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Memorandum

TO Distribution

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Memo #M-ASTR-TSJ-33-62

FROM SATURN Office, Astrionics Division
M-ASTR-TSJ

SUBJECT Technical Information Summary Concerning SATURN Vehicle SA-3

This memorandum outlines, through a series of sketches, some of the important features and sequences concerning the third SATURN flight vehicle. The sketches are devoted primarily to the control and instrumentation aspects of the vehicle but also touch on the launch facility and countdown schedule.

1. Introduction

The SATURN C-1 Program has as its primary objective, the development of a large two stage vehicle for use in space operations. Ten vehicles are planned for the research and development phase and are divided into Block I (SA-1 through SA-4) and Block II (SA-5 through SA-10). The first four SATURN vehicles will be launched from complex VLF 34 at Cape Canaveral, on an azimuth of 100 degrees East of North. The general arrangement of launch complex VLF 34 is seen in Figure 1.

In the Block I series, only the S-I stage is propelled and there is no separation of the S-I stage from the dummy upper stages. The S-IV stage will be active on the Block II vehicles (SA-5 and subsequent).

2. Review of Previous Flight Test Results

a. The first vehicle of this series (SA-1) was launched with no technical holds, at 1006 EST on October 27, 1961 from Launch Complex 34, AMR, on an azimuth of 100° East of North.

The flight performance of the vehicle was excellent; no malfunctions or deviations were observed which could be considered a serious system failure or design deficiency. However, sloshing instability was encountered after 90 seconds of flight; although there was more sloshing than expected, it did not approach the point of endangering vehicle control or structural integrity. The maximum engine deflections due to the effects of sloshing were ±1/2 degree in pitch and yaw, and ±1/4 degree in roll. Additional anti-slosh baffles have been placed into the lower end of the eight outer tanks (See Figure 9) on SA-2, 3 and 4 to control propellant sloshing during the latter part of the propulsion period.

Pitch actuator deflections of 2 degrees resulted from the tilt program commands, as expected. Even though this did not have any appreciable effect on the stability of the vehicle, a "smooth" tilt program (See Figure 8) was introduced on SA-2 and subsequent vehicles.

SA-1 did not have active path guidance; however, passenger guidance hardware was onboard for the purpose of R&D testing. In addition, certain R&D control sensors were also flown.

SA-1 had a total of 505 inflight measurements of which only 8 failed, and 11 only partially failed. The inflight calibrator on Link 3 failed during flight. All RF systems performed satisfactorily.

For a detailed analysis of the flight performance of SA-1, see MPR-SAT-WF-61-8, SATURN SA-1 Flight Evaluation, dated December 14, 1961.

b. The second SATURN flight vehicle (SA-2) was also launched from VLF 34 with no technical holds at 0900 EST on April 24, 1962. The launch proceded without difficulties and the flight test was a complete success.

Operation of the control system was satisfactory; the sloshing instability noted in the SA-1 flight was successfully supressed by the addition of the baffles in the lower end of the outer propellant tanks. Engine pitch deflections of 2 degrees resulted from an unexpected binding of the tilt device cam. These transient deflections appeared at intervals of approximately 13 seconds. This condition has been eliminated by a redesign of the fine zero cam of the tilt program transmission. In addition, a special laboratory check of the operation of this device is now made.

SA-2 did not have active path guidance; however, passenger guidance hardware was onboard for R&D testing. R&D control sensors were again flown.

A total of 526 inflight measurements were flown on SA-2. Of this total, only 6 measurements failed, and 1 measurement partially failed. All RF systems performed satisfactorily.

A water cloud experiment (Project Highwater) was successfully accomplished by injecting the upper stages' water ballast (190,000 pounds) into the upper atmosphere at an altitude of 105 km by rupturing the upper stages with primacord at L. O. + 162 seconds.

For a detailed analysis of the flight performance of SA-2, see MPR-SAT-WF-62-5, SATURN SA-2 Flight Evaluation, dated June 5, 1962.

3. Resume of Main Features of SA-3

a. Full Propellant Loading (620, 000 pounds on SA-1 and SA-2 versus 780, 000 pounds on SA-3).

This required a change in the control gains program for SA-3. This additional weight of 160, 000 pounds has reduced the liftoff acceleration considerably (1. 4 g on SA-1 and SA-2 versus 1. 2 g on SA-3).

b. Project Highwater

This experiment will be carried out for the second time on SA-3. The main differences are:

	SA-2	SA-3
Time	L. O. + 162 sec.	L. O. + 295 sec.
Altitude	105 km	167 km
Range	81 km	211 km

c. Centaur Experiment

This is a dynamic pressure study conducted in support of the Centaur program. The details of the simulated Centaur weather shield are shown in Figure 3. The failure of the Centaur flight is believed to have resulted from deficiencies in its weather shield.

d. ST-124 P Inertial Platform System

A laboratory model of the ST-124 system (manufactured by M-ASTR) will be flown for the first time.

e. The S-I retrorockets will be fired at Inboard Engine cutoff + 12 seconds.

f. Outboard Engine Cutoff will be given by a propellant depletion signal instead of by a timer as in SA-1 and SA-2.

g. An umbilical tower swing arm will service the forward end of the S-I stage instead of the long cable mast used for SA-1 and SA-2.

4. <u>Control System</u> (See Figure 6)

There is no active path guidance in SA-3. Control information is supplied to the Flight Control Computer by the following sensors:

a. The ST-90 Stabilized Platform System which provides the attitude reference signals, and

b. The 4 Local Angle-of-Attack Transducers which provide the angle-of-attack signals.

The necessary attitude rate information is obtained by electrical differentiation of the three attitude signals in the Flight Control Computer by means of R-C networks.

This computer filters, amplifies, and/or attenuates, shapes, and sums these signals and in turn issues steering commands to the eight hydraulic actuators for proper positioning of the four outer H-1 engines, which effect vehicle control in pitch, yaw and roll. The control system gain factors (a_o, a_1, and b_o') for the pitch, yaw and roll axes are shown in Figure 7, along with the engine and control actuator locations. It should be noted that this gain program is somewhat different from SA-2 because the vehicle's control characteristics were changed due to the full propellant loading. With this new gain program, the stability of the vehicle is improved over SA-1 and SA-2.

Sloshing of the propellants in the S-I stage is controlled by the anti-slosh baffles to the level where it does not significantly affect the control system. First and second bending mode influences on the control system are suppressed by phase shaping and/or attenuation of those frequencies (≈ 2 to ≈ 4 cps and ≈ 6 to ≈ 12 cps) in the Flight Control Computer. (See Figure 12).

Pitch programming of the vehicle is provided by a cam device located in the Servo Loop Amplifier Box which contains the pre-selected tilt program.

After D. C. power transfer at L. O. -35 seconds, the primary 28 v. d. c. power for the vehicle system is supplied by two 2650 amp-min. capacity batteries. These batteries also supply

a. The 1800 VA Rotary Inverter which provided 400 cycle, 115 v. a. c. power primarily to the ST-90 and the vehicle control system, and

b. The 400 VA Static Inverter which supplies 400 cycle, 115 v.a.c. power to the ST-124 Inertial Platform System.

5. Guidance and Control R&D Hardware (See Figure 6)

The following devices are being test flown on SA-3 to obtain some of the necessary engineering information required for the development of the guidance and control system of future SATURN C-1 vehicles:

a. Three ST-90 mounted AB-3 Accelerometers which provide velocity information in "digital" form.

b. A Guidance Signal Processor - Repeater (GSP-R) which processes the "digital" velocity signals and conditions them for telemetering.

c. A 3 axes Control Rate Gyro Package which provides attitude rate information as a.c. signals to the Control Signal Processor.

d. A Control Signal Processor which converts the attitude rate information to d.c. control signals and conditions them for telemetering.

e. Pitch and yaw Control Accelerometers which measure lateral vehicle accelerations, convert the signals to d.c. control signals and condition them for telemetering.

f. A Q-ball Transducer which measures pitch and yaw angles-of-attack and dynamic pressure, converts the signals to d.c. and conditions them for telemetering.

g. A ST-124P Inertial Platform System (Platform, Electronic Box and GSP-R) which provides attitude error signals from its gimbal resolvers to the telemetering system and velocity information in "digital" form from its three AB-3 Accelerometers through its GSP-R where they are conditioned for telemetering.

h. In addition, a Horizon Sensor System and a Time Base Selector are also being flight tested.

6. Trajectory

The basic flight trajectory for SA-3 (with all eight engines operating) is outlined in Figure 5. The tilt program is based on the seven engines operating case after L. O. + 30 seconds. The vehicle pitch angle-of-attack brought about by this compromise is rather small and therefore acceptable from the control standpoint. Cutoff of the inboard engines is initiated by the propellant level sensors around 140 seconds after liftoff. (See Figure 9). The outboard engines cutoff about 8 seconds later when they receive a signal from the first "Thrust OK" pressure switch to sense turbopump pressure decay.

7. Telemetry System

The telemetry system of ten separate RF links, has 35 components. Figure 10 shows the type of telemetry unit, its transmitter frequency, and measuring capacity. FM/FM is used extensively on SA-3. Two SS/FM units are used to transmit high frequency information (vibration and accoustical measurements). A UHF system and PCM system are being flown for the first time.

8. Measuring System

The measuring system has more than 1000 measuring components (signal conditioners; a. c. and d. c. amplifiers, zone boxes, etc., and measuring transducers; flowmeters, accelerometers, pressure gauges, etc.), which provide over 700 individual measurements (611 flight and 106 blockhouse).

9. R. F. Systems (Range Safety and Tracking)

The four R. F. systems used for range safety and tracking are shown in Figure 11. These systems are comprised of 19 components.

a. Command System: The function of the command system is to energize the correct vehicle function upon receipt of the proper R. F. command signal from the ground transmitter (range safety officer). Range safety requires that each vehicle launched from the Atlantic Missile Range carries an approved command destruct system. The system is comprised of two separate and independent units; the only items that are common are the antennas and some cabling. Each unit receives its power from a separate 28 v. d. c. battery.

On the SA-3 flight, release of the water ballast in the S-IV and S-V dummy stages will be made (Project Highwater - See Figure 5). The release will be by command from the range safety officer through the vehicle command destruct system, about 150 seconds after cutoff. This experiment will also be a positive test of the S-I stage command destruct system.

b. Azusa and C-Band Radar Systems: These systems provide signals to a ground computer complex to obtain position and velocity information. These trajectory data are presented on plotting boards for the range safety officer to use in determining "real time" vehicle performance. In addition, they are also used for the post flight evaluation of the vehicle's trajectory.

c. UDOP System: This system provides trajectory data (vehicle position and velocity) for the post flight evaluation of the vehicle's performance.

for CB Jones
F. W. BRANDNER

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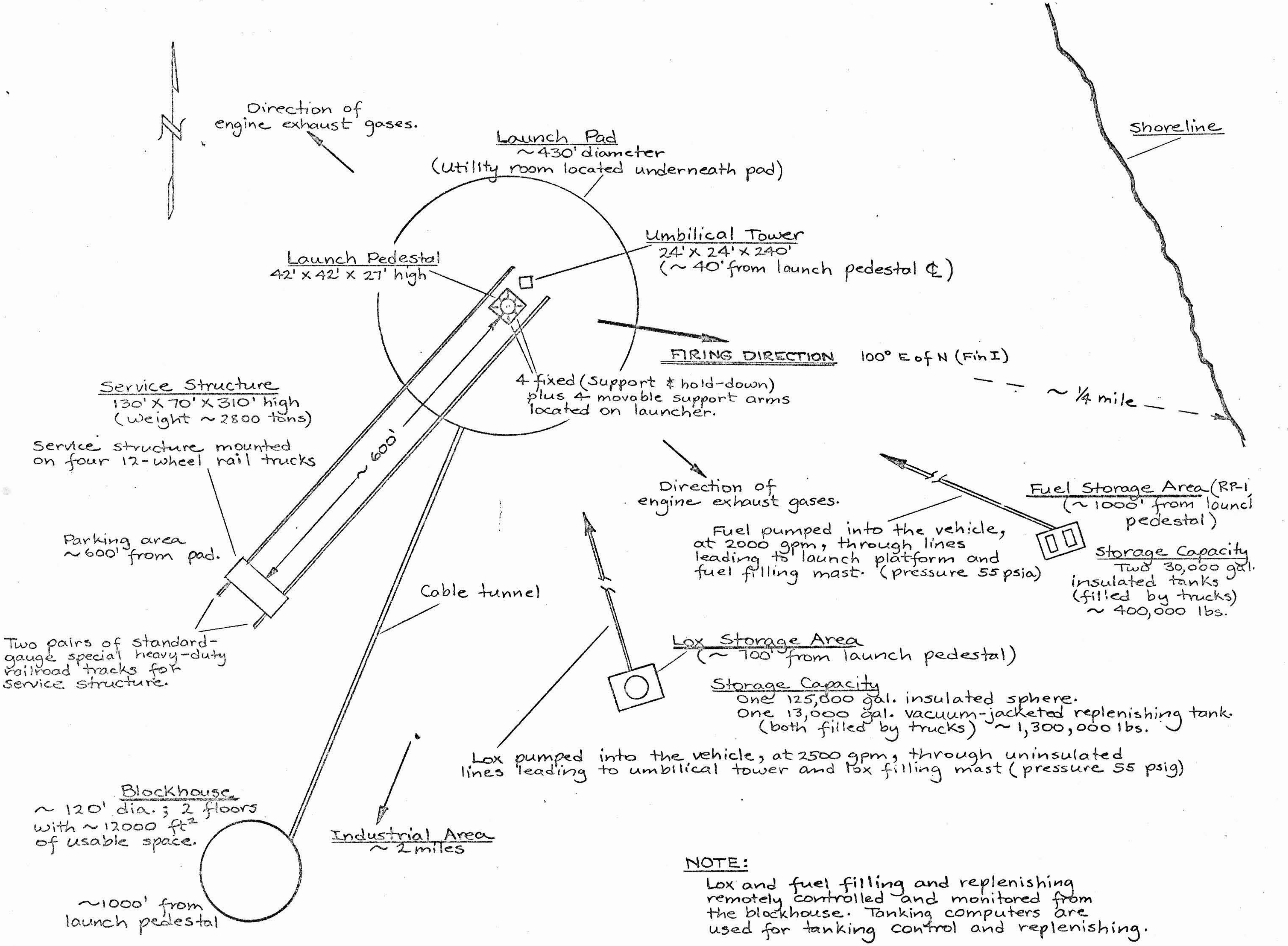

Direction of engine exhaust gases.
Launch Pad
~430' diameter
(Utility room located underneath pad)
Shoreline
Umbilical Tower
24' x 24' x 240'
(~ 40' from launch pedestal ℄)
Launch Pedestal
42' x 42' x 27' high
FIRING DIRECTION
100° E of N (Fin I)
~ 1/4 mile
4 fixed (Support & hold-down) plus 4 movable support arms located on launcher.
Service Structure
130' x 70' x 310' high
(weight ~2800 tons)
Service structure mounted on four 12-wheel rail trucks
~ 600'
Direction of engine exhaust gases.
Fuel Storage Area (RP-1
(~ 1000' from launch pedestal)
Storage Capacity
Two 30,000 gal. insulated tanks (filled by trucks) ~ 400,000 lbs.
Fuel pumped into the vehicle, at 2000 gpm, through lines leading to launch platform and fuel filling mast. (pressure 55 psia)
Parking area ~600' from pad.
Cable tunnel
Two pairs of standard-gauge special heavy-duty railroad tracks for service structure.
Lox Storage Area
(~ 100' from launch pedestal)
Storage Capacity
One 125,000 gal. insulated sphere.
One 13,000 gal. vacuum-jacketed replenishing tank.
(both filled by trucks) ~ 1,300,000 lbs.
Lox pumped into the vehicle, at 2500 gpm, through uninsulated lines leading to umbilical tower and lox filling mast (pressure 55 psig)
Blockhouse
~ 120' dia.; 2 floors with ~ 12000 ft² of usable space.
~1000' from launch pedestal
Industrial Area
~ 2 miles
NOTE:
Lox and fuel filling and replenishing remotely controlled and monitored from the blockhouse. Tanking computers are used for tanking control and replenishing.

Figure 1

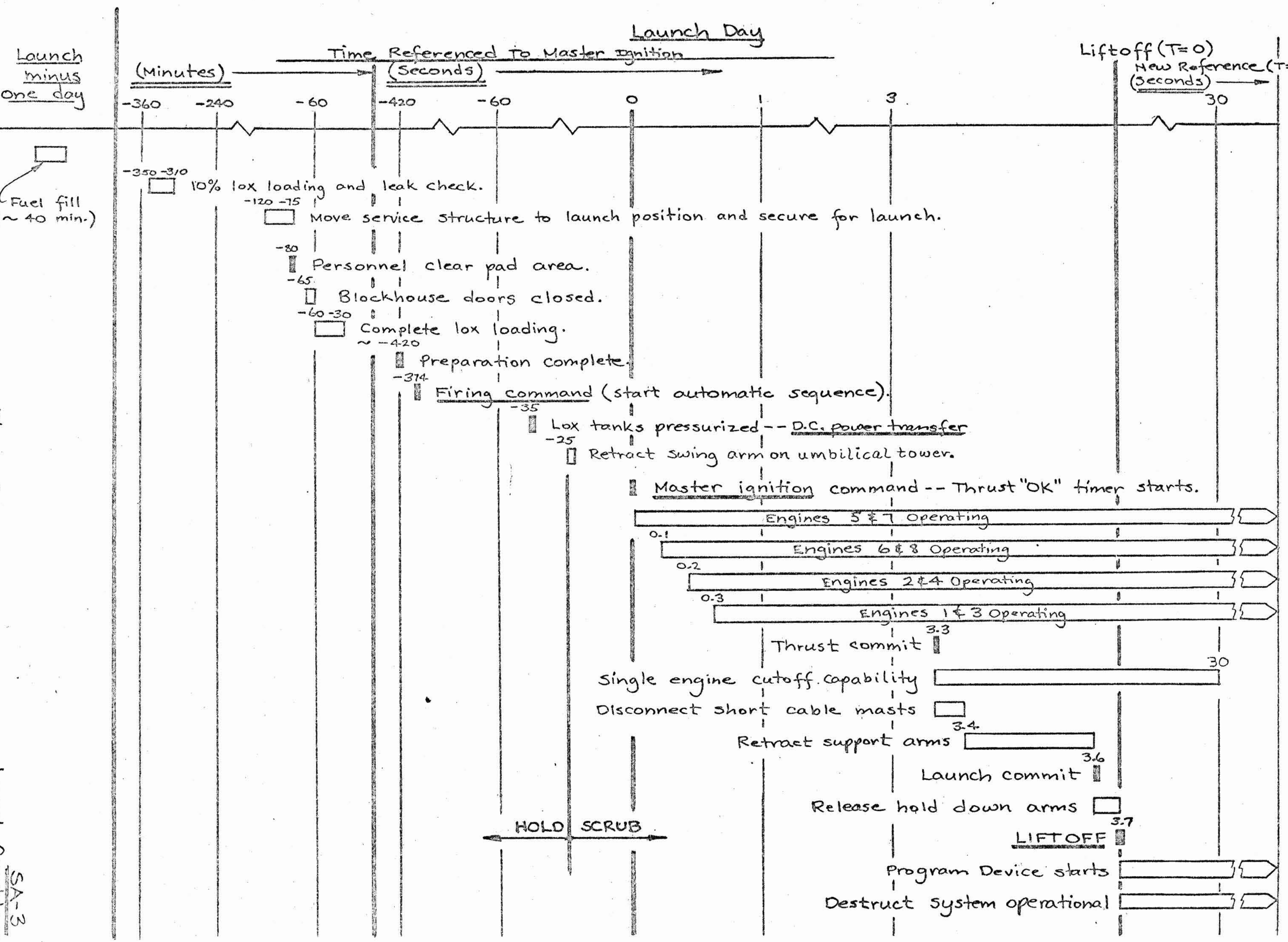
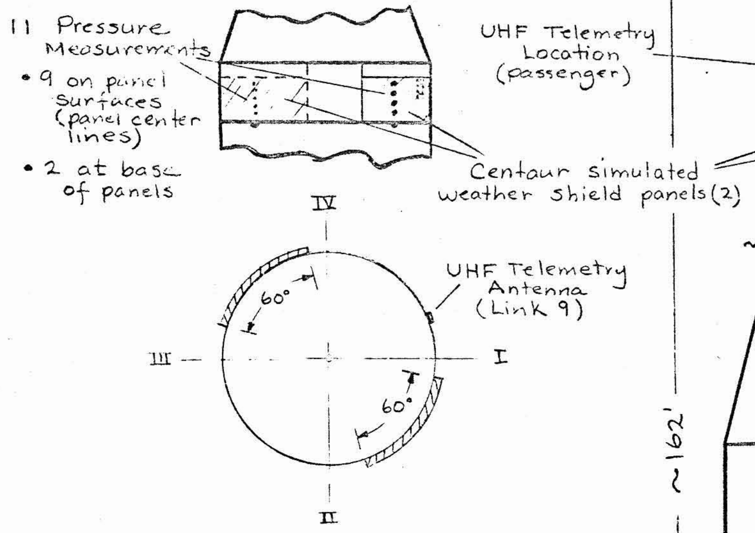
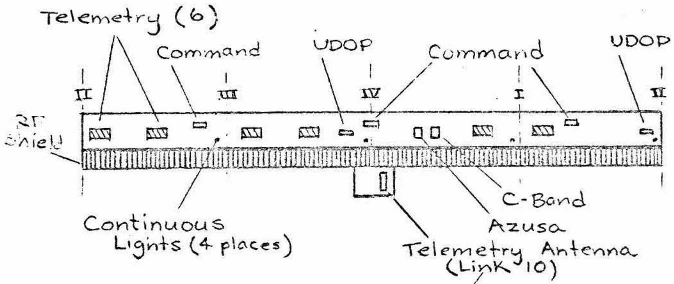


Figure 2

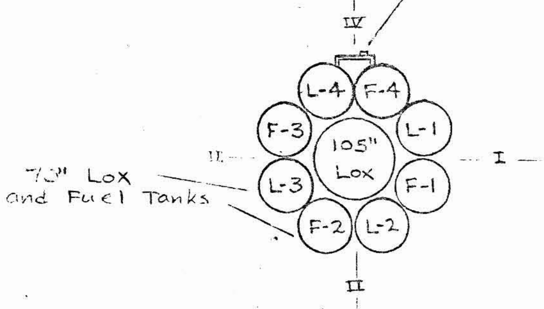
SA-3
Launch Countdown



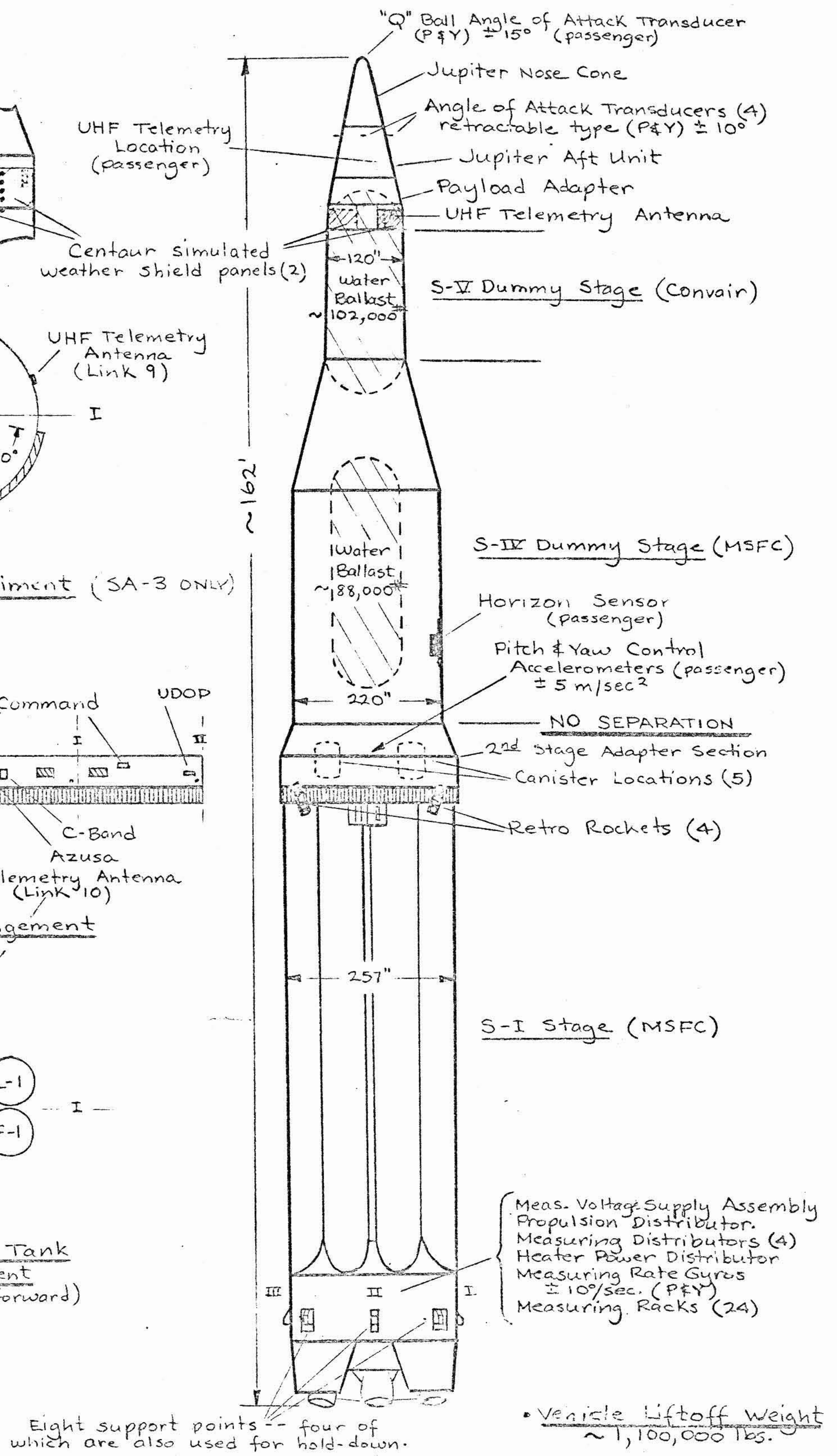
Centaur Experiment (SA-3 ONLY)



Antenna Arrangement



Lox and Fuel Tank Arrangement
(View looking forward)



• Vehicle Liftoff Weight ~ 1,100,000 lbs.

• Propellant Weight at Liftoff ~ 780,000 lbs. (Lox + RP-1)

ENGINE DATA:

- Start System: Solid propellant turbine spinner plus hypergolic fuel mixture.
- Four inboard engines fixed mounted; 3° cant angle.
- Four outboard engines gimble mounted - provides ± 7° gimbaling; 6° cant angle.
- ~ 165,000 lbs. thrust each engine. (Total Thrust ~ 1,320,000 lbs.)

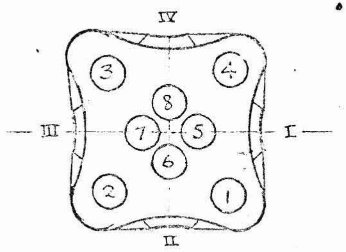
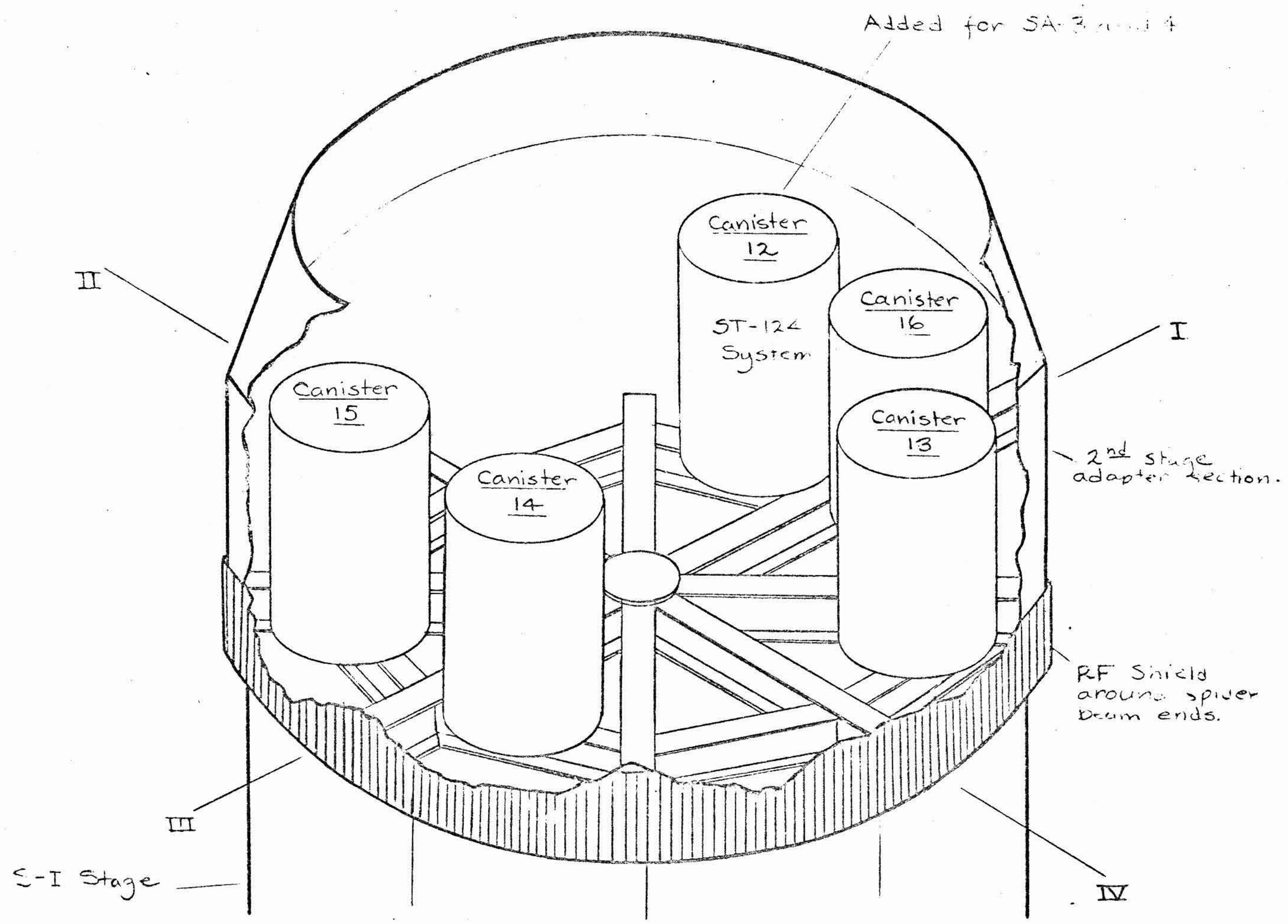


Figure 3

View Looking Forward

SA-3 Vehicle Configuration



Major Electrical Components Located In Pressurized Canisters

Canister 12

- ST-124 P & Electronics Box
- Guidance Signal Processor-R
- Main Distributor
- Measuring Racks (4)

Canister 13

- Master Measuring Voltage Supply.
- Measuring Distributor
- Time Base Selector
- Meas. Rate Gyros (P,Y,R) ±100°/sec.
- Measuring Racks (9).

Canister 14

- Batteries (2); 28 vdc
- Inverter (1800 VA)
- Static Inverter (400 VA)
- Power Distributor
- UDOP
- Azusa
- C-Band Radar

Canister 15

- ST-90 & Servo Loop Amplifier Box
- Control Computer
- Program Device J
- Control Rate Gyros (P,Y,R) ± 10°/sec.
- Guidance Signal Processor-R
- Control Voltage Supply
- Flight Sequencer & Slave
- Control Distributor
- Command Receivers & Decoders (2)
- Control Signal Processor.

Canister 16

- All telemeter Equipment except Link 10 (9 telemeter assemblies)

NOTE:

Canisters have pre-flight cooling ONLY!

Figure 4

SA-3
Canister Arrangement

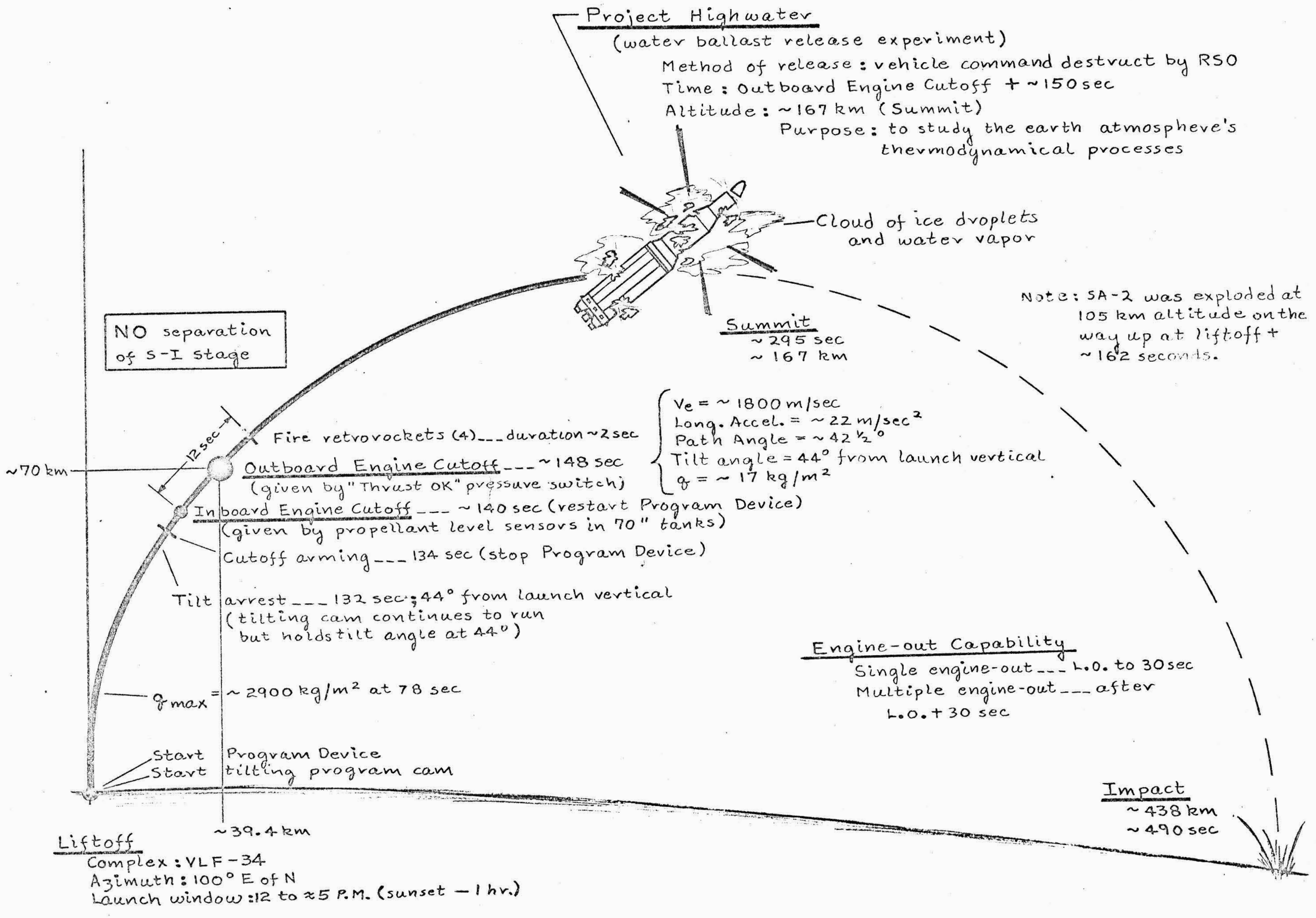
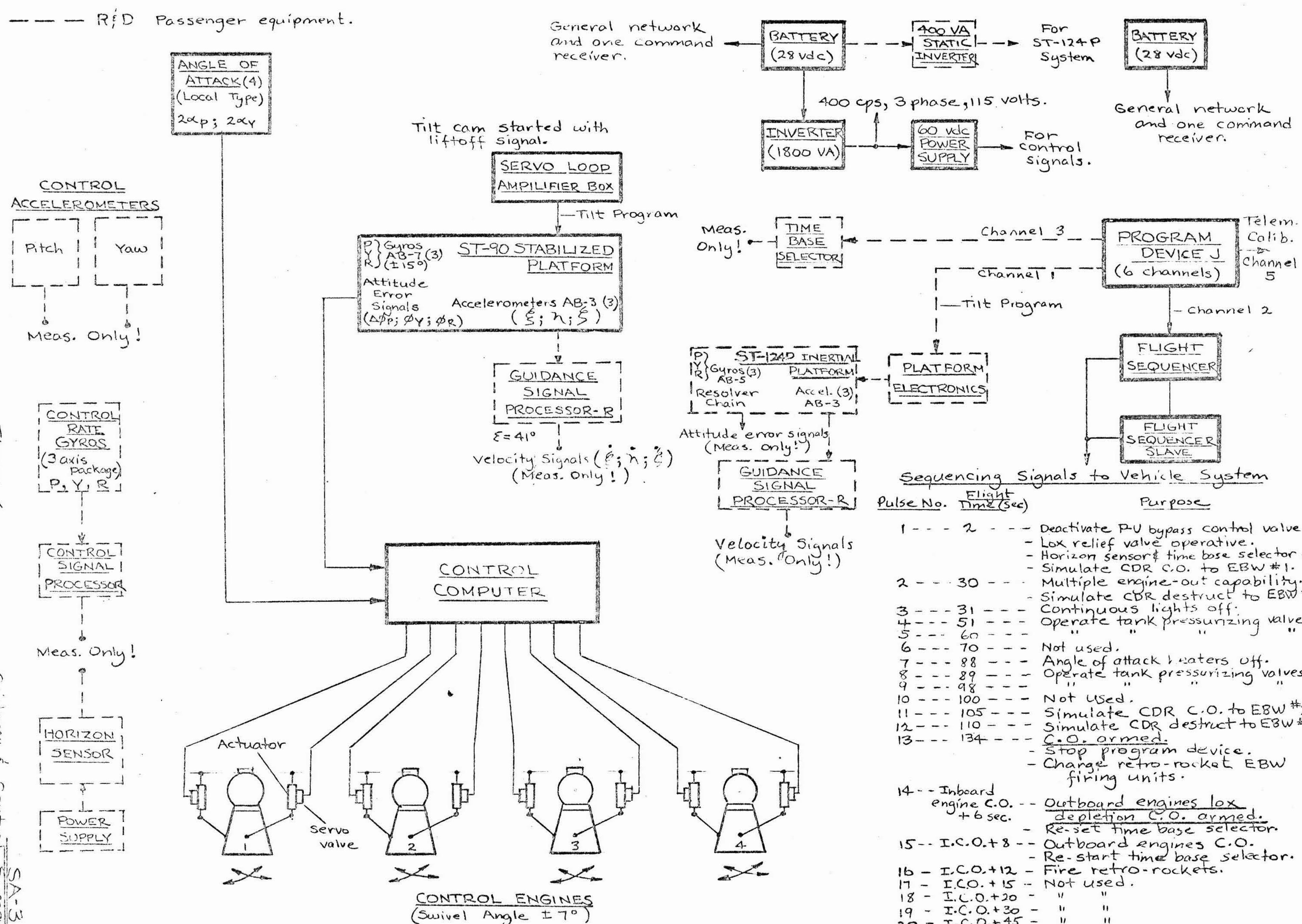


Figure 5

SA-3
Trajectory Information



Sequencing Signals to Vehicle System

Pulse No.	Flight Time (sec)	Purpose
1	2	Deactivate P-U bypass control valve.
		Lox relief valve operative.
		Horizon sensor & time base selector or
		Simulate CDR C.O. to EBW #1.
2	30	Multiple engine-out capability.
		Simulate CDR destruct to EBW #1
3	31	Continuous lights off.
4	51	Operate tank pressurizing valves
5	60	" " "
6	70	Not used.
7	88	Angle of attack heaters off.
8	89	Operate tank pressurizing valves.
9	98	" " " "
10	100	Not used.
11	105	Simulate CDR C.O. to EBW #2
12	110	Simulate CDR destruct to EBW #2
13	134	C.O. armed.
		Stop program device.
		Change retro-rocket EBW firing units.
14	Inboard engine C.O. + 6 sec.	Outboard engines lox depletion C.O. armed.
		Re-set time base selector.
15	I.C.O. + 8	Outboard engines C.O.
		Re-start time base selector.
16	I.C.O. + 12	Fire retro-rockets.
17	I.C.O. + 15	Not used.
18	I.C.O. + 20	" "
19	I.C.O. + 30	" "
20	I.C.O. + 45	" "

Figure 6

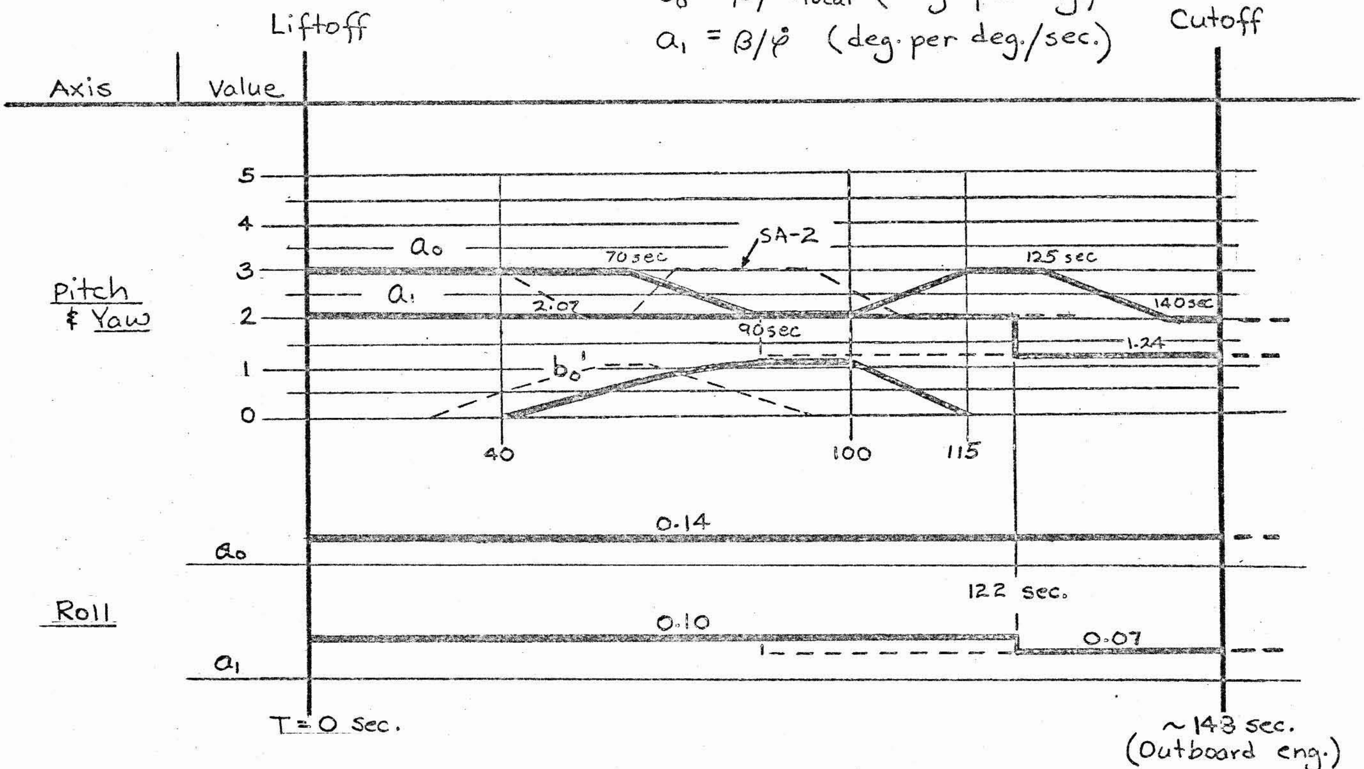
SA-3
Guidance & Control System Block Diagram

Control System Gain Factors

$a_0 = \beta/\varphi$ (deg. per deg.)

$b_0' = \beta/\alpha_{local}$ (deg. per deg.)

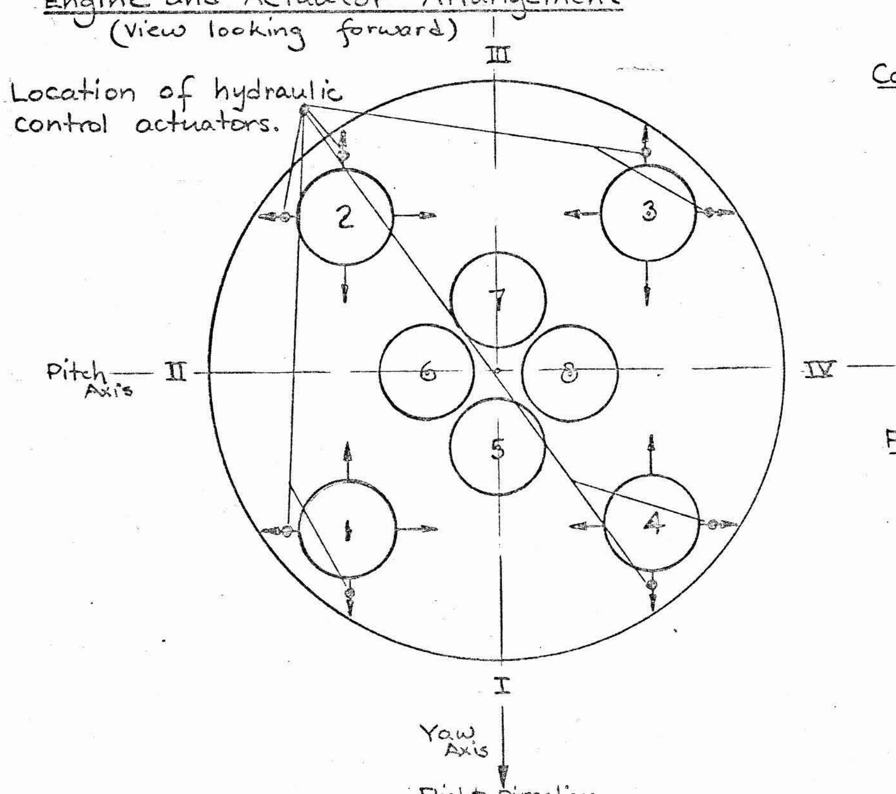
$a_1 = \beta/\dot{\varphi}$ (deg. per deg./sec.)



NOTE: For exact gain values see Astrionics Division Memo. NAV 451/62 dated Sept. 25, 1962

SA-2 gains are shown thus ---

Engine and Actuator Arrangement
(View looking forward)



Control Engines (1, 2, 3, 4)
Swivel angle ±7°
Mounting radius 95"
Cant angle 6°

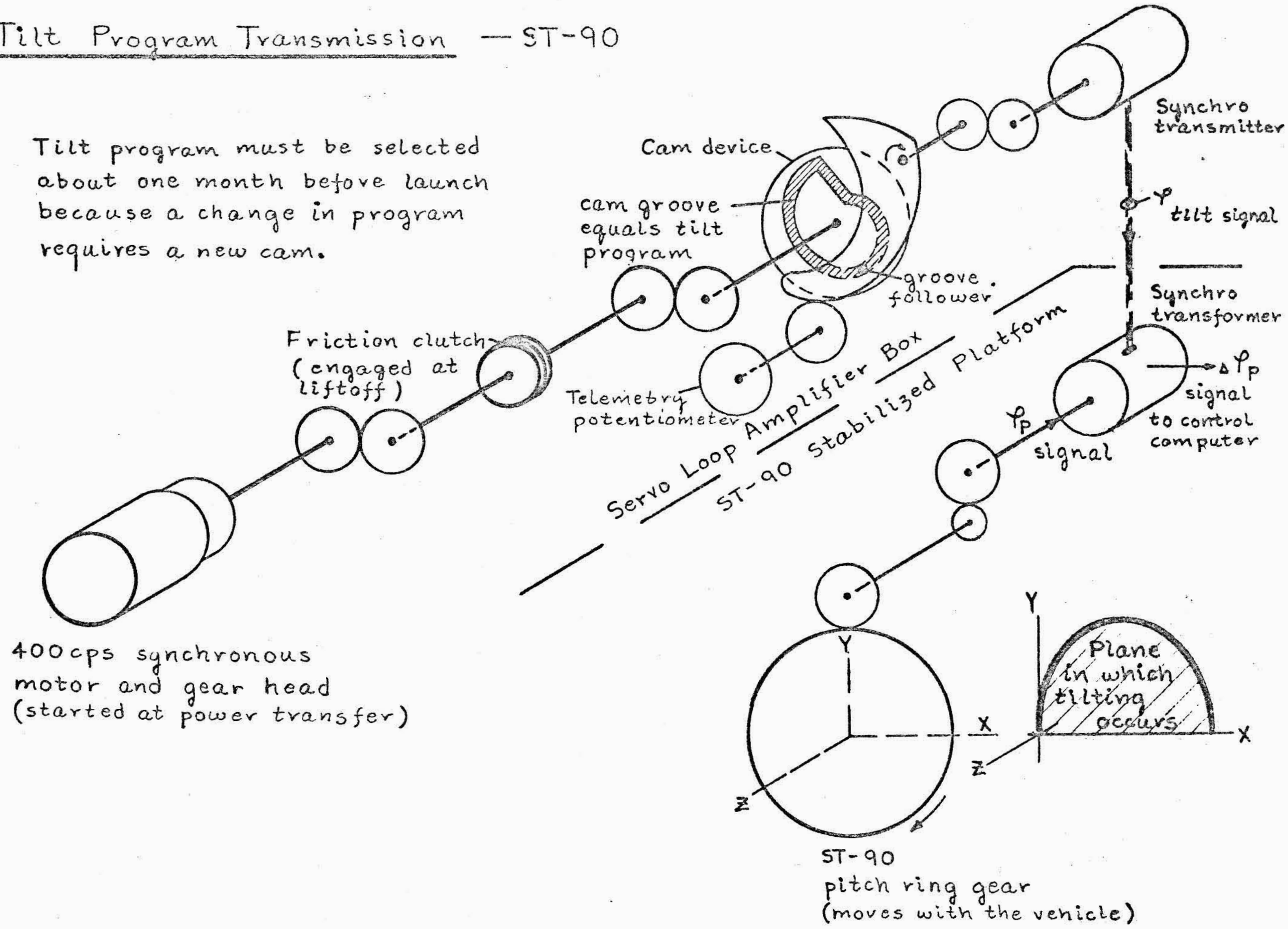
Fixed Engines (5, 6, 7, 8)
Mounting radius 32"
Cant angle 3°

Figure 7

SA-3
Control Information

Tilt Program Transmission — ST-90

Tilt program must be selected about one month before launch because a change in program requires a new cam.



Tilt Program Information — ST-90

Maximum tilt rate: 0.6°/sec

Final tilt angle: 44° from launch vertical

Tilt arrest: 132 sec after liftoff

Tilt program is based upon the engine-out concept; that is, the tilt angle is proper for only 7 engines operating from liftoff + 20 seconds.

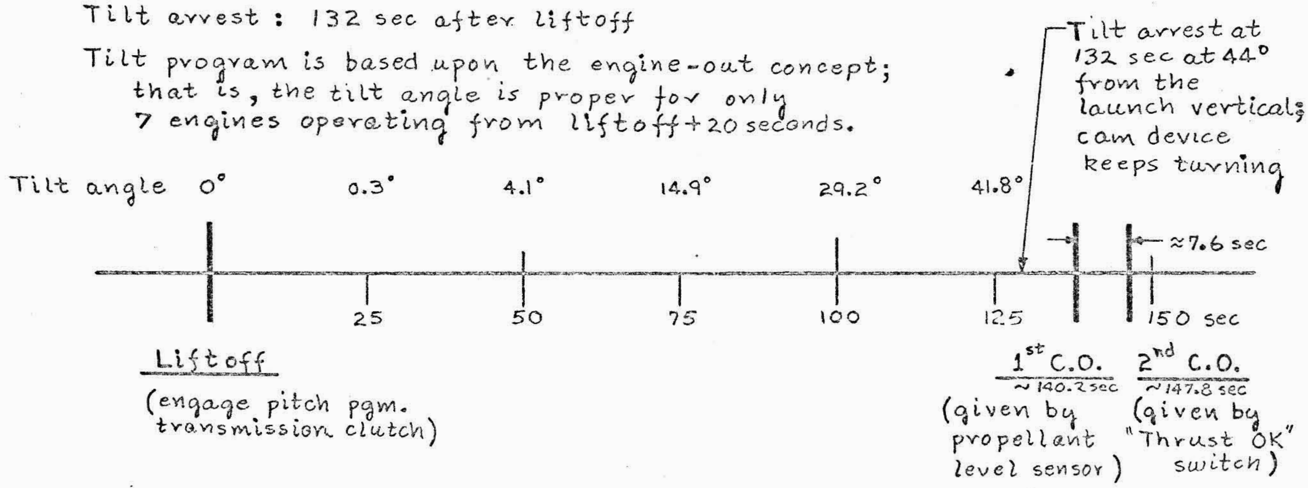


Figure 8

SA-3

Tilt Program Information

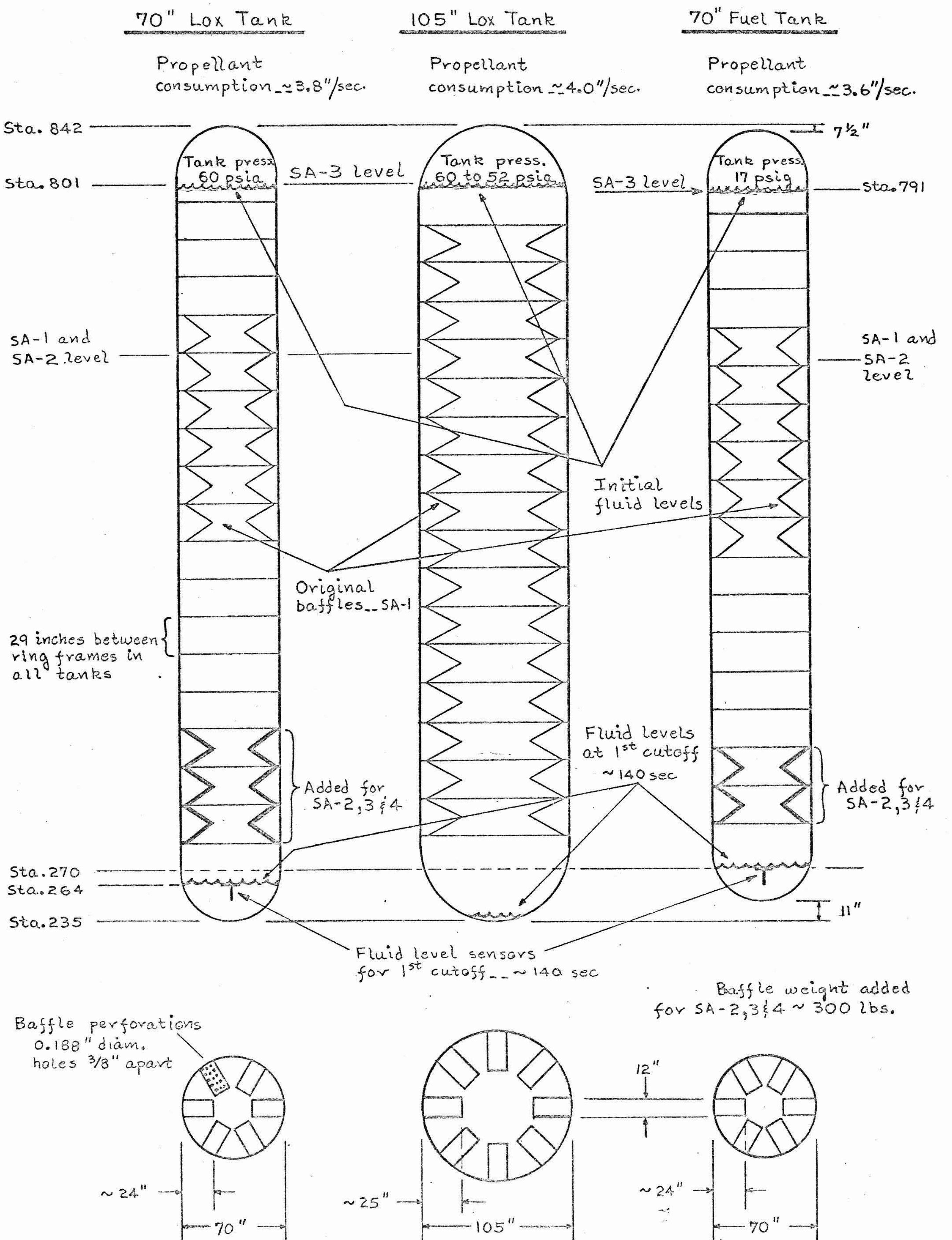


Figure 9

SA-3

Propellant Tanks

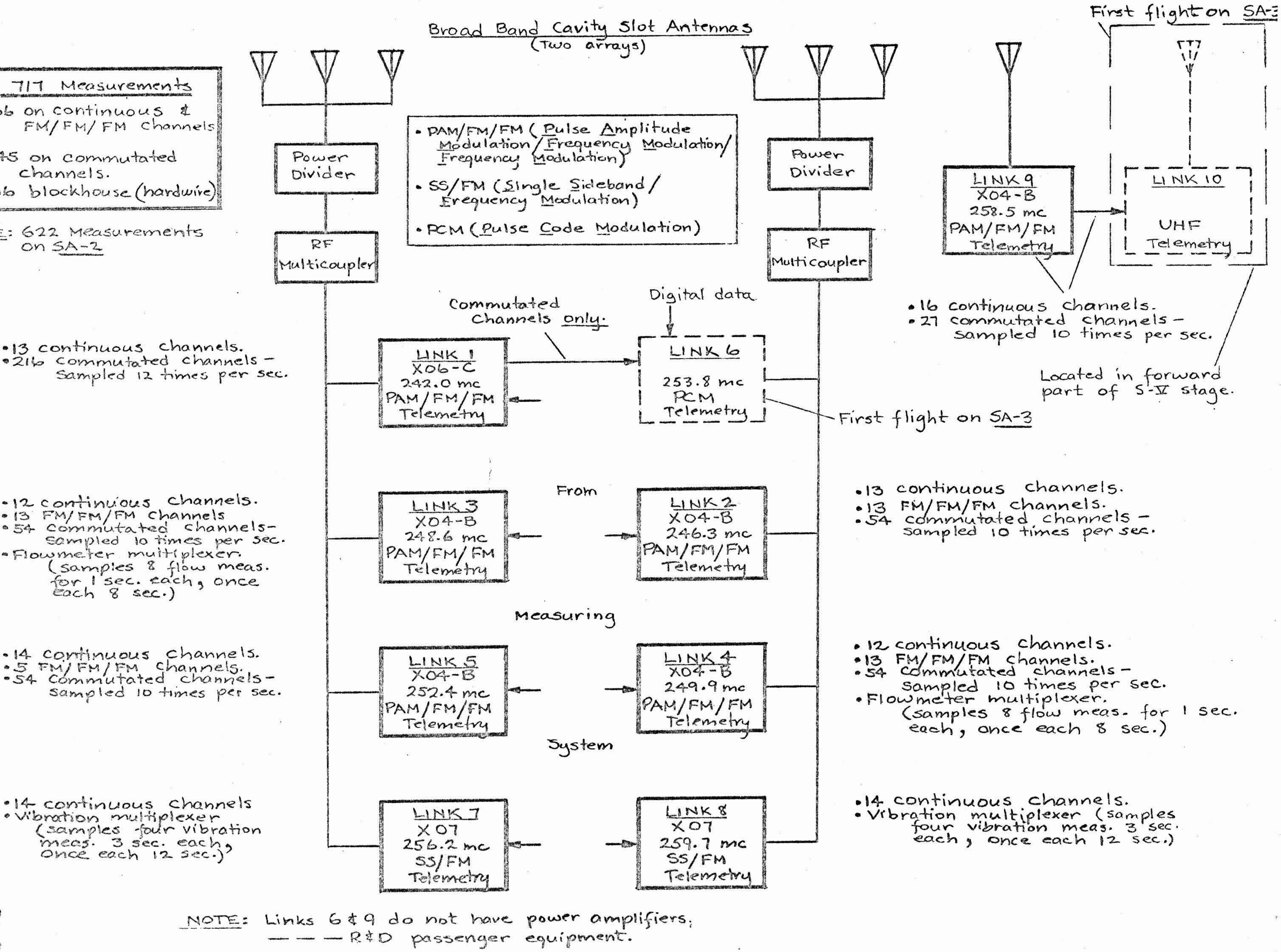
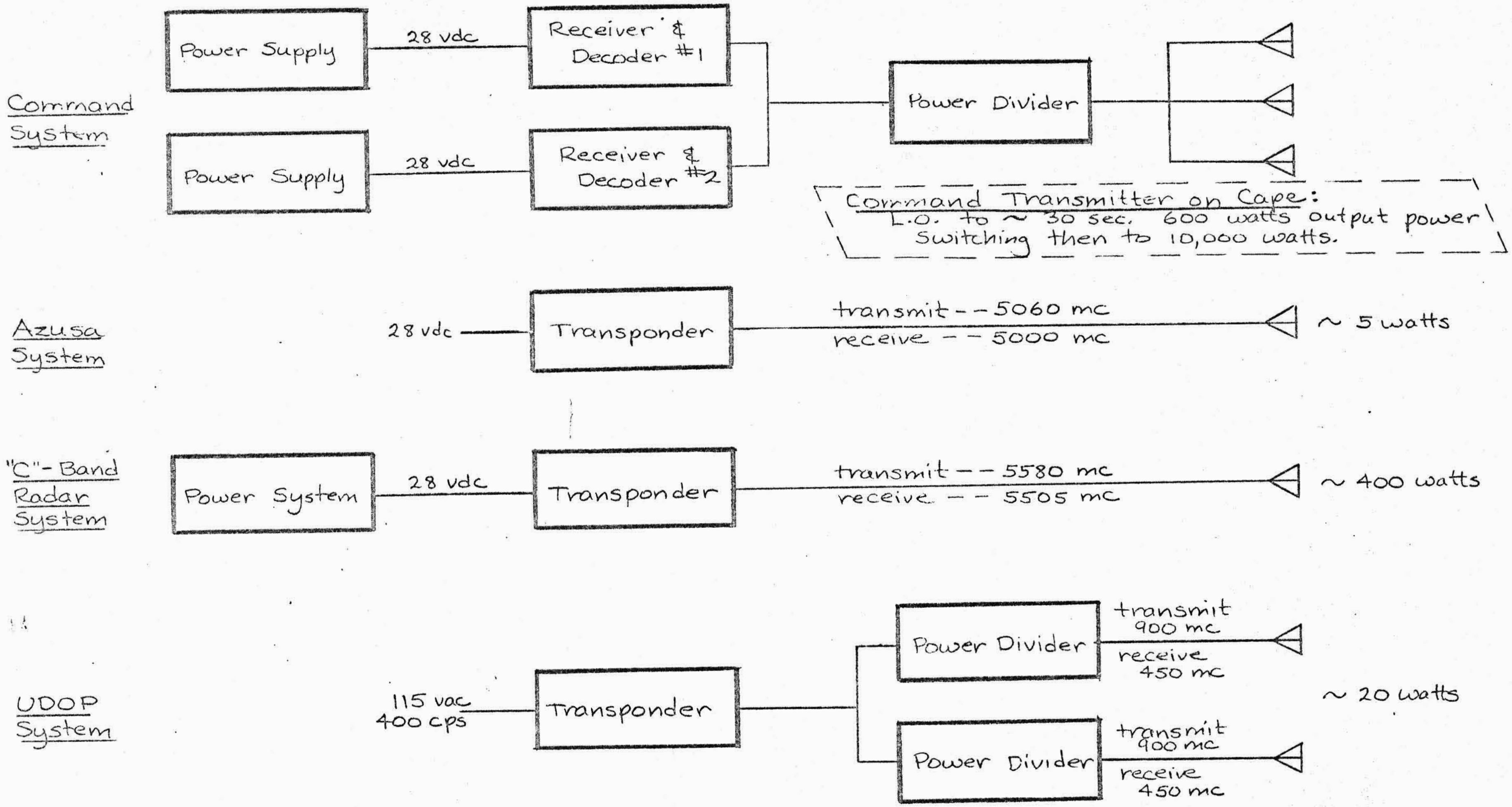


Figure 10

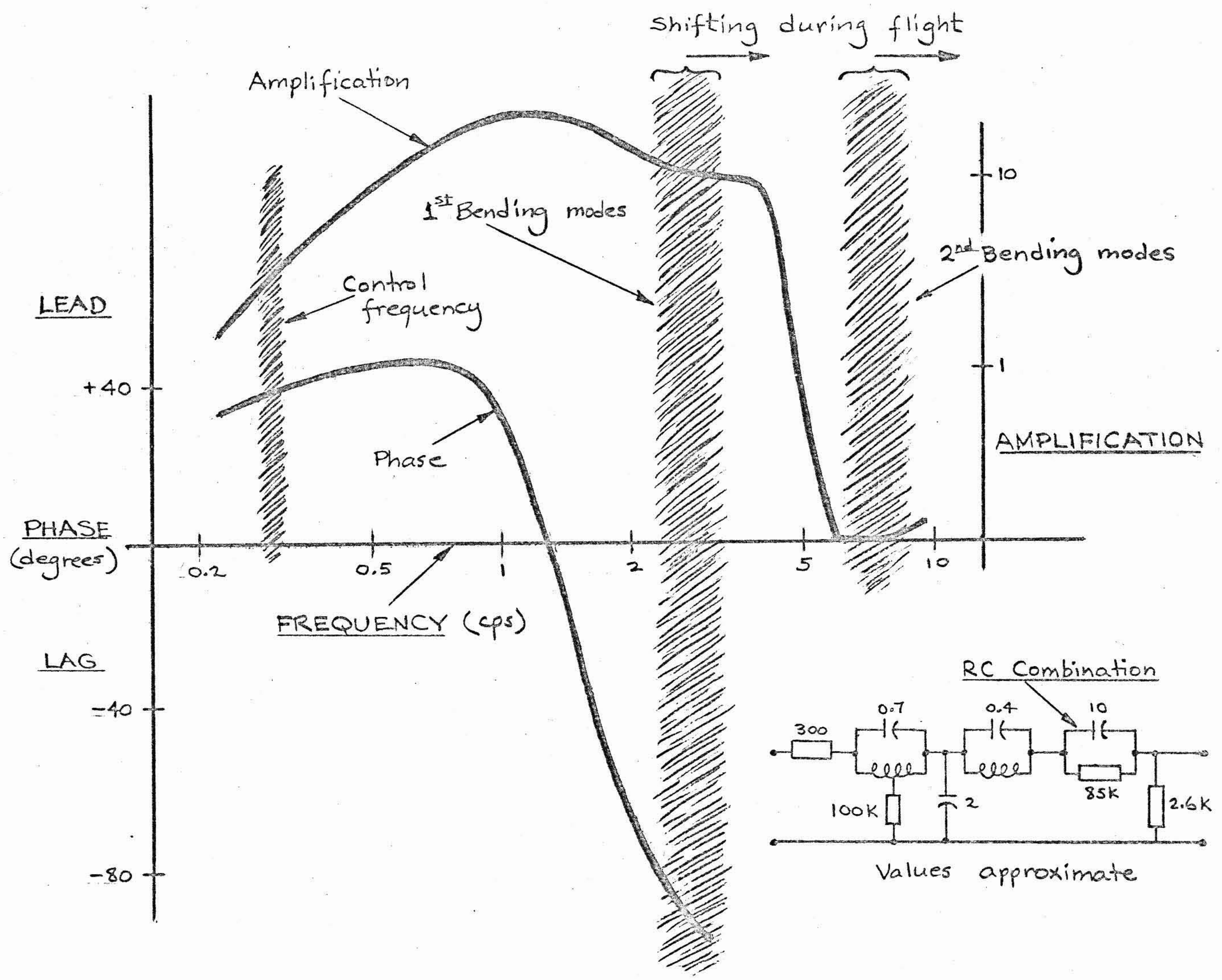
SA-3 Telemetry System



NOTE: "S"-Band Radar was on SA-1 and 2 ONLY

Figure 11

SA-3
RF Systems



NOTE: Same as SA-2

The shaping network operates in the following ways:

1. For the control frequency (~ 0.3 cps) it acts as a RC combination where a 40° phase lead with respect to the output signal (φ) is achieved.

2. For the 1st bending frequency (2-4 cps) it acts as a shaping network which provides approximately 60-80° phase lag. An amplification goes with it but has no significant importance.

3. For the 2nd bending frequency (6-12 cps) it acts as an attenuator.

Frequencies above 10 cps are suppressed by the servo loop.

SA-3

Simplified Explanation of Shaping Network - $\varphi_{P,Y}$

Figure 12