional testing of modules and valves is a part of the testing program.

The helium sphere is proof and leak tested, using existing equipment and facilities.

C. FINAL INSTALLATION AND CHECKOUT

The completed S-IVB stage as modified at Huntington Beach will be shipped to STC. At STC, final installation of the experiment-peculiar hardware will be made. Also, components which cannot be scheduled into the program earlier will be installed at STC. The man hole cover assembly, which includes the TV cameras and the incandescent lamps from MSFC, is also installed at this time. After all installations have been completed, an all-systems checkout is performed prior to test firing.

D. STATIC FIRING

Subsequent to stage checkout, the stage will be static fired. In addition to normal testing on the stage, verification will be made that the experiment-peculiar hardware is functioning as required.

SECTION XIII. DATA RETRIEVAL

A. ACQUISITION

The high-rate TV data should be recorded and displayed at the three receiving stations - KSC, Bermuda, and somewhere in Texas or Mexico (several locations are suitable). After the flight, motion picture film copies of the high-rate TV data should be made as soon as possible. Should the high-rate TV system fail, motion picture film copies of the low-rate data (taken during the time the high-rate TV was inoperative) will be needed as soon as possible. Otherwise, the low-rate data will not be required immediately in the form of motion pictures, but can be supplied later.

B. REDUCTION

The instrumentation will be received for at least three orbits and perhaps as many as four orbits at various points around the world. Besides recording the data as it is received, there is a requirement for real-time display of at least fifteen channels of information at the Cape, Bermuda and the Texas location. After the flight the telemetry tapes will be sent to DAC where they will be linearized and returned to MSFC. At MSFC the Computation Laboratory will reduce the linearized tapes and provide SC 4020 plots and digitized data for initial analysis. Later EAI plots will be required for reports. It is understood that the additional measurements, and the increased transmission time, will not significantly increase the work load of the MSFC Computation Laboratory.

C. ANALYSIS

It is desired that DAC analyze the data received only to determine that the system performed satisfactorily and to the extent necessary to explain and correct failures or inaugurate improvements for future flights. Detailed analysis of a research nature will be performed by MSFC.

D. DATA MEASUREMENTS

The necessary data measurements will be evaluated and analyzed to determine system performance in the following areas:

1. <u>Orbital Venting</u>

   a. Adequacy of 10^{-5} "g" to maintain propellant settling

b. Thrust levels and unbalances of blowdown vent system, continuous vent system, and 70 pound ullage motor simulation system

c. LH_2 settling time at low "g" level

d. Mechanics of low "g" heat transfer with respect to determining model to define orbital pressure schedule

e. Determination of liquid/gas behavior and adequacy of ullage control during post shutdown transients at orbital insertion

f. Influence of APS orbital maneuvering on propellant level and liquid/gas interface reactions

g. The need for liquid vapor separator at 10^{-5} "g"

h. Orbital storage characteristics of ambient helium bottle

2. <u>Restart Conditioning</u>

a. Adequacy of the liquid-vapor separator during depressurization and the evaluation of the depressurization operating conditions for the Saturn V

b. Adequacy of recirculation system chilldown in determining stabilized chill temperatures for the planned Saturn V chilldown duration

c. Solution to anti-vortex screen bubble removal

d. Thrust chamber chilldown

e. Repressurization of hydrogen tank when using the ambient helium bottle

3. <u>Pre-ignition Test</u>

a. Start bottle performance (and orbital storage characteristics)

b. General engine performance including pump characteristics

4. System Evaluation

a. Performance of orbital storage characteristics of partially loaded helium bottles

b. Ullage pressures, temperatures, etc.

SECTION XIV. RELIABILITY AND QUALITY ASSURANCE

A. GENERAL

Experiment hardware, which is peculiar to S-IVB/SA-203 and normal flight equipment for the Saturn V S-IVB stages, shall be required to meet the Saturn V contract requirements for that item of hardware.

B. RELIABILITY

Douglas Aircraft Company Report Number 46644, Formal Reliability Program Plan, will be imposed on the experiment-peculiar hardware required for the S-IVB/SA-203 Liquid Hydrogen Orbital Experiment.

C. QUALITY CONTROL

The S-IVB/SA-203 experiment-peculiar hardware will be handled in accordance with the controls established by Douglas Aircraft Company Report Number SM 41891.

D. DOCUMENTATION

The following paragraphs of DAC Report Number SM 4644 shall be imposed on documentation procedures:

1. Math Models
2. Failure Mode and Effect Analysis
3. Failure Reporting and Corrective Action
4. Math Assessment

DAC shall provide MSFC with the following:

1. Qualification status of experiment peculiar hardware.

2. Copies of design evaluation quality (DEQ) reports on experiment hardware.

3. On DAC-provided components, not common to S-IVB/V and S-IVB/IB, a test program shall be prepared and submitted to MSFC for review. Parts may be approved by similarity.

4. Checkout test procedures and test and test requirements shall be provided to MSFC.

5. DAC shall provide MSFC with a definition of all experiment-associated checkout equipment requirements, including source, i.e., GFE or DAC provided. Equipment, in addition to the present S-IVB checkout equipment, shall be so designated.

Documentation requirements, in addition to the test procedures and test requirements, shall include, as a minimum, the following:

1. Addendum to Model Specification, Program Plan, and General Test Plan covering experiment, and up-dated schematics including the modification/changes resulting from this experiment.

2. All documentation required to complete the Data Package to KSC.

a. Instrumentation list

b. Sequence of events

c. Assembly drawing (by location and size of experimental-peculiar items)

E. DAC PERFORMANCE

Douglas Aircraft Company shall perform all actions necessary to insure the quality and reliability of all DAC-provided experiment hardware.

Receiving inspection shall be performed on all experiment hardware.

The S-IVB stage automatic checkout equipment shall be utilized to checkout the experiment-peculiar equipment where only software changes are required.

DAC shall provide all additional checkout equipment required for the experiment other than that furnished by MSFC.

DAC shall perform checkout and verification of the S-IVB stage experiment-associated items.

F. PRESSURE LEAK CHECK

Quality and Reliability Assurance Laboratory will provide a specially built pressure vessel which can accommodate the S-IVB manhole cover. This will simulate the LH_2 flight container flange configuration. Appropriate drawings will be provided by Douglas Aircraft Company to Quality and Reliability Assurance Laboratory, Analytical Operations Division. An envelope drawing of the cover installations will be provided by Propulsion and Vehicle Engineering Laboratory. The above drawing documentation should be available at an early date to facilitate timely design and manufacture of the pressure device.

The outside of the manhole cover, including the flange connection to the test vessel, will be tested for leaks using the most appropriate leak detecting technology according to established specifications.

G. ELECTRICAL-OPTICAL FUNCTIONAL TEST

The electrical-optical functional test will be performed on the manhole cover under pressurized conditions and will include TV and light installations by utilizing a simulated electrical power source. Provided that normal equipment for the Saturn TV monitoring system can be used, no special equipment is needed.

H. RECEIVING INSPECTION

All parts and components to be installed on the manhole cover will undergo receiving inspection by Quality and Reliability Assurance Laboratory prior to installation.

SECTION XV. GROUND SUPPORT EQUIPMENT

A. ELECTRICAL

The modifications to the S-IVB Stage will require modifications and additions to the electrical support equipment. The addition of LOX tank ullage system valves and LH_2 continuous vent valves require repatching of the SACTO Beta patch panel -150 and one of the Vertical Checkout Lab patch panels -146 or -148. This entails revising the patching documents and additional patching on the subject boards.

As a result of new Forward Battery #3 and Forward Buss #3 and their associated E/I, and Load Test switches, a repatching effort is required on -150 and -146 or -148. The patching document must be revised. Also, a ground load will have to be developed and added to the proposed load test box to allow dissipation of the peroxide over-voltage in the new battery.

Ground power must be provided to Forward Buss #3 during system test and static firing. It is required for the incandescent light sources during test and for the heaters when fuel is in the vehicle. Since the heaters are thermostatically controlled, switching transients will probably occur on this line and a separate power supply is desirable. There are airborne provisions for remote sensing of Forward Buss #3 which could be used to regulate this supply even though regulation is not a critical parameter. DAC will utilize a source controlled power supply. This will be the most economical and expedient approach.

The tape programs for the experimental stage at Vertical Checkout Lab and Sacramento must be modified to include new commands and responses associated with the experimental hardware. These changes will be the direct result of alterations in the Test Requirements documents generated in the various airborne sections.

Program and patching modifications must be incorporated to verify the experimentally added instrumentation outputs. The programs for Vertical Checkout Lab and SACTO will require changes and the patching variations can only be determined after release of the Test Requirements document and the IP&C List.

The experimental manhold cover, installed at SACTO, will contain only two light sources and two cameras, one high speed scan and one low speed scan. During flight the camera control units and RF links will be housed in the IU. Therefore, in order to check out the TV cameras and lamp units, it is necessary to provide control units and monitoring devices as part of the GSE. Safety restrictions associated with H_2 dictate that all modules on the stand be either purged and pressurized or be located in a safe area. The Forward Umbilical Room provides a safe area and is less than 100 ft from the camera location via cable trays. According to MSFC information, the control units must be within 100 ft of the cameras. A new piece of GSE must be provided consisting primarily of GFE equipment. It will be called the LH_2 Tank TV Monitor and will consist of the following items:

1. Slow speed scan camera control unit - GFE

2. High speed scan camera control unit - GFE

3. Real time monitor capable of presenting either control unit output - GFE (An identical real time monitor is required in the blockhouse - GFE)

4. Video waveshap analyzer (scope) - GFE

5. Video line drive amplifiers (required to return video to monitor in the blockhouse during static fire) - GFE

6. Rack to house video line drive amplified and provide signal switching and power distribution - DAC

7. Two 70-foot cables between control units and cameras - DAC

8. Two 2000-foot cables between line drive amplifier and blockhouse monitor - DAC

This equipment is a manual console utilized at SACTO Forward Umbilical Room only.

B. MECHANICAL

Due to a new tank instrumentation support structure, no modifications will be required to the LH_2 tank access kit

C. GOVERNMENT FURNISHED PROPERTY

NASA will furnish to Douglas (Sacramento Facility), on or before September 1, 1965, the following GFE items:

Item Number	Quantity	Description
1*	1	High speed (30 FPS) TV camera
2*	1	Low speed (one-half FPS) TV camera
3*	2	Lamp unit
4*	1	Manhole Cover
5**	1	High Speed Scan Camera Control Unit
6**	1	Slow Speed Scan Camera Control Unit
7**	2	Real Time Monitor capable of presenting either control unit output
8**	1	Video Waveshape Analyzer (Oscilloscope)
9**	TBD***	Video Line Drive Amplifiers (Required to return video to Monitor in Blockhouse during Static Firing)

* Will be delivered as a package, already tested and ready for installation.

** Will be sent to DAC with an engineer from MSFC for the duration of test, then returned to MSFC.

*** To be determined.

DEFINITION OF ABBREVIATIONS

	Definition
AMO	Advanced Material Order
ANT	Antenna
APS	Auxially Propulsion System
cg	Center of Gravity
DAC	Douglas Aircraft Company
db	Decibel
EAI	Electronics Associated Incorporated
EMC	Electro-Magnetic Capability
"g"	Gravity
GFE	Government Furnished Equipment
GND	Ground
GOX	Gaseous Oxygen
GSE	Ground Support Equipment
H_2	Hydrogen
I_{sp}	Specific Impulse
LH_2	Liquid Hydrogen
LOX	Liquid Oxygen
mc	Megacycle
MSFC	Marshall Space Flight Center
PAM	Pulse Amplitude Modulation
P&VE	Propulsion and Vehicle Engineering Laboratory
STC or SACTO	Sacramento Test Center or Sacramento Test Operations
SSB	Single Side Band
S_{pp}/N_{rms}	Signal to Noise ratio
SPS	Samples per Second

APPENDIX A

SATURN IB (SA-203) PERFORMANCE CAPABILITY

The purpose of the appendix is to publish the Saturn IB (SA-203) two-stage performance capability for carrying out the liquid hydrogen orbital experiment.

The ground rules used in this study are presented below:

1. Launch on an aximuth 72° east of north from Cape Kennedy, Florida.

2. Inject into a 100-N. M. circular orbit.

3. The Apollo payload configuration was replaced by the generalized nose shape.

4. Place the S-IVB stage in orbit with maximum LH_2 onboard after injection based on a tank capacity of 44,393 pounds of hydrogen for an ullage volume of 1.73 per cent.

The weights used in this study are presented in Table I and are the proposed control weights for SA-203. The aerodynamic characteristics were taken with the concurrence of R-AERO-AA.

Figure 1 presents the cutoff weight in orbit as a function of second stage lift-off weight for a constant engine mixture ratio of 5.0, 5.2, and 5.4 in the S-IVB stage, respectively.

Figure 2 presents the nominal liquid hydrogen that will be in the tanks of the S-IVB stage at injection as a function of S-IVB jettison weight. A nominal flight is defined to be one which does not require the use of S-IVB reserve propellants to account for flight perturbations. The minimum hydrogen in orbit would correspond to the use of all reserve propellant prior to injection and a reduction in the liquid hydrogen in the tanks of approximately 300 pounds from the values presented. The following table presents the jettison weight definition.

Table 1. S-IVB Jettison Weight Definition

S-IVB Dry		24,782 lb
Nose Cone	Est.	3,200
I. U.		4,650
LH_2 Exp. Equipment	Est.	1,250
Residuals		1,752
Flight Performance and Propellant Utilization Reserves		1,870
Total		37,504 lb

Figure 3 presents a schematic of the distribution of the propellants in the hydrogen. Note the definition for nominal liquid hydrogen at injection.

Figure 4 presents the altitude as a function of the range. Note that injection is achieved from below the orbit rather than from above the orbit and at a considerably shorter range distance than the normal orbital flight. Also, the maximum dynamic pressure is approximately 750 kg/m^2 higher than a nominal Saturn IB two-stage vehicle of approximately 3100 kg/m^2. The maximum dynamic pressure could be reduced through trajectory shaping. A rough tradeoff is approximately 50 pounds of hydrogen for 100 kg/m^2 reduction. This is very nonlinear.

Figure 5 presents the nominal liquid hydrogen in orbit as a function of time spent at upper mixture ratio for a 5.4/4.7 program. The analysis is presented for a fixed second stage lift-off weight and an estimated S-IVB jettison weight of 37,504 pounds. The liquid hydrogen in orbit varies between 19,100 and 18,580 pounds as the burn time at the 5.4/1 mixture ratio is increased from zero to full duration (246.46 sec). This represents a reduction in hydrogen available as compared to continuous mixture ratio programs; however, further study should reduce present performance differences.

Table II presents a typical trajectory provided for engineering analysis.

If the Apollo configuration is used instead of the standard Saturn IB nose shape, the available hydrogen in orbit will be between 1500 and 2000 pounds less. This is due to approximately a 2800-pound increase in S-IVB jettison weight in orbit and different aerodynamic drag losses.

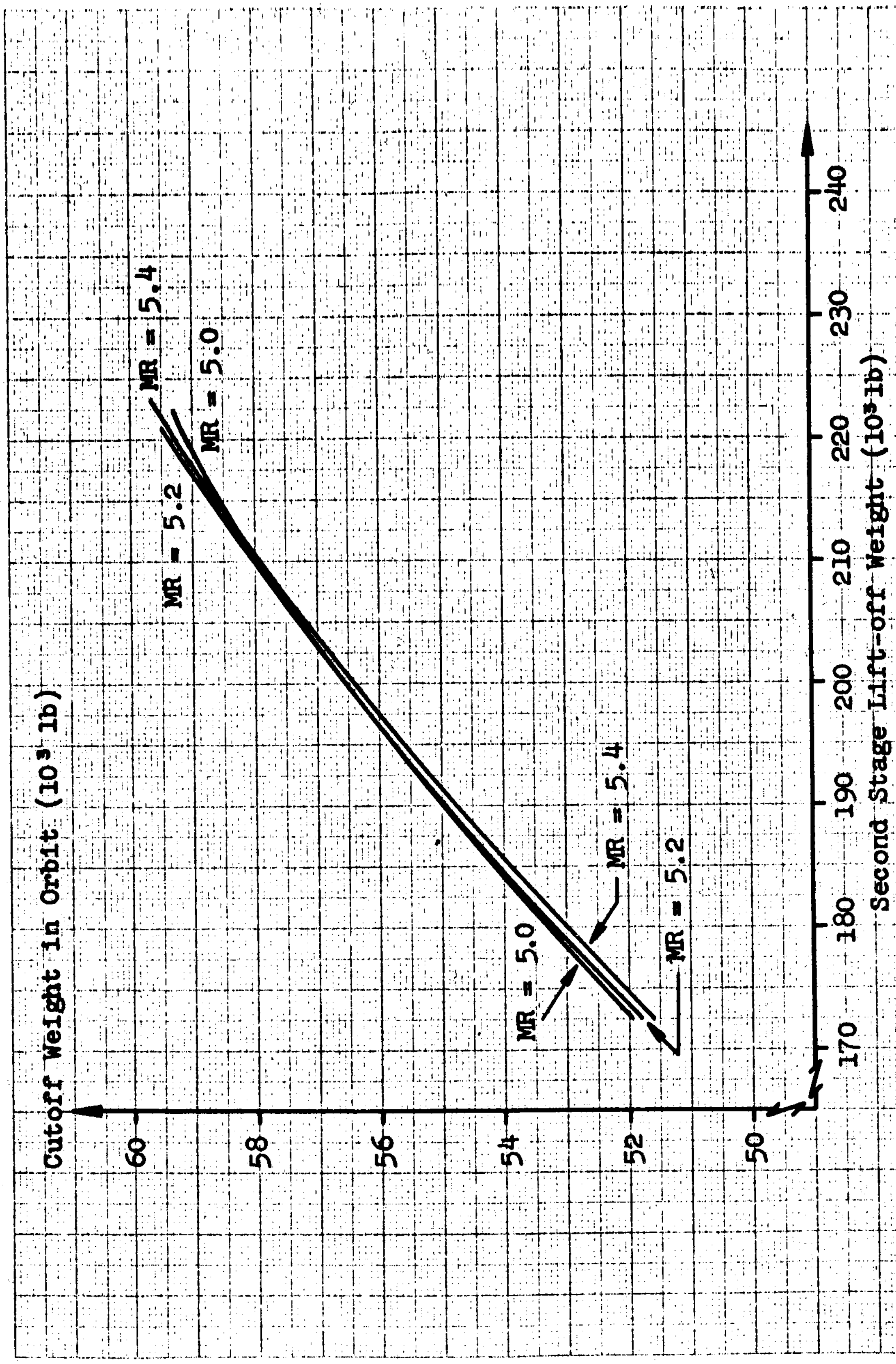


FIG. 1. SATURN IB SA-203

CUTOFF WEIGHT IN ORBIT AS A FUNCTION OF SECOND STAGE LIFT-OFF WEIGHT FOR A 100 NAUTICAL MILE CIRCULAR ORBIT

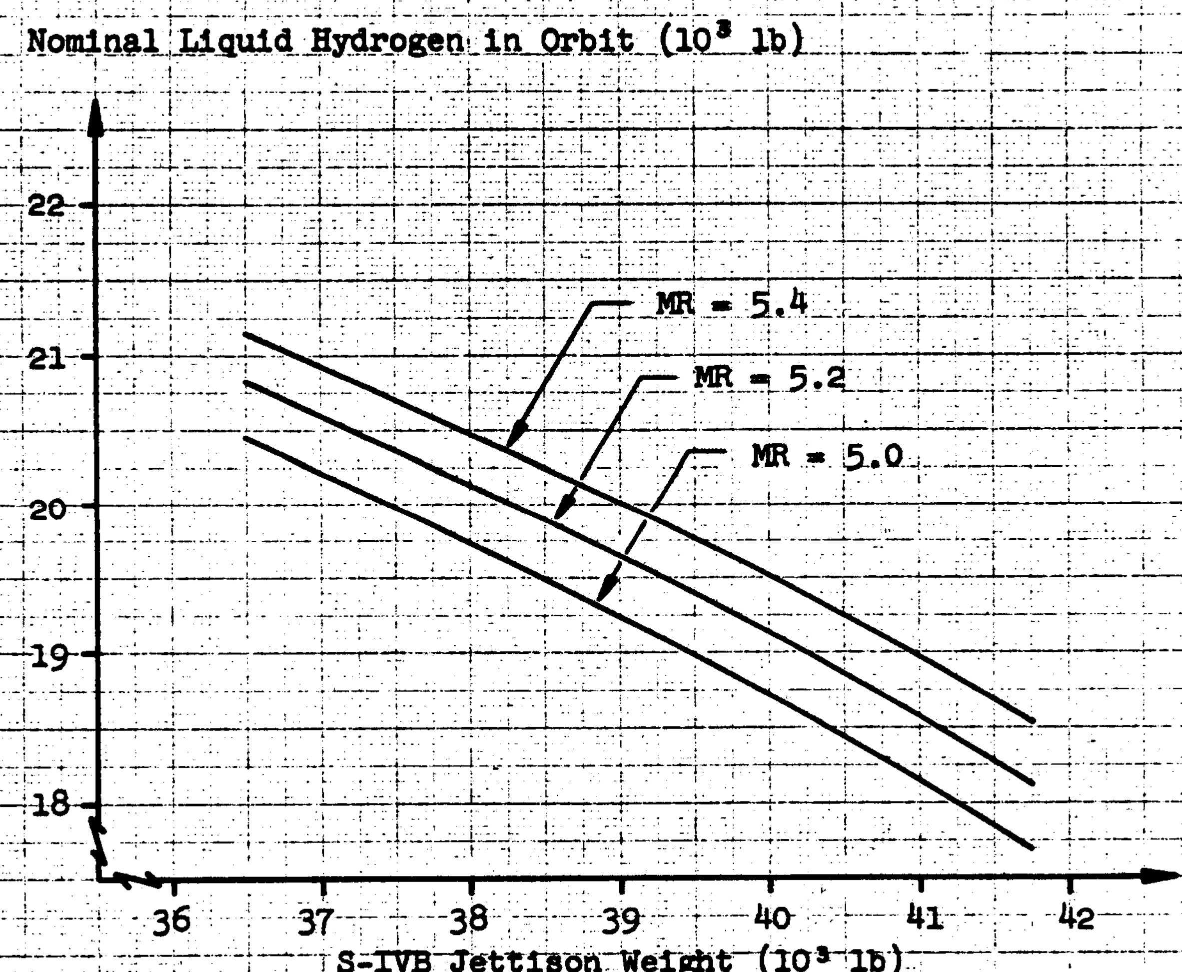
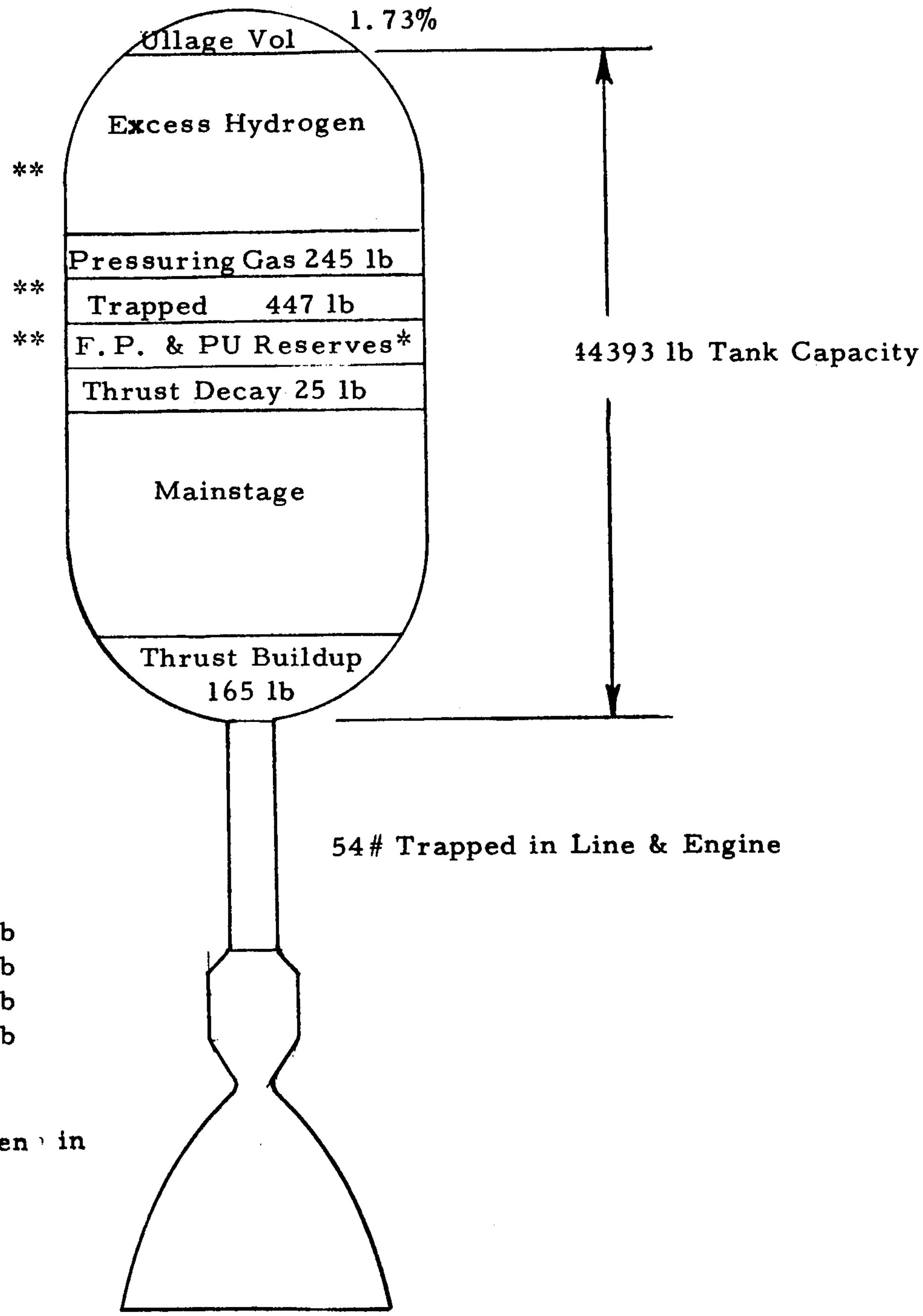


FIG. 2. SATURN IB SA-203
NOMINAL LIQUID HYDROGEN IN ORBIT AS A FUNCTION OF S-IVB JETTISON WEIGHT FOR A 100 NAUTICAL MILE CIRCULAR ORBIT

FIGURE 3

SCHEMATIC HYDROGEN TANK



*	5.0	312 lb
	5.2	302 lb
	5.4	292 lb
	5.4/4.7	328 lb

**Nominal hydrogen in orbit.

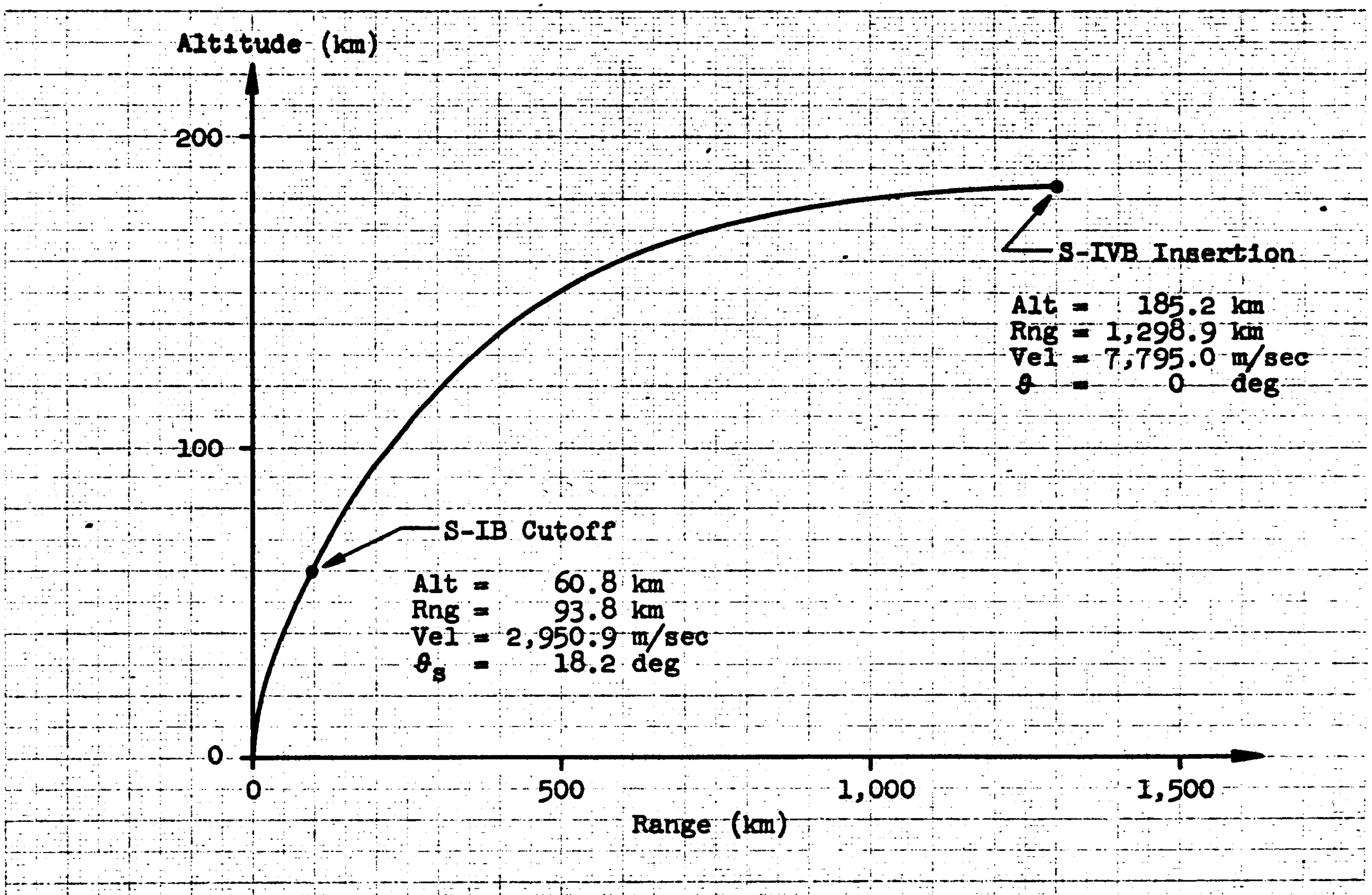


FIG. 4. SATURN IB SA-203
ALTITUDE AS A FUNCTION OF RANGE FOR A 100 NAUTICAL MILE CIRCULAR ORBIT

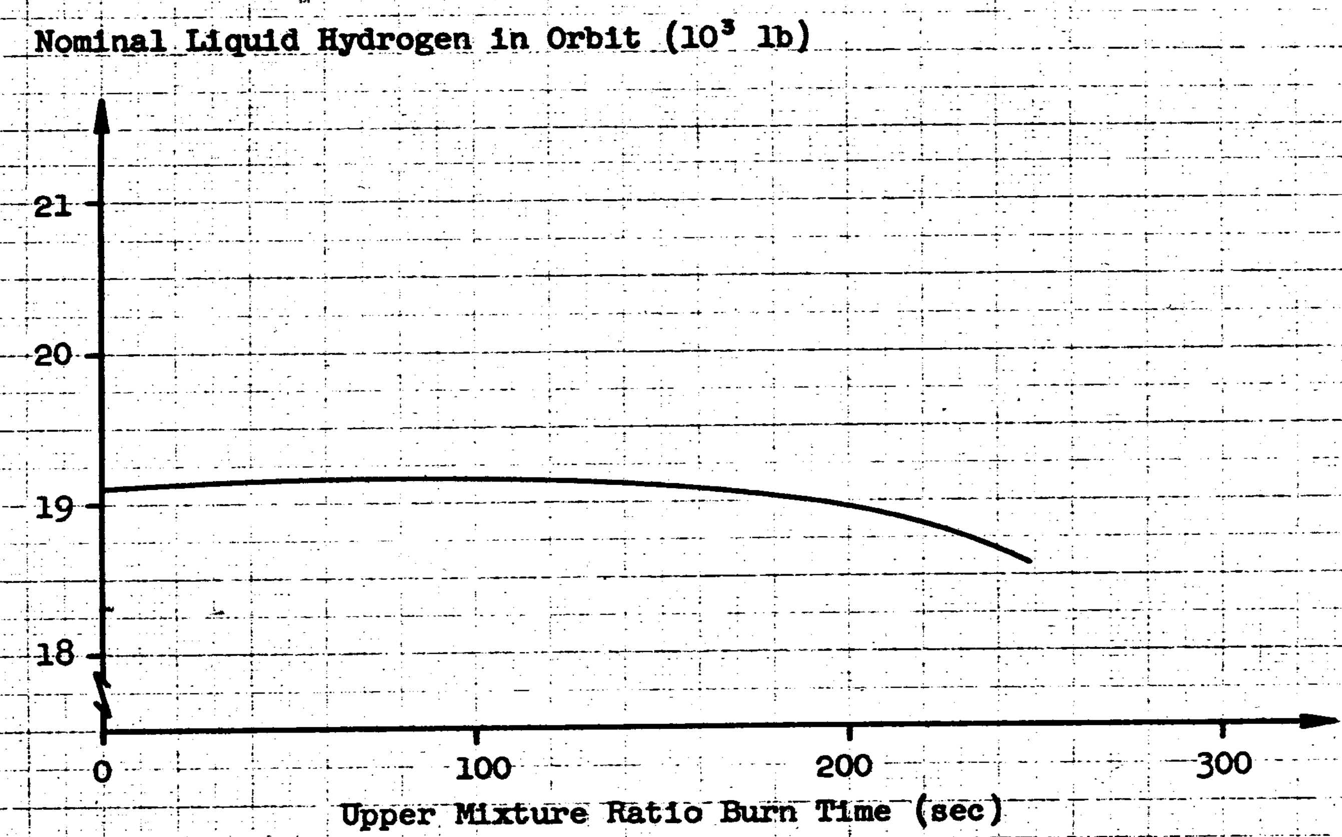


FIG. 5. SATURN IB SA-203
NOMINAL LIQUID HYDROGEN IN ORBIT AS A FUNCTION OF UPPER MIXTURE RATIO BURN TIME FOR A STEP MIXTURE RATIO PROGRAM OF 5.4/4.7
(100 N.M. CIRCULAR ORBIT)

MARSHALL FLIGHT CENTER FLIGHT CE

M-AERØ-D Table 2 4 AUGUST 1964 4

SATURN IB TWO STAGE TO 100 N. M. CIRCULAR ORBIT FOR (SA-203) LH_2 EXPERIMENT

	TIME SEC	WEIGHT LBS	THRUST LBS	LØNG ACCEL M/(SEC)SQ	ALT M	RANGE N.MI	VS M/SEC	THETA S DEG	CHI DEG	MACH
LIFT ØFF	.000	1190045.0	1600011.0	13.113	-.063	.000	408.8595	360.0000	90.0000	.000
	8.000	1140700.3	1602482.3	13.665	112.000	.000	409.8353	4.0245	90.0000	.083
	16.000	1091355.6	1610266.1	14.300	472.688	.000	414.0120	8.6477	88.4581	.161
	24.000	1042010.9	1623620.7	14.991	1121.500	.000	428.2660	13.6115	84.2059	.295
	32.000	992666.2	1642205.0	15.778	2098.313	.080	456.2279	18.4264	79.5498	.432
	40.000	943321.5	1664975.5	16.668	3442.188	.246	498.8736	22.6873	74.3021	.597
	48.000	893976.8	1690221.6	17.532	5186.438	.567	558.3875	25.8964	68.1341	.800
	56.000	844632.1	1715726.2	17.759	7342.563	1.110	632.4287	27.7143	61.8425	1.044
	64.000	795287.4	1739098.1	18.345	9877.250	1.937	716.6304	28.1880	55.6394	1.334
	64.361	793060.8	1740072.0	18.426	10000.000	1.982	720.7777	28.1891	55.3542	1.349
	72.000	745942.7	1758653.7	20.467	12766.750	3.119	818.8102	27.9735	49.7176	1.710
Q MAX	73.000	739774.7	1760771.2	20.747	13154.125	3.297	833.1957	27.9154	49.0044	1.753
	75.131	726626.2	1765019.9	21.379	14000.000	3.699	865.0727	27.7699	47.5284	1.831
	80.000	695598.1	1773329.9	22.830	16037.938	4.753	944.2111	27.3369	44.3015	2.162
	88.000	647253.4	1782768.3	25.442	19718.063	6.943	1073.7731	26.3797	39.5002	2.612
	96.000	597908.8	1788151.5	28.199	23827.688	9.901	1268.4803	25.2247	35.3230	3.114
	104.000	548564.1	1791070.8	31.226	28383.063	13.440	1469.4009	23.9793	31.7234	3.705
	112.000	499219.5	1792600.0	34.669	33402.625	17.979	1698.8725	22.7301	28.6345	4.335
	120.000	449874.8	1793347.8	38.704	38912.688	23.548	1960.4272	21.5372	25.9978	4.975
	128.000	400530.2	1793702.1	43.610	44953.563	30.292	2259.5486	20.4408	23.7210	5.694
	136.000	351185.5	1793872.7	49.826	51587.063	38.332	2604.5457	19.4664	21.7910	6.633
	140.124	325747.6	1793922.6	53.747	55267.188	43.144	2804.2352	19.0174	20.8939	7.324
1 ENG CØ	140.124	325747.6	896961.3	26.781	55267.188	43.144	2804.2352	19.0174	20.8939	7.324
	144.000	313794.2	896977.6	27.826	58828.125	47.723	2897.7649	18.6090	20.1072	7.828
CUTØFF	146.124	307243.4	896984.1	28.429	60790.125	50.626	2950.9247	18.2384	19.6474	8.127
SEPARATIØN	146.124	193296.4	.0	-.017	60790.125	50.626	2950.9247	18.2384	19.6374	8.127
END CØAST	151.624	193296.4	.0	-.009	65753.438	57.701	2934.6366	17.3943	18.6040	8.446
	151.624	193296.4	.0	-.009	65753.438	57.701	2934.6366	17.3943	18.6040	8.446
BØØSTER IMP.	421.180	113947.0	.0	-.000	-.000	401.793	3145.6706	334.0618	-37.5329	8.065
START CØV	151.624	193296.4	207000.0	10.502	65753.438	57.701	2934.6366	17.3943	25.7599	8.446
	161.624	188414.3	207000.0	10.774	74367.625	70.783	3011.5378	16.2268	24.4504	9.513
DRØP WEIGHT	161.624	188171.3	207000.0	10.788	74367.625	70.783	3011.5378	16.2268	24.4504	9.513
	209.000	165042.1	207000.0	12.300	110451.750	139.553	3441.1487	11.3808	17.9792	11.827
	257.000	141608.1	207000.0	14.335	139402.688	222.375	3995.9659	7.5278	10.9431	13.952
	305.000	118174.1	207000.0	17.178	161072.813	321.309	4695.7180	4.5758	3.4873	16.649
	353.000	94740.2	207000.0	21.427	175734.688	440.250	5585.8224	2.3657	-4.2707	20.092
	401.000	71306.2	207000.0	28.468	183607.125	584.934	6755.0408	.7724	-12.1555	24.621
CUTØFF	433.422	55477.5	207000.0	36.591	185198.875	701.377	7794.9993	-.0001	-17.4739	28.651

MARSHALL SPACE

M-AERØ-D Table 3 4 AUGUST 1964

SATURN IB TWO STAGE TO 100 N. M. CIRCULAR ORBIT FOR (SA-203) LH_2 EXPERIMENT

	TIME SEC	XXX M	YYY M	ZZZ M	DXX M/SEC	DYY M/SEC	DZZ M/SEC	DRAG KG	DYN PRES KG/(M)SQ
LIFT ØFF	.000	.0	.0	.0	388.849	.000	126.345	1500.0	.000
	8.000	3110.9	111.3	1010.3	388.864	28.554	126.232	3417.0	49.430
	16.000	6222.4	469.4	2019.7	389.461	61.832	126.108	6048.4	224.079
	24.000	9361.9	1114.0	3028.0	396.878	100.152	125.973	11417.2	555.862
	32.000	12600.3	2084.7	4035.2	414.447	143.333	125.830	17926.5	1059.273
	40.000	16022.3	3420.2	5041.3	443.287	191.255	125.672	25370.1	1722.042
	48.000	19733.3	5153.2	6045.9	487.155	242.337	125.498	39088.3	2484.998
	56.000	23859.0	7294.2	7049.2	546.745	292.119	125.312	81795.1	3194.760
	64.000	28518.1	9808.7	8050.9	620.605	335.791	125.113	111305.0	3655.770
	64.361	28742.8	9930.3	8096.1	624.350	337.727	125.104	110680.7	3671.109
	72.000	33842.2	12670.9	9051.0	714.242	380.405	124.903	89831.4	3868.533
Q MAX	73.000	34563.1	13054.2	9175.9	727.614	386.263	124.876	85041.1	3867.789
	75.131	36145.3	13890.9	9442.0	757.388	398.918	124.817	79329.7	3838.289
	80.000	40010.7	15905.0	10049.3	832.043	428.594	124.680	66038.9	3615.695
	88.000	47222.8	19534.4	11045.8	975.359	479.091	124.446	44191.1	2867.568
	96.000	55687.2	23574.3	12040.4	1145.244	531.068	124.200	28449.5	2129.607
	104.000	65619.9	28034.0	13033.0	1342.644	584.023	123.943	17327.3	1509.195
	112.000	77248.1	32922.2	14023.5	1569.533	638.308	123.674	9803.8	993.357
	120.000	90819.1	38252.8	15011.8	1829.012	694.813	123.393	5294.9	617.022
	128.000	106612.3	44049.3	15997.7	2126.079	755.113	123.102	2901.0	375.713
	136.000	124957.0	50351.0	16981.4	2468.513	821.596	122.800	1551.3	230.607
	140.124	135540.1	53816.2	17487.5	2666.488	859.381	122.639	1112.0	181.040
1 ENG CØ	140.124	135540.1	53816.2	17487.5	2666.488	859.381	122.639	1112.0	181.040
	144.000	146064.3	57146.4	17962.5	2764.791	859.053	122.486	767.5	132.215
CUTØFF	146.124	151995.9	58971.0	18222.6	2820.502	858.920	122.401	621.7	110.102
SEPARATIØN	146.124	151995.9	58971.0	18222.6	2820.502	858.920	122.401	153.9	110.102
END CØAST	151.624	167505.0	63549.4	18895.2	2819.145	805.969	122.178	83.0	59.399
	151.624	167505.0	63549.4	18895.2	2819.145	805.969	122.178	83.0	59.399
BØØSTER IMP.	421.180	905211.6	-64724.3	49790.3	2603.546	-1762.324	104.918	.0	472246.559
START CØV	151.624	167505.0	63549.4	18895.2	2819.145	805.969	122.178	.0	59.399
	161.524	195162.2	71355.3	20114.9	2912.800	755.072	121.759	.0	19.032
DRØP WEIGHT	161.624	195162.2	71355.3	20114.9	2912.800	755.072	121.759	.0	19.032
	209.000	345445.9	101202.5	25832.5	3402.446	500.571	119.554	.0	.027
	257.000	522430.1	118364.0	31510.3	3988.904	206.686	116.960	.0	.002
	305.000	730238.0	120085.6	37055.1	4692.011	-147.650	114.014	.0	.003
	353.000	975360.7	102647.4	42450.2	5552.467	-599.388	110.725	.0	.001
	401.000	1266931.1	60023.5	47679.3	6644.721	-1211.112	107.099	.0	.001
CUTØFF	433.422	1497095.7	12062.1	51109.3	7589.727	-1774.018	104.462	.0	.002

APPENDIX B

DRAG FORCE, ORBITAL LIFETIME, AND GROUND COMMUNICATIONS VISIBILITY FOR SATURN IB LIQUID HYDROGEN ORBITAL EXPERIMENT

This appendix contains information in support of MSFC study efforts on the Saturn IB Liquid Hydrogen Orbital Experiment. Three areas are covered: orbital drag forces, orbital lifetime, and ground tracking and data acquisition coverage. The orbiting configuration is shown in Figure 1. The S-IVB stage and nose cone are inserted into a 185-km (100-N. M.) earth orbit with maximum LH_2 remaining in the S-IVB stage. The experiment is designed to provide special TV coverage of the propellant behavior.

A. ORBITAL DRAG FORCES

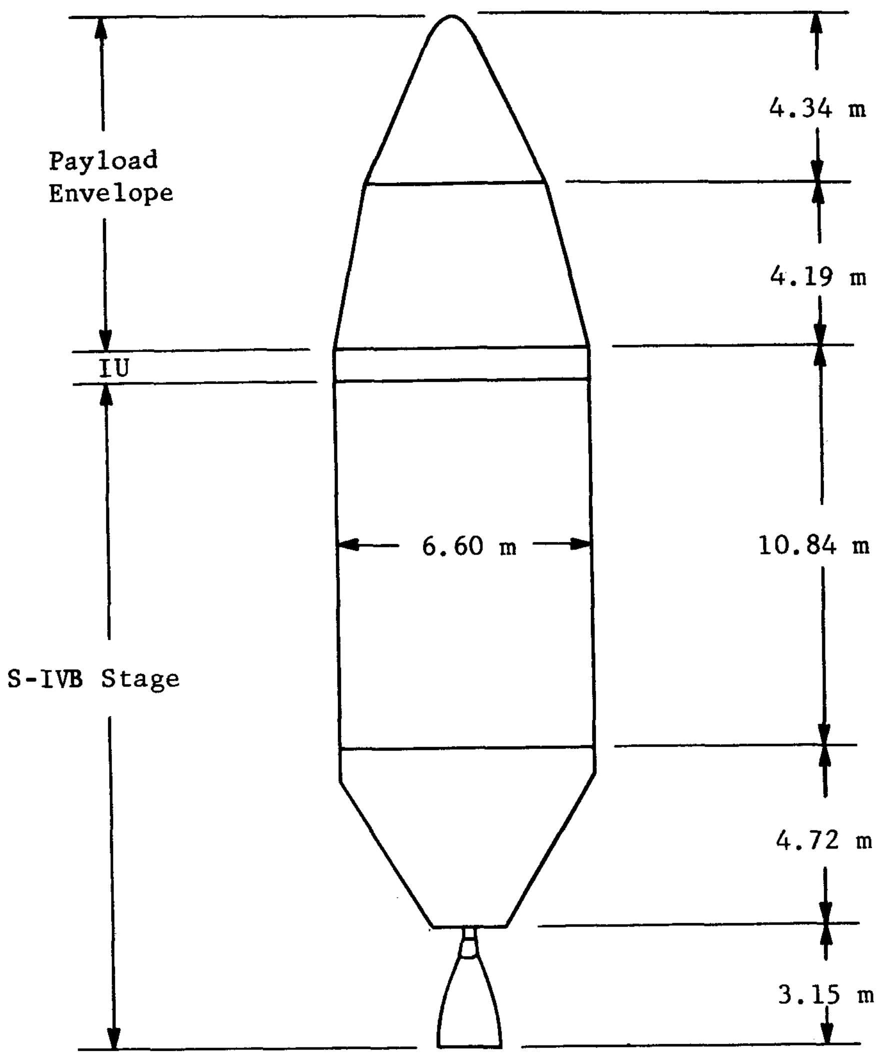
The predicted drag forces are given in the table below for constant angles of attack of 0 degree (nose-on), 6 degrees (per request) and 90 degrees (broadside) and considering a 1969 launch year.

Angle of Attack	C_DA	Force: Nominal		Force: Maximum Limit ($+2\sigma$)	
(deg)	(M^2)	(N)	(lb)	(N)	(lb)
0	70.5	1.0	0.22	3.3	0.73
6	92.0	1.3	0.29	4.3	0.96
90	275.7	3.9	0.88	12.9	2.9

Uncertainties in extrapolating the atmospheric model with time and prediction of the orbital drag coefficient reflect in considerable uncertainty in prediction of the drag force. The maximum limit force given in the table represents the possible 2σ variation in prediction. The maximum force is about 3.3 times the nominal.

B. ORBITAL LIFETIME

If a propulsive venting force is applied to the orbiting vehicle, the orbital lifetime will be dependent on the magnitude and direction of this force. If the venting force is applied to keep the propellants seated and is, therefore, larger than the drag force, the orbit altitude will increase during venting, rather than decay.



From: Drawing 0787
R-P&VE-AVD

Figure 1. Orbiting Configuration

In the absence of venting, a minimum lifetime of about 24 hours would be expected for a nose-on attitude stabilization. This considers an initial orbiting mass of 25,630 kg (56,500 lb) and a propellant boiloff rate of 420 kg/hr (930 lb/hr), based on information received from R-P&VE-PTF. On the other hand, attitude stabilization will nominally be lost after ten hours in orbit. If the vehicle then acquires a random tumble, a total minimum lifetime of about 14 hours could be expected.

It may be seen that the actual lifetime will be strongly dependent upon the vehicle attitude history and upon the propellant venting scheme. However, there should be no difficulty in achieving a desired 10-hour lifetime, assuming attitude control for that length of time.

C. DRAG VARIATION

The orbital drag force and lifetime to be expected will vary with the launch year, since the density of the upper atmosphere varies with the eleven-year solar activity cycle. The effect of this variation will produce changes in the drag forces and lifetimes in the years 1965-1971. Complete details on this variation can be found in Memorandum from Chief, Operations Studies Branch, R-AERO-FO, Drag Force for LH_2 Experiment Configuration, August 17, 1964. The atmospheric density used in calculating the orbital drag force and lifetime was obtained from Marshall Technical Paper MTP-AERO-63-2, Earth's Aerospace Properties from 100 to 100,000 km Altitude, January 3, 1964.

D. TRACKING AND COMMUNICATION VISIBILITY

An analysis was made of the ground station tracking, data acquisition, and possible TV coverage for the orbital flight phase of the missions. Pertinent information is given for planning the required ground network. Figure 2 shows the ground projections of the first three orbital revolutions. Visibility circles are shown for a five-degree elevation angle for primary existing or planned Manned Space Flight Network and DOD ground stations. The dashed circles represent sites with existing or planned 85-foot dishes. The coverage time for the three revolutions is given in Table 1. The columns represent acquisition time, loss time, and total coverage time above the five-degree elevation. Several points should be noted.

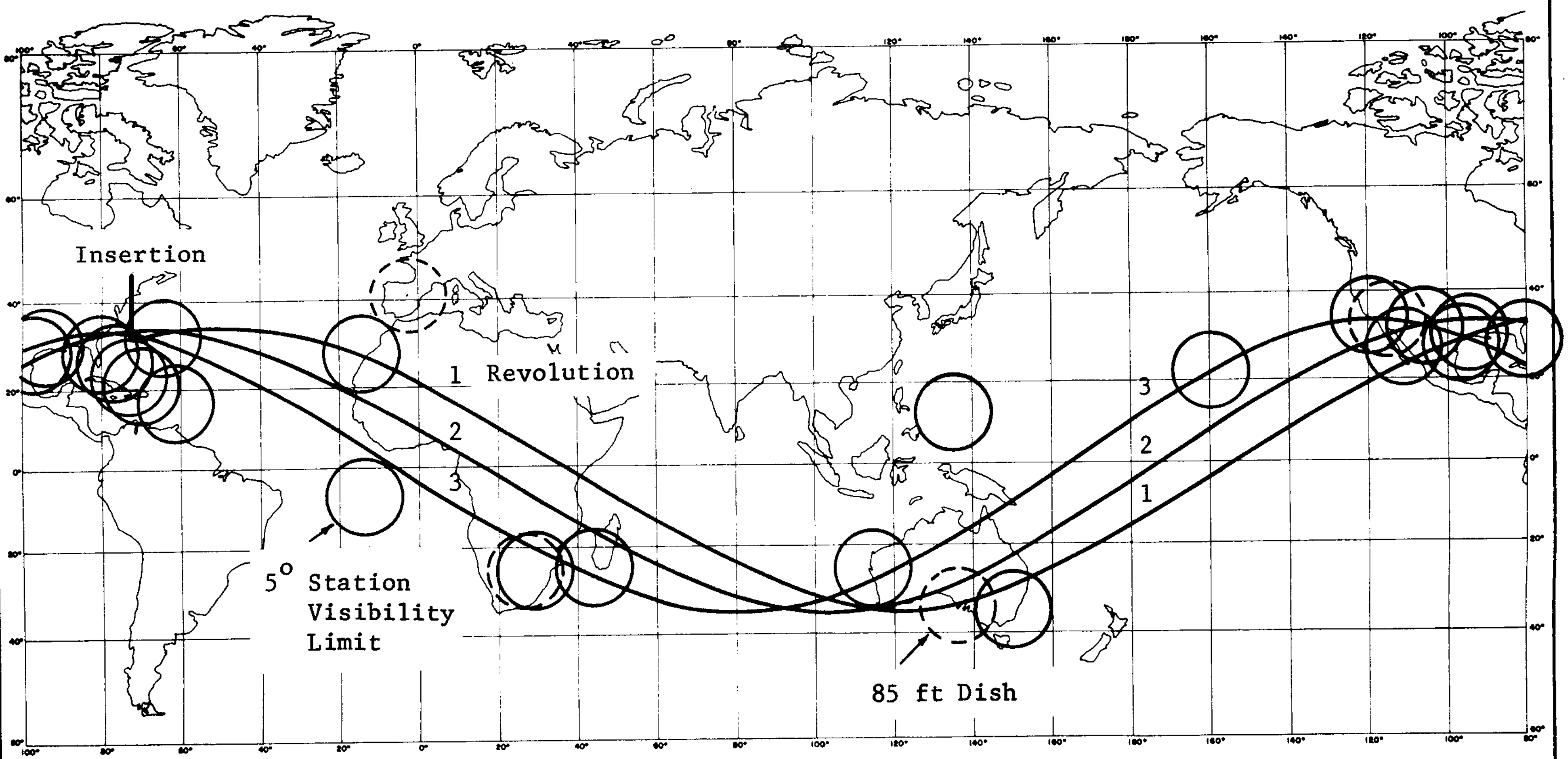


Figure 2. Orbital Ground Projection 185 km Circular Orbit

TABLE 1

GROUND COMMUNICATIONS TIME LINE

POST INSERTION

STATION	TRACK TIME (min)
Cape Kennedy	0.5
Grand Bahama	0.8
San Salvador	1.0
Bermuda	4.2

ORBITAL COVERAGE

Station	Rev I Time Acquired* H	M	S	Rev I Time Lost* H	M	S	Rev I Track Time min	Rev II Time Acquired* H	M	S	Rev II Time Lost* H	M	S	Rev II Track Time min	Rev III Time Acquired* H	M	S	Rev III Time Lost* H	M	S	Rev III Track Time min
Canary Islands	0	17	32	0	22	15	4.7														
Ascension															3	28	18	3	31	57	3.7
Pretoria, S. A.															3	39	09	3	43	49	4.8
Madagascar								2	09	46	2	14	07	4.4	3	42	48	3	46	45	4.0
Carnarvon, Aus.	0	53	46	0	56	11	2.4	2	26	11	2	30	00	3.8	3	58	34	4	03	12	4.4
Canberra, Aus.	1	01	34	1	03	27	1.9														
Hawaii								2	51	03	2	55	05	4.3	4	23	31	4	27	55	4.4
Pt. Arguello	1	29	45	1	29	51	.1	3	00	09	3	04	41	4.5	4	32	34	4	37	23	3.2
Guaymas, Mexico	1	29	00	1	33	53	4.8	3	02	05	3	06	30	4.4	4	35	03	4	39	30	4.5
White Sands	1	30	25	1	35	13	4.8	3	02	53	3	07	49	4.9	4	35	38	4	40	31	4.9
Corpus Christi	1	32	36	1	36	41	4.1	3	05	15	3	09	27	4.2	4	37	54	4	40	18	2.6
Houston	1	32	30	1	37	21	4.9	3	05	26	3	10	08	4.7	4	38	09	4	43	02	4.9
Cape Kennedy	1	36	0	1	40	26	4.4	3	08	47	3	13	31	4.7	4	41	35	4	46	4	4.5
Grand Bahama	1	36	49	1	40	38	3.8	3	09	31	3	14	00	4.5	4	42	10	4	46	48	4.6
San Salvador	1	38	32	1	40	45	2.2	3	10	46	3	14	48	4.3	4	43	13	4	47	55	4.7
Grand Turk								3	12	08	3	15	23	3.3	4	44	12	4	48	59	4.8
Antigua								3	15	06	3	17	32	2.4	4	46	46	4	51	27	4.7
Bermuda	1	39	15	1	44	02	4.8	3	12	13	3	16	20	4.1							

DSIF COVERAGE

Station	Rev I Time Acquired* H	M	S	Rev I Time Lost* H	M	S	Rev I Track Time min	Rev II Time Acquired* H	M	S	Rev II Time Lost* H	M	S	Rev II Track Time min	Rev III Time Acquired* H	M	S	Rev III Time Lost* H	M	S	Rev III Track Time min
Woomera	0	57	42	1	02	22	5.3	2	31	06	2	33	55	2.8							
Joburg, S.A.															3	39	08	3	43	48	4.7
Goldstone	1	30	00	1	31	42	1.7	3	00	56	3	05	28	4.5	4	33	24	4	38	06	4.7

* Time is referenced to liftoff in hours (H), minutes (M) and seconds (S).

1. The orbital insertion point occurs at 433 seconds flight time at a ground range of 845 km from Cape Kennedy, near the five-degree pickup by the Bermuda site. This yields 4.2 minutes of Bermuda coverage following insertion. Bermuda also covers the flight on two successive revolutions, making it a most desirable location for TV coverage. The orbital as well as immediate post-insertion behavior of the propellant may be observed.

2. Excellent coverage is supplied by at least four continental North American locations on three successive revolutions. These include Guaymas, White Sands, Houston, and Corpus Christi. The selection of any one site as a primary TV station should be weighed principally on existing equipment to satisfy the required needs, as comparable coverage is provided from all sites. The White Sands site is already highly instrumented. Very little instrumentation presently is installed either at Guaymas, Corpus Christi or Houston, although future instrumentation is planned.

3. The Cape Kennedy site provides excellent coverage on three revolutions as well as 30 seconds of data following orbital insertion.

4. The coverage provided by the 85-foot dish located at Goldstone, California, is 1.7 min on revolution 1, 4.5 and 4.7 min on revolutions 2 and 3. Intermittent coverage is supplied by the three other 85-foot dish sites. The Woomera site covers revolutions 1 and 2. Although coverage by the Goldstone site is scanty on revolution 1, excellent coverage is provided on the two successive revolutions. As essential facilities are already existing at Goldstone and at Woomera, consideration should be given to their use.

November 12, 1964	APPROVAL	TM X-53158

SATURN IB LIQUID HYDROGEN ORBITAL EXPERIMENT DEFINITION

Compiled By

Advanced Studies Office

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This document has also been reviewed and approved for technical accuracy.

F B Cline

F. B. CLINE
Acting Director, Propulsion and Vehicle Engineering Laboratory

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