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Saturn IB/V - Instrument Unit

Technical Manual

MSFC No. III-5-509-2

IBM No. 66-966-0003

Navigation, Guidance, and Control System Description



NOTICE

This publication replaces the original technical manual titled: Navigation, Guidance, and Control System Description, MSFC No. III-5-509-2 / IBM No. 66-966-0003, dated 15 April 1966 and Change No. 1 thereto dated 1 May 1966.

The original manual should be destroyed since this new issue revises, enlarges, and updates the original subject matter to the AS-206 / 502 level.

George W. Ely
412

MSFC No. III-5-509-2

IBM No. 66-966-0003

TECHNICAL MANUAL

**NAVIGATION, GUIDANCE, AND
CONTROL SYSTEM DESCRIPTION**

Prepared under Contract

NAS 8-14000

by

International Business Machines Corporation

Federal Systems Division

Huntsville, Alabama

This publication replaces MSFC No. III-5-509-2/IBM No. 66-966-0003
dated 15 April 1966 and Change No. 1 thereto dated 1 May 1966.

1 November 1966

LIST OF EFFECTIVE PAGES

NOTE: The portion of the text affected by the changes is indicated by a vertical line in the outer margins of the page.

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Change	Revision							
1 May 66	1 Nov 66							

PREFACE

This technical manual provides system – level information on the Up-rated Saturn I and Saturn V Navigation, Guidance, and Control System. The contents of this manual will familiarize the reader with the complete system by three approaches:

- A description of the system
- A description of the separate functions – navigation, guidance, and control
- A description of each system component and its function.

Most of the information contained herein is of a general nature and is not referenced to any particular vehicle. However, in some areas, such as the flight sequence charts and flight program, the subject matter is at the AS-206 and/or AS-502 level and should be considered typical for all vehicles.

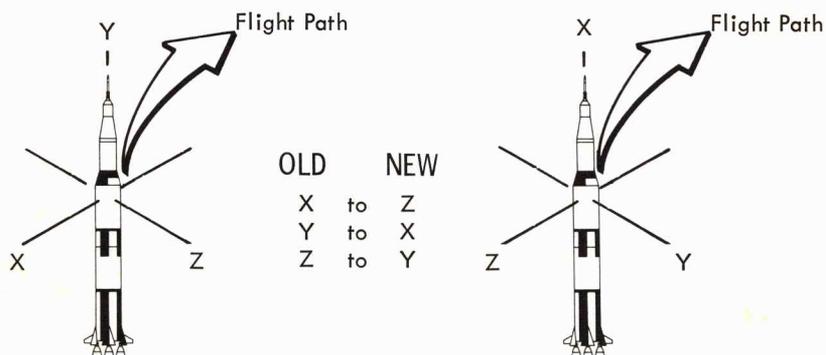
The contents will be updated as more information becomes available or when vehicle design changes dictate. Areas where changes are most likely to occur are: the flight program, sequence and mode control, and component characteristics.

NOTICE

SATURN/APOLLO COORDINATE CHANGES

The XYZ coordinates used in this book reflect the Project Apollo Coordinate System Standards (SE 008-001-1). Under these standards, the XYZ axes are defined as: the X axis is vertical through the launch site, the Z axis is parallel to the aiming azimuth, and the Y axis completes the right-handed system. Vehicle axes for roll, pitch, and yaw are also defined as X, Y, and Z, respectively.

This coordinate scheme becomes effective for vehicles 206 and 502 (and subsequent). The conversion from the old system to the new is shown below.



LIST OF RELATED DOCUMENTS

The following manuals have been published under NASA contracts as source and reference information on IU systems and/or components.

Title	Number		Published Date	Changed Date
	IBM	MSFC		
Structure Repair Manual	65-966-0011H	III-5-510-1	1 September 1965	
Auxiliary Power Distributors	65-966-0013H	III-5-510-2	1 October 1965	
Power Distributor	65-966-0014H	III-5-510-3	1 October 1965	
Emergency Detection System Distributor	65-966-0015H	III-5-510-4	1 October 1965	
Control Distributor	65-966-0016H	III-5-510-5	1 October 1965	
Measuring Distributors	65-966-0017H	III-5-510-6	1 October 1965	
56 Volt Power Supply (S-IU-202 thru 212/501 thru 515)	65-966-0018H	III-5-510-7	1 October 1965	1 November 1966
5 Volt Measuring Voltage Supply	65-966-0019H	III-5-510-8	1 October 1965	
Switch Selector, Model II	66-966-0001	III-5-510-9	1 February 1966	
Component Handling Equipment, Description and Operating Instructions	66-966-0005	III-5-510-10	1 February 1966	
C-Band Radar Transponder Set SST-135C	66-966-0008	III-5-510-11	31 July 1964	1 March 1966
C-Band Radar Transponder Set SST-135C (S-IU-204, 205 and 501)	66-966-0020	III-5-510-18	15 June 1966	
Control Accelerometer	66-966-0012	III-5-510-12	1 March 1966	
Control-EDS Rate Gyro Package	66-966-0013	III-5-510-13	1 March 1966	1 October 1966
Control Signal Processor	66-966-0014	III-5-510-14	15 November 1966	
Flight Control Computer	66-966-0015	III-5-510-15	15 March 1966	
Flight Control Computer (S-IU-204 and 205)	66-966-0021	III-5-510-19	15 June 1966	1 October 1966
Flight Control Computer (S-IU-501)	66-966-0025	III-5-510-21	15 July 1966	

LIST OF RELATED DOCUMENTS (CONT)

Title	Number		Published Date	Changed Date
	IBM	MSFC		
Instrumentation System Description (S-IU-202 thru 204/501 thru 503)	65-966-0021	III-5-509-1	1 June 1966	
Navigation, Guidance, and Control System	66-966-0003	III-5-509-2	1 November 1966	
System Test Reference Manual Volume I Control System Volume II Guidance System Volume III ST-124M-3 Inertial Stabilizer System	66-966-0004	III-5-509-3	1 March 1966	
System Description and Component Data	66-966-0006	III-5-509-4	1 June 1966	
Environmental Control System Description	66-966-0009	III-5-509-5	15 March 1966	
Apollo-Saturn Emergency Detection System Description (SA-203, AS-204, and AS-205)	66-966-0010	III-5-509-6	1 June 1966	1 August 1966
Apollo-Saturn Emergency Detection System Description (S-IU-501, and 502)	66-966-0022	III-5-509-7	1 August 1966	1 October 1966
Command Decoder (S-IU-204 thru 212/501 thru 515)	66-966-0019	III-5-510-17	1 June 1966	
Battery (S-IU-201 thru 212/501 thru 515)	66-966-0024	III-5-510-20	1 August 1966	

LIST OF SOURCE AND REFERENCE DOCUMENTS

The following documents contain source and reference information on the IU Navigation, Guidance, and Control System and/or components.

Apollo Saturn AS-502 Instrument Unit System Functional Interconnection Diagram

MSFC No. III-4-418-13
IBM No. 66-256-0008
31 May 1966

LIST OF SOURCE AND REFERENCE DOCUMENTS (Cont)

Astrionics System Handbook (Saturn Vehicles)

NASA MSFC
1 August 1965 (changed 15 August 1966)

General Description of the ST-124-M Inertial Platform System

NASA TN D-2983
Herman E. Thomason
NASA MSFC
September 1965

Guidance and Control of Saturn Launch Vehicles

AIAA Paper No. 65-304
Walter Haeussermann
NASA MSFC

Interface Control Document

Definition of Saturn SA-207 Flight Sequence Program
NASA MSFC
Drawing No. 40M33607
26 August 1966

Interface Control Document

Definition of Saturn SA-503 Flight Sequence Program
NASA MSFC
Drawing No. 40M33623
12 August 1966

LVDC Equation Defining Document for the AS-206 Flight Program

MSFC No. III-4-423-7
IBM No. 66-207-0003
12 April 1966

LVDC Equation Defining Document for the AS-502 Flight Program

MSFC No. III-4-423-8
IBM No. 66-207-0004
31 May 1966

Memorandum - Control System Specification for Saturn IB/201 and 202

Chief, Guidance and Control Systems Analysis Branch, R-ASTR-NG
NASA MSFC
16 December 1965

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SECTION I

INTRODUCTION

1-1 SATURN MISSIONS

The primary mission of the Uprated Saturn I is to serve as a launch vehicle for the Apollo Spacecraft earth orbital flight tests. These earth-orbital flights will simulate certain phases of the lunar landing mission and will provide flight tests for the spacecraft and the S-IVB/IU Stage. Saturn V is the launch vehicle for the actual Apollo lunar landing missions.

In addition, the Saturn Vehicles are capable of performing other types of missions which can generally be classified as the insertion of heavy payloads into earth orbits and escape trajectories. These missions may include:

- Transfer between earth orbits
- Rendezvous in earth orbit
- Direct ascent and injection into escape trajectory
- Injection into escape trajectory following extended earth-orbit phases
- Extended missions beyond injection.

1-2 SATURN LAUNCH VEHICLES

Saturn vehicles are numbered consecutively beginning with AS-201 for the first Uprated Saturn I Flight Vehicle and AS-501 for the first Saturn V Flight Vehicle. The first few vehicles of each series are considered as research and development vehicles.

1-3 UPRATED SATURN I VEHICLE DESCRIPTION

The Uprated Saturn I Launch Vehicle (Figure 1-1) is made up of two propulsion stages (S-IB and S-IVB), an Instrument Unit (IU), and a payload (Apollo Spacecraft).

The S-IB Stage (first stage) is powered by eight engines. The four outboard engines are mechanically swivelled to provide steering maneuverability

during flight. It is used to lift the launch vehicle through the atmosphere.

The S-IVB Stage (second stage) is powered by one engine. The single engine, which is also mechanically swivelled, provides pitch and yaw capabilities but must depend upon an auxiliary steering system for roll maneuvers. This stage is designed to provide the final "boost" to put the payload into orbit.

The IU contains most of the Astrionics System equipment. It is the "nerve center" of the vehicle. All guidance and control commands, telemetry, sequence commands, etc., originate in the IU.

The payload varies with each vehicle as the mission specifies. Most of the Uprated Saturn I Vehicles will be boosting an Apollo Spacecraft.

1-4 SATURN V VEHICLE DESCRIPTION

The Saturn V Launch Vehicle (Figure 1-2) is made up of three propulsion stages (S-IC, S-II, and S-IVB), an IU, and a payload.

The S-IC Stage (first stage) is powered by five engines. The four outboard engines are swivelled to provide the steering maneuverability as in the first stage of the Uprated Saturn I Vehicle.

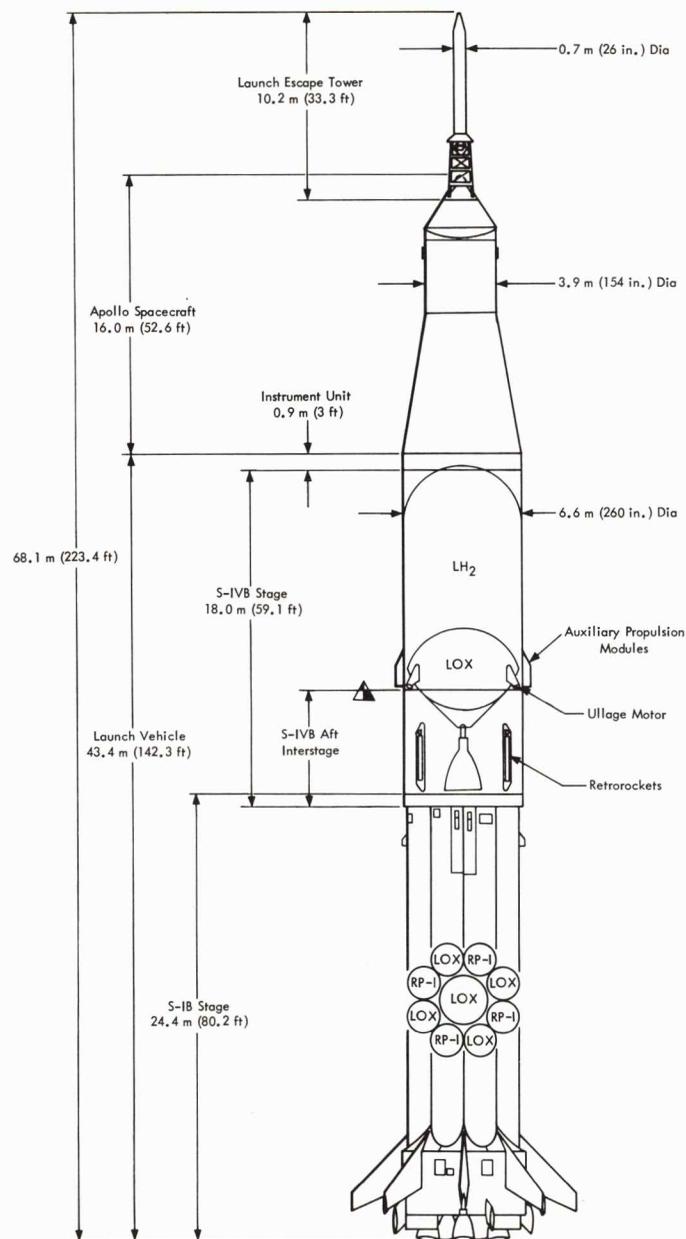
The S-II Stage (second stage) is powered by five engines and is similar to the S-IC Stage except for physical size and the type of fuel used. This stage provides additional boost to the vehicle after the S-IC Stage fuel has been consumed and the S-IC Stage jettisoned.

The S-IVB Stage and IU are similar to those used in the Uprated Saturn I Vehicles

1-5 SATURN FLIGHT DESCRIPTIONS

1-6 UPRATED SATURN I FLIGHT DESCRIPTION

The Uprated Saturn I flight is divided into 5 modes or time bases. These modes are generally



SATURN IB

- Overall Length 68.1m (223.4 ft)

S-IB

- Dry Weight 39,861 kg (87,800 lbs)
- Main Propulsion Engine Rocketdyne H-1 (8)
- Total Nominal Thrust 7,116,000 N (1,600,000 lbs) (sea level)
- Propellants LOX and RP-1
- Engine Cant Angle Inboard (4) 3°
Outboard (4) 6°
- Gimbal Pattern ± 8° Square Pattern (outboard engines only) (4)
- Retromotors Thiokol TE-29-1B (4) ①
- Propellant Solid
- Arrangement Equally spaced circumferentially on aft interstage.

S-IVB

- Dry Weight 10,805 kg (23,800 lbs)
- Main Propulsion Engine Rocketdyne J-2 (1)
- Total Nominal Thrust 912,250 N (205,000 lbs) (vacuum)
- Propellants LOX and LH₂
- Engine Cant Angle None
- Gimbal Pattern ± 7° Square Pattern
- Attitude Control Engines: TAPCO (6)
- Nominal Thrust (Each) 666 N (150 lbs) (vacuum)
- Propellants Hypergolic (MMH & N₂O₄)
- Arrangement Two auxiliary propulsion modules containing 3 engines each, located at positions I and III on aft skirt.
- Ullage Motors/Engines Thiokol TX-280 (3)
- Propellant Solid
- Arrangement Equally spaced circumferentially on aft skirt.

INSTRUMENT UNIT

- Dry Weight 1,884 kg (4,150 lbs)

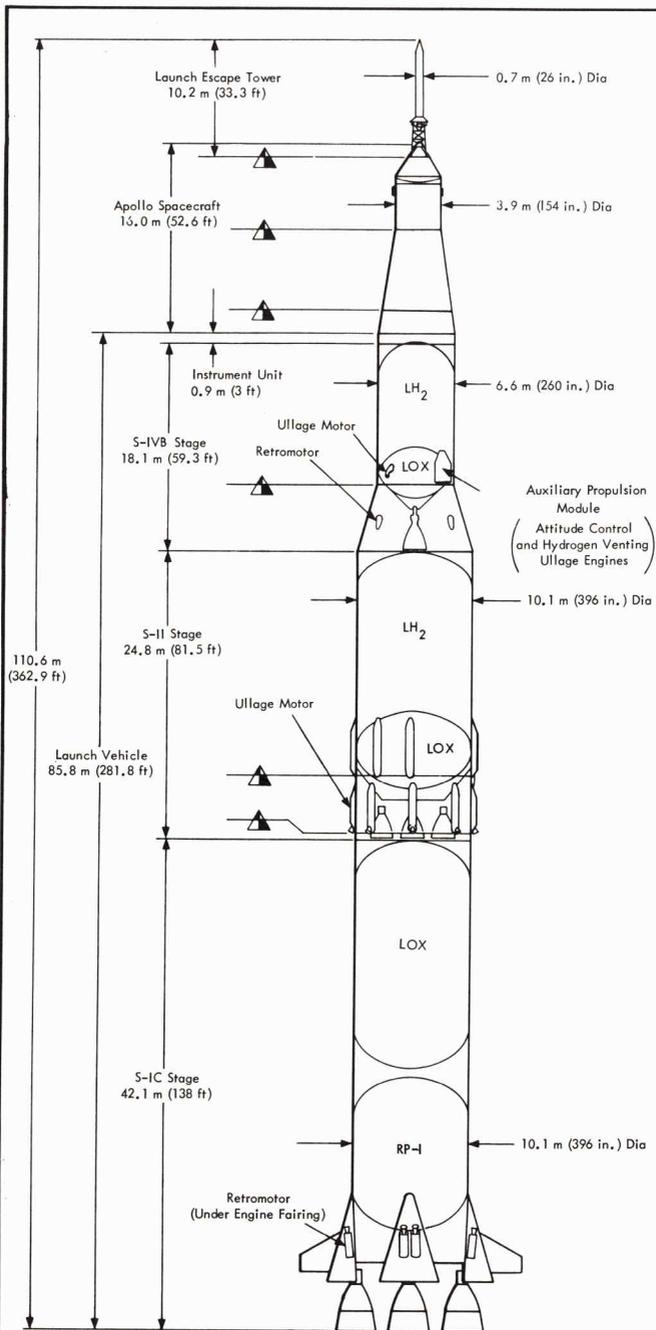
Note:

① Retromotors are used for S-IB retrograde acceleration.

▲ Flight Separation

Figure 1-1. The Upgraded Saturn I Launch Vehicle Characteristic Data

Figure 1-2. Saturn V Launch Vehicle Characteristic Data



SATURN V

- Overall Length 110.6 m (362.9 ft)

S-IC

- Dry Weight 136,200 Kg (300,000 lbs)
- Main Propulsion Engines : Rocketdyne F-1 (5)
- Total Nominal Thrust 33,864,500 N (7,610,000 lbs)
- Propellants LOX and RP-1
- Engine Cant Angle None
- Gimbal Pattern ± 5° 9' Square Pattern (Outboard Engines) (4)
- Retromotors 8
- Propellants Solid
- Arrangement Two in each F-1 engine fairing

S-II

- Dry Weight 37,183 kg (81,900 lbs)
- Mainstage Propellant Capacity 440,380 kg (970,000 lbs)
- Main Propulsion Engines : Rocketdyne J-2 (5)
- Total Nominal Thrust 4,561,250 N (1,025,000 lbs)
- Propellants LOX and LH₂
- Engine Cant Angle None
- Gimbal Pattern ± 7° Square Pattern (Outboard Engines) (4)
- Ullage Motors/Engines RS-U-501 (8)
- Nominal Thrust (Each) 101,900 N (22,900 lbs) (vacuum)
- Propellants Solid
- Arrangement Equally spaced around S-IC/S-II Interstage, in line with S-IC fins and positions I, II, III, & IV.

S-IVB

- Dry Weight 12,440 kg (27,400 lbs)
- Mainstage Propellant Capacity 104,420 kg (230,000 lbs)
- Main Propulsion Engine : Rocketdyne J-2 (1)
- Total Nominal Thrust 912,250 N (205,000 lbs)
- Propellants LOX and LH₂
- Engine Cant Angle None
- Gimbal Pattern ± 7° Square Pattern
- Attitude Control Engines : TAPCO (6)
- Nominal Thrust (Each) 670 N (150 lbs) (vacuum)
- Propellants Hypergolic (MMH & N₂O₄)
- Arrangement Two auxiliary propulsion modules containing 3 engines each, located at positions I and III on aft skirt.
- Ullage Motors/Engines Thiokol TX-280 (2)
- Nominal Thrust (Each) 15,560 N (3,500 lbs) (vacuum)
- Propellant Solid
- Arrangement Equally spaced circumferentially on aft skirt.
- Hydrogen Venting Ullage Engines Gemini OAMS (2)
- Nominal Thrust (Each) 320 N (72 lbs) (vacuum)
- Propellants Hypergolic (MMH & N₂O₄)
- Arrangement One in each of two auxiliary propulsion modules located at positions I and III on aft skirt.
- Retromotors TE-29-1B (4) ①
- Propellants Solid
- Arrangement Positions I, II, III, and IV S-II/S-IVB Interstage.

INSTRUMENT UNIT

- Dry Weight 1,884 kg (4,150 lbs)

Note:

① Retromotors are used for S-II retrograde acceleration

▲ Flight Separation

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time-referenced to a specific vehicle event. The time bases for Uprated Saturn I are:

- Time base No. 0 (T_0) - Initiated 5 seconds prior to liftoff
- Time base No. 1 (T_1) - Initiated at liftoff
- Time base No. 2 (T_2) - Initiated by actuation of the S-IB propellant level sensors
- Time base No. 3 (T_3) - Initiated by S-IB outboard engine cutoff
- Time base No. 4 (T_4) - Initiated when S-IVB cutoff conditions are satisfied

A profile of a typical Uprated Saturn I mission is shown in Figure 1-3.

First Stage Flight

Eight engines are used on the S-IB Stage to lift the launch vehicle through the denser portion of the earth's atmosphere.

Prior to launch, the vehicle must be roll-oriented so that shortly after liftoff the vehicle can perform a programmed roll maneuver. Thus, the vehicle aligns itself to the desired flight azimuth. A tilt program is then initiated by the guidance system which sends predetermined pitch commands to the control system. These roll and pitch commands are stored in the guidance computer and are functions of time only.

As the vehicle traverses the atmosphere, aerodynamic forces are kept within a tolerable range by achieving a minimum angle of attack. For this reason, the first stage uses a standard tilt program (open-loop type of guidance) instead of a closed-loop type of guidance.

Second Stage Flight

Beginning with ignition of the S-IVB Stage, an iterative guidance system is used to guide the vehicle into orbit. This "path adaptive" system has been designed for minimum propellant consumption. The S-IVB Stage provides the final velocities and direction needed to achieve earth orbit. The Guidance System commands engine cutoff when the precalculated velocity has been achieved.

Orbital Flight

Mission objectives determine the vehicle activities during orbital flight. Generally, this flight period is used for IU equipment checkout and S-IVB restart preparations. Navigation, guidance, and control functions are continued during the coast mode but operate in a limited capacity to allow more computer time for IU equipment checkout and telemetry processing.

Normally, attitude control during the coast mode will maintain the vehicle roll axis at right angles to the local vertical (which is determined by navigation calculations).

Tracking stations on the ground, as well as onboard equipment, are used in navigation. Position and velocity data can be updated in the guidance computer by radio transmission from ground stations.

Post-Orbital Flight

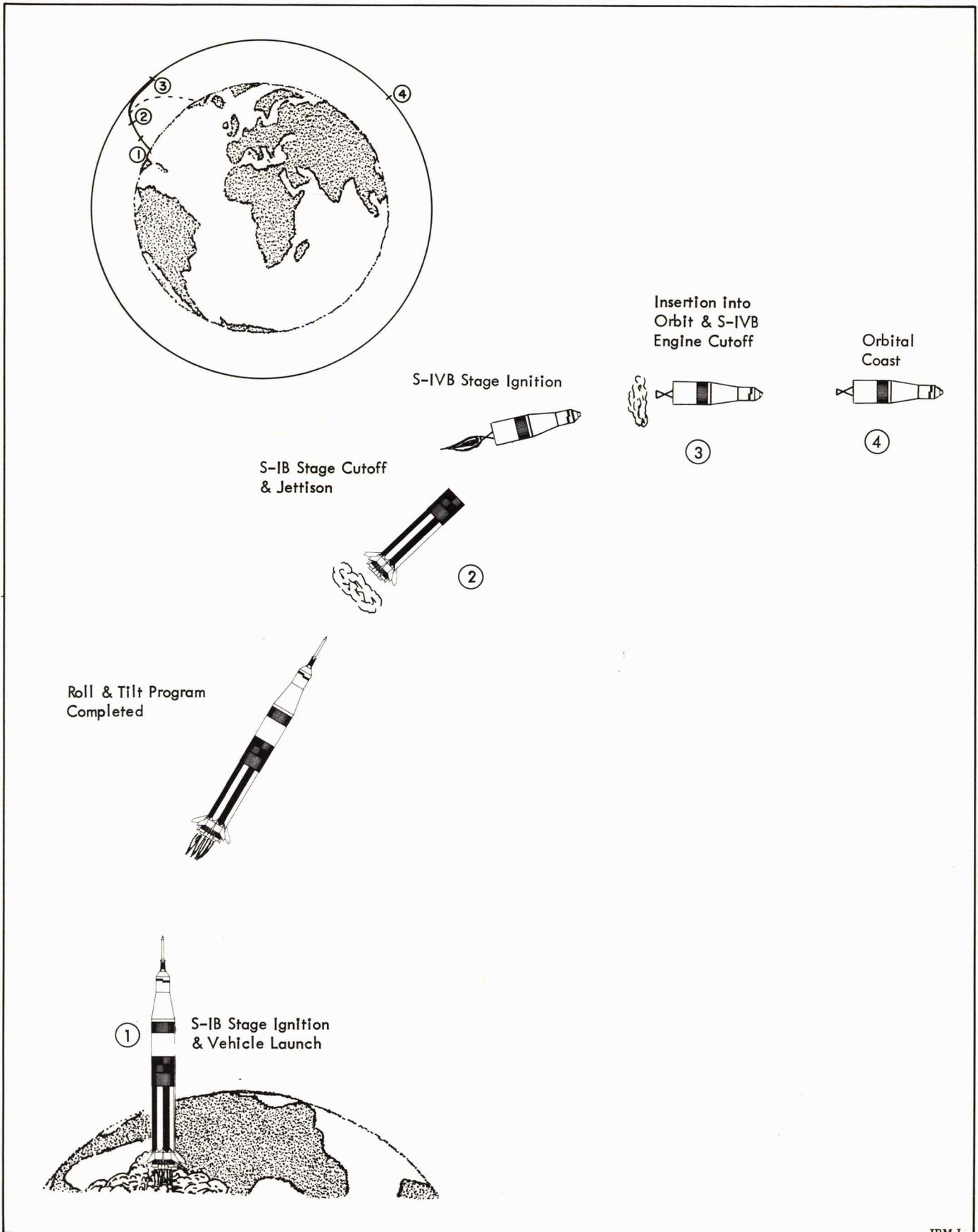
As in orbital flight, mission objectives will determine vehicle activities during any post-orbital flight. A second firing of the S-IVB Stage is necessary for many of the scheduled experiments and tests where a change in orbit or flight path is planned. Guidance maneuvers will be in the iterative mode and are pre-programmed into the guidance computer.

Table 1-1 defines the specific Uprated Saturn I missions and their individual objectives.

1-7 SATURN V FLIGHT DESCRIPTION

The Saturn V flight is divided into 8 modes or time bases. These modes are generally time-referenced to specific vehicle events. The time bases for Saturn V are:

- Time base No. 0 (T_0) - Initiated 10 seconds prior to liftoff
- Time base No. 1 (T_1) - Initiated at liftoff
- Time base No. 2 (T_2) - Initiated at S-IC inboard engine cutoff
- Time base No. 3 (T_3) - Initiated at S-IC outboard engine cutoff
- Time base No. 4 (T_4) - Initiated at S-II engine cutoff



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Figure 1-3. The Up-rated Saturn I Mission Profile

Table 1-1. Uprated Saturn I Flight Missions

AS-202	<p>The AS-202 flight is an unmanned, suborbital mission. The primary objective of the mission is generation of an acceptable maximum total heat load on the command module heat shield during re-entry. Shortly after S-IVB engine cutoff, the S-IVB/IU and the command module separate. A service propulsion system is then used to give additional velocity to the command module. The S-IVB/IU performs attitude maneuvers throughout the rest of its flight.</p>
SA-203	<p>The SA-203 flight is an unmanned orbital mission designed to:</p> <ul style="list-style-type: none">● Evaluate the dynamics of liquid hydrogen (LH₂) at near zero gravity.● Provide limited orbital checkout for the S-IVB Stage and IU.● Demonstrate mission control and network operations. <p>To achieve these objectives, a 100-nautical mile (185-kilometer) circular orbit trajectory with a 4-orbit mission is planned.</p>
AS-204	<p>The AS-204 will be the first manned orbital flight of the Saturn series. The trajectory planned for this mission is divided into the following 4 phases:</p> <ul style="list-style-type: none">● Phase 1 is from liftoff to S-IB cutoff.● Phase 2 is from S-IVB ignition to cutoff.● Phase 3 is the coast phase with the Command and Service Module (CSM) attached to the S-IVB/IU.● Phase 4 is the coast phase of the S-IVB/IU after separation from the CSM. <p>Phase 3 is presently planned to last about 3 hours. To achieve the objectives of this mission, an elliptical orbit of 85 nautical miles (157 kilometers) perigee altitude and 130 nautical miles (241 kilometers) apogee altitude has been selected.</p>
AS-205	<p>The AS-205 is scheduled to be the second manned flight of the Apollo-Uprated Saturn I series. Principle mission objectives are to:</p> <ul style="list-style-type: none">● Evaluate launch vehicle structures● Demonstrate orbital checkout of the S-IVB and IU● Demonstrate stage separation capability. <p>The vehicle will be launched from Launch Complex 34 at KSC into a target orbit with a perigee of 85 nautical miles and an apogee of 130 nautical miles.</p>
AS-206	<p>The AS-206 is scheduled as an unmanned flight of the Apollo-Uprated Saturn I Space Vehicle. The primary test objectives are to:</p> <ul style="list-style-type: none">● Test a complete LM for verification of subsystem operations● Evaluate launch vehicle structures, propulsive system capabilities, and EDS operations

Table 1-1. Uprated Saturn I Flight Missions (Cont)

AS-206 (Cont)	<ul style="list-style-type: none"> ● Demonstrate stage separations and orbital checkout of the S-IVB Stage and IU. <p>The target orbit has a perigee of 85 nautical miles and an apogee of 120 nautical miles. The LM will be separated from the S-IVB/IU after one orbit.</p>
AS-207 and subsequent vehicles	(To be supplied)

Time base No. 5 (T₅) - Initiated at S-IVB engine cutoff

Time base No. 6 (T₆) - Initiated at the beginning of S-IVB restart preparations

Time base No. 7 (T₇) - Initiated at the second S-IVB engine cutoff

A typical Saturn V mission profile is shown in Figure 1-4. Saturn V flight missions are given in Table 1-2.

First Stage Flight

Five engines are used on the S-IC Stage to lift the mammoth vehicle and payload from the ground and provide the initial boost through the denser portion of the atmosphere. As in the first-stage flight of the Uprated Saturn I, a standard open loop roll and tilt guidance program is used.

Second Stage Flight

The second stage flight (S-II Stage) continues to boost the vehicle toward an earth orbital velocity and position. This boost stage also utilizes 5 engines for its thrust. Second plane separation and launch escape system jettisoning occur early in this flight phase. An iterative guidance scheme (path adaptive) is initiated during this phase of the flight and continues until orbital flight has been achieved.

Third Stage Flight

The first burn of the single S-IVB Stage engine is designed to give the vehicle its final boost and heading into earth orbit. Engine cutoff occurs at the instant the vehicle reaches its predetermined velocity. After cutoff, the engine is prepared for a later restart.

Attitude control for the S-IVB burn phase differs from the control scheme used on the two previous stages because of the single-engine configuration. Since the single engine can only control pitch and yaw movements, an auxiliary steering system is utilized to control the roll functions.

Orbital Flight

Orbital flight follows cutoff of the S-IVB engine. The vehicle, which is now reduced to the S-IVB/IU Stage and Apollo payload, will orbit the earth at an approximate altitude of 185 kilometers (100 nautical miles). This flight phase is scheduled to continue for a maximum of 3 orbits. Normally, attitude control of the vehicle during this coast period will maintain the roll axis at right angles to the local vertical.

Seven major operations are performed during orbital coast. They are: navigation, guidance, attitude control, data management (telemetry), ground command processing, and IU equipment checkout. When all systems have been checked and orbital position is correct, the S-IVB engine is restarted, and the vehicle is injected into its translunar trajectory.

S-IVB Second Burn - Translunar Flight

The second powered flight of the S-IVB Stage is used to "break away" from the earth's gravitational pull and thus inject the launch vehicle/spacecraft into a translunar trajectory. After final computation and corrections to the flight path, the engine is cut off when the correct velocity has been attained.

Translunar Coast

The final operational phase for the Saturn Launch Vehicle is the translunar coast flight. The primary function of the vehicle during this phase is to maintain a steady attitude while transposition and docking maneuvers are performed. At the conclusion of these maneuvers, the launch vehicle mission is

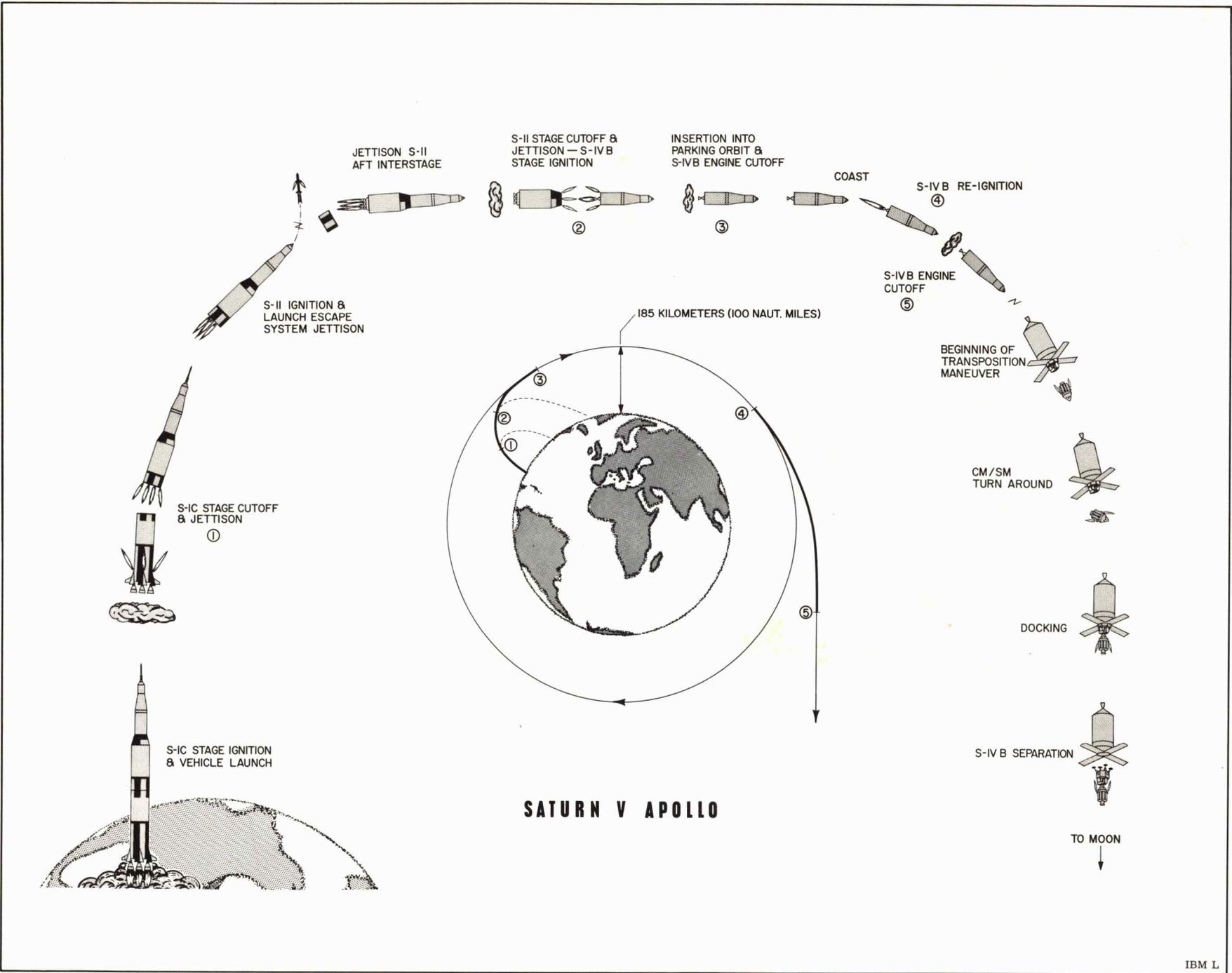


Figure 1-4. Saturn V Mission Profile

considered complete, and the S-IVB/IU Stage is separated from the Apollo payload.

1-8 SYSTEM DESCRIPTION

The Uprated Saturn I and Saturn V Navigation, Guidance, and Control System (N G & C System) has the important function of directing each space vehicle to its predetermined space mission. As the system title indicates, there are three separate system functions. These functions, shown in Figure 1-5, are:

- Navigation is the determination of vehicle position and velocity by means of onboard measurements and calculations.

- Guidance is the determination of the best possible path or trajectory to complete the mission. By comparing the navigation information, vehicle attitude, and target position, the N G & C System is able to issue accurate steering and sequence commands.
- Control is the continuous execution of the steering and sequence commands which are generated within the guidance function.

Figure 1-6 is a block diagram of the Uprated Saturn I and Saturn V Navigation, Guidance, and Control System.

Table 1-2. Saturn V Flight Missions

AS-501	<p>The AS-501 is the initial flight of the Saturn V series. The mission calls for 2 revolutions in a circular parking orbit, followed by 1 revolution in an elliptical waiting orbit and re-entry. The primary mission objectives are:</p> <ul style="list-style-type: none"> ● Demonstrate the S-II propulsion system. ● Demonstrate the S-IVB APS capabilities. ● Demonstrate the control and guidance system during boost flight. ● Demonstrate the sequencing system. ● Demonstrate dual-plane separation of S-II from S-IC, S-II from S-IVB and S-IVB restart capability. ● Monitor the EDS in an open-loop configuration. ● Demonstrate prelaunch, launch, and mission support capabilities. ● Determine launch vehicle internal environment.
AS-502	<p>The AS-502 is the second mission of the Saturn V launch vehicle. The mission profile calls 2 revolutions in a circular parking orbit, followed by S-IVB restart to simulate a typical lunar transfer injection, and lunar re-entry. The test objectives include:</p> <ul style="list-style-type: none"> ● Determine steering rates; angle of attack; longitudinal velocity and acceleration; lateral accelerations; and gimbal angles and rates as functions of time of flight. ● Evaluate vehicle bending modes and frequency and effects of propellant sloshing. ● Determine bending moment versus vehicle station. ● Determine vehicle thermal and acoustic environment. ● Evaluate performance of: EDS, propulsion systems, and IU. ● Determine effectiveness of automatic checkout. ● Determine environmental effects on astronics system.
AS-503 and subsequent vehicles	(To be supplied)

Engine actuators receive the final control command and actually "gimbal" or move their respective engines to the desired angle. This gimbaling has the effect of changing the direction of the thrust vector of the vehicle and thus moving it about its roll, pitch, and yaw axes.

1-9 NAVIGATION, GUIDANCE, AND CONTROL EQUIPMENT

Table 1-3 is a list of equipment used for the N G & C function. Section VII of this manual contains

a general description of each component and its functions. For detailed descriptions, refer to the List of Related Documents in the front matter of this manual.

An IU equipment layout is shown in Figure 1-7 and, with the exception of the Control Accelerometer, is typical for most Uprated Saturn I and Saturn V flights. As indicated, the N G & C equipment comprises approximately 25 percent of the IU flight hardware. Component layout is such that the N G & C equipment is grouped together to facilitate interconnection of signals and power.

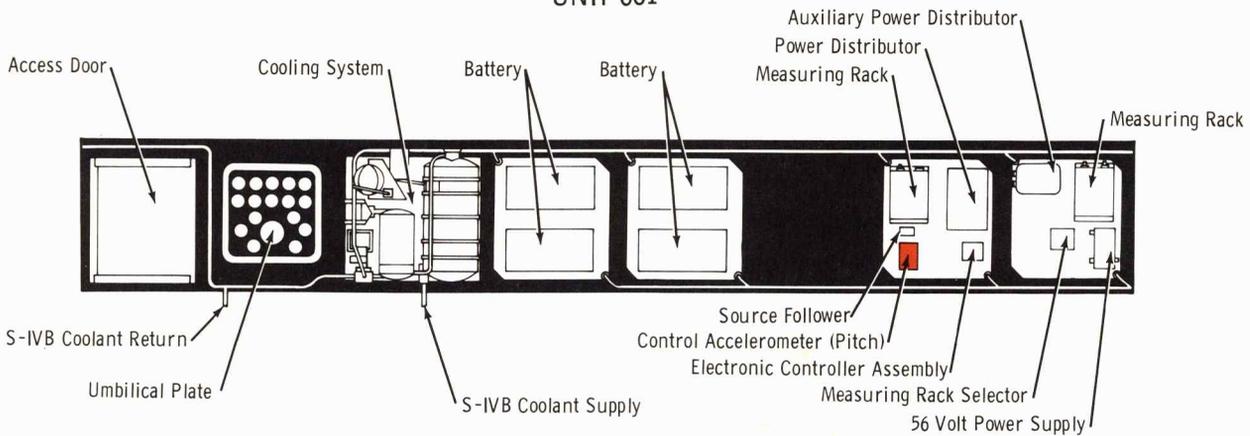
Table 1-3. Navigation, Guidance, and Control Components

Inertial Components	Digital Components	Control Components
ST-124M-3 Inertial Platform Assembly	LVDA	Flight Control Computer
ST-124M-3 Platform Electronic Assembly	LVDC	Control Sensors — Control Accelerometers* Control-EDS Rate Gyros Control Signal Processor
ST-124M-3 Platform AC Power Supply		Switch Selectors **
Accelerometer Signal Conditioner		Auxiliary Propulsion System ** Engine Actuators **

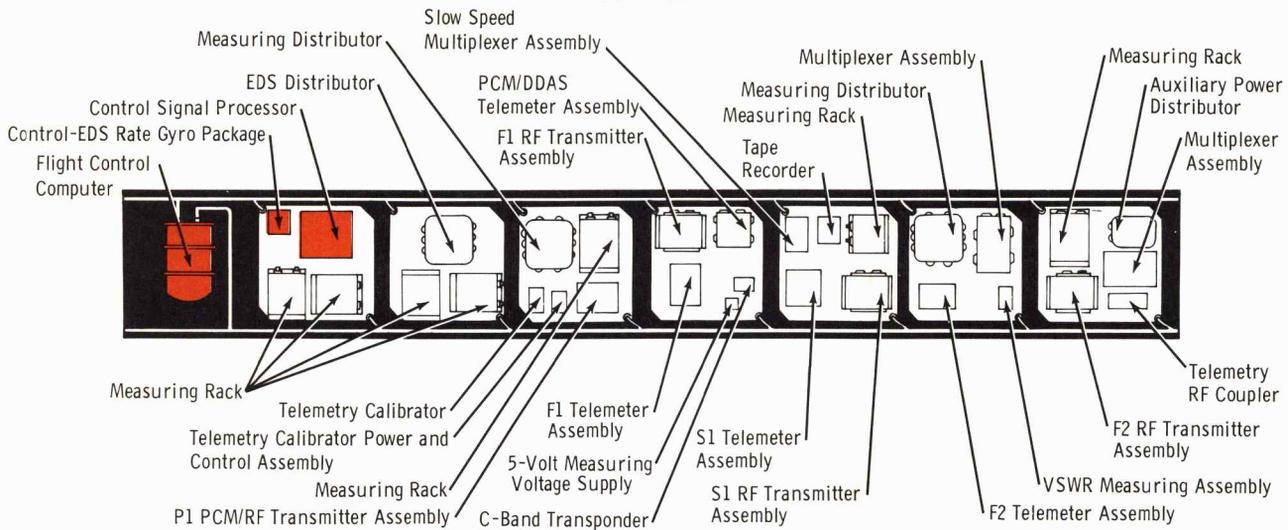
* Uprated Saturn I only

** By definition, these components are not N G & C components; however, they are included since they complete the control function.

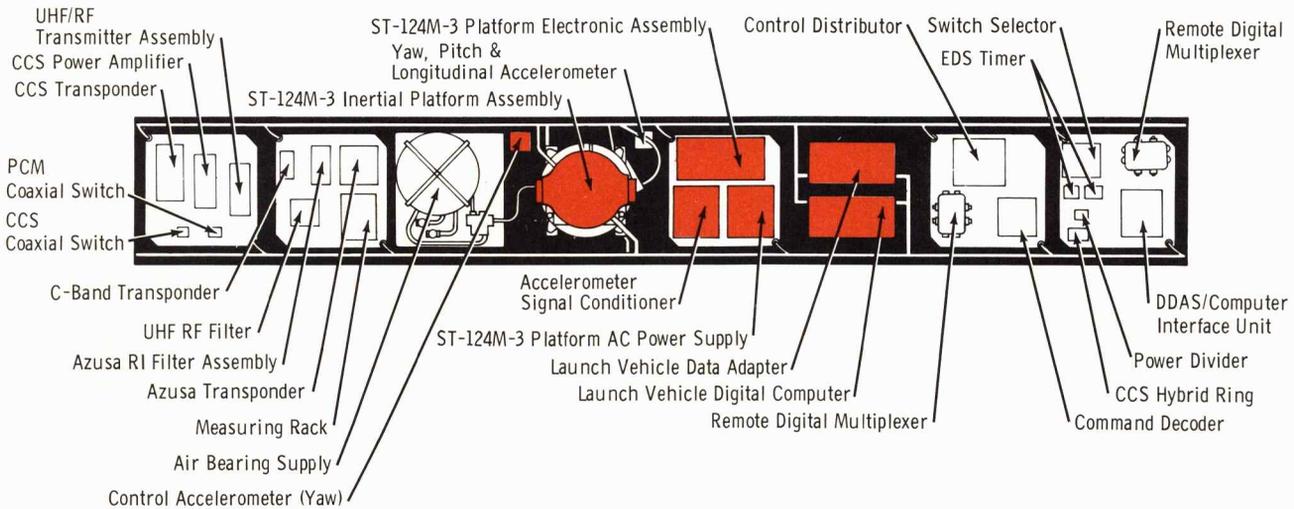
UNIT 601



UNIT 602



UNIT 603



Navigation, guidance, and control components are shown in color.

IBM L-B

Figure 1-7. Typical Saturn Instrument Unit Equipment Layout

SECTION II

NAVIGATION

2-1 GENERAL DESCRIPTION

During powered flight, the Uprated Saturn I and Saturn V Navigation System determines vehicle position, velocity, and acceleration from measurements made on board the vehicle. The initial measurements are supplied by integrating accelerometers which are mounted on an inertial platform within the ST-124M-3 Inertial Platform Assembly.*

Three coordinate reference systems (three-dimensional) are associated with the Saturn Navigation System. Using these three coordinate systems and the accelerometer measurements, the LVDC is programmed to compute the instantaneous vehicle velocity and position. These values are presented to the guidance system in terms of X Y Z coordinates.**

During coast flight (orbital flight), vehicle position is computed from equations of motion which are based on the flight conditions at the time of orbital insertion. During this phase of the flight, data for navigation and guidance calculations can be updated from the ground stations via a radio command system.

2-2 NAVIGATION COORDINATE REFERENCE SYSTEMS

References for vehicle origin, position, and destination must be defined before a navigation scheme can function. The three primary coordinate systems used for Saturn navigation are:

*For the purpose of brevity, the ST-124M-3 Inertial Platform Assembly will hereinafter be referred to as the Platform.

**The XYZ coordinates used in this manual reflect the Project Apollo Coordinate System Standards. This coordinate scheme becomes effective for vehicles AS-206 and AS-502 (and subsequent).

- The gravitational coordinate system (U V W)
- The navigational or Platform coordinate system ($X_S Y_S Z_S$)
- The inertial coordinate system ($X_I Y_I Z_I$)

The references for these coordinate systems are either earth fixed or space fixed. An earth-fixed reference vector is shown in A of Figure 2-1. This vector will always exist in a line from the earth's center through a point on the earth's surface (e.g., launch site). As the earth rotates, the vector will remain oriented between these two points and is therefore, earth fixed.

A space-fixed vector reference is illustrated in B of Figure 2-1. It is always aimed at the same point in space and is completely independent of the earth's revolution. After a quarter-revolution of the earth, the earth-fixed vector will have rotated 90 degrees while the space-fixed vector has remained pointed in its original direction.

2-3 GRAVITATIONAL COORDINATE SYSTEM

The gravitational (U V W) system is a space-fixed, rectangular coordinate system whose origin is at the center of the earth. See Figure 2-2. It is used in computing the effect that gravity has upon the Platform-mounted accelerometers. The W axis (not shown in the figure) is aligned with the earth's spin axis and points south. The V axis is in the equatorial plane and intersects the equator at the longitude of the launch site (at launch time). The U axis which is perpendicular to the W and V axes completes the right-handed orthogonal system.

2-4 NAVIGATIONAL OR PLATFORM COORDINATE SYSTEM

A navigational ($X_S Y_S Z_S$) coordinate system (see Figure 2-2) is used for navigation and guidance computations. Its origin is also at the center of the earth. The X_S axis is parallel to the gravity vector

at the launch site and the Z_S axis is parallel to the earth-fixed firing azimuth. Thus, the $X_S - Z_S$ plane contains the flight plane. The Y_S axis completes the right-handed system. The system is earth-fixed until Platform release (5 to 10 seconds before launch). At that time, the X_S axis is established, and the system becomes permanently space fixed.

2-5 INERTIAL COORDINATE SYSTEM

The inertial ($X_I Y_I Z_I$) coordinate system is used for velocity and acceleration measurements. Unlike the first two systems, the $X_I Y_I Z_I$ system has its point of origin at the Platform, see Figure 2-2. The $X_I Y_I Z_I$ coordinates, sometimes referred to as $X_M Y_M Z_M$, are parallel with the $X_S Y_S Z_S$ coordinates. Thus, any increment of acceleration measured at the Platform is an indication of motion along the $X_S Y_S Z_S$ axes. Before launch, both the navigation and inertial coordinate systems are earth fixed (i. e., they rotate with the earth), but at the moment of Platform release (5 to 10 seconds before launch), both systems become space fixed.

A Note of Caution: Do not confuse the two X Y Z coordinate systems as being the same - they are only parallel to each other. The $X_S Y_S Z_S$ coordinates are references of vehicle position, while the $X_I Y_I Z_I$ coordinates reference the vehicle's measured progress along the $X_S Y_S Z_S$ coordinates.

2-6 NAVIGATION CALCULATIONS

2-7 POWERED FLIGHT

The acceleration values, measured by the Platform accelerometers, are processed within the LVDA and forwarded to the LVDC as increments of velocity. Velocity is integrated to determine position. The basic navigation scheme is shown in Figure 2-3.

External forces, such as gravity and initial velocity, directly affect the acceleration measurements. The effect produced by these forces must be compensated for within the navigational calculations and will be shown later.

Figure 2-4 is a detailed flow diagram of the navigation scheme. Starting at the upper left of the figure, accelerometer measurements (integrated into velocity values) are obtained from the Platform via the LVDA. Within the LVDC, initial velocity (imparted by the spinning earth), gravitational velocity (caused by the effects of gravity), and the Platform velocities are algebraically summed together. Their sum is inertial vehicle velocity in the space-fixed $X_S Y_S Z_S$ coordinate system. This velocity is integrated and added to the initial position (distance from earth's center to the launch site) to determine vehicle position. The value of position is used in guidance computations and to compute the gravitational

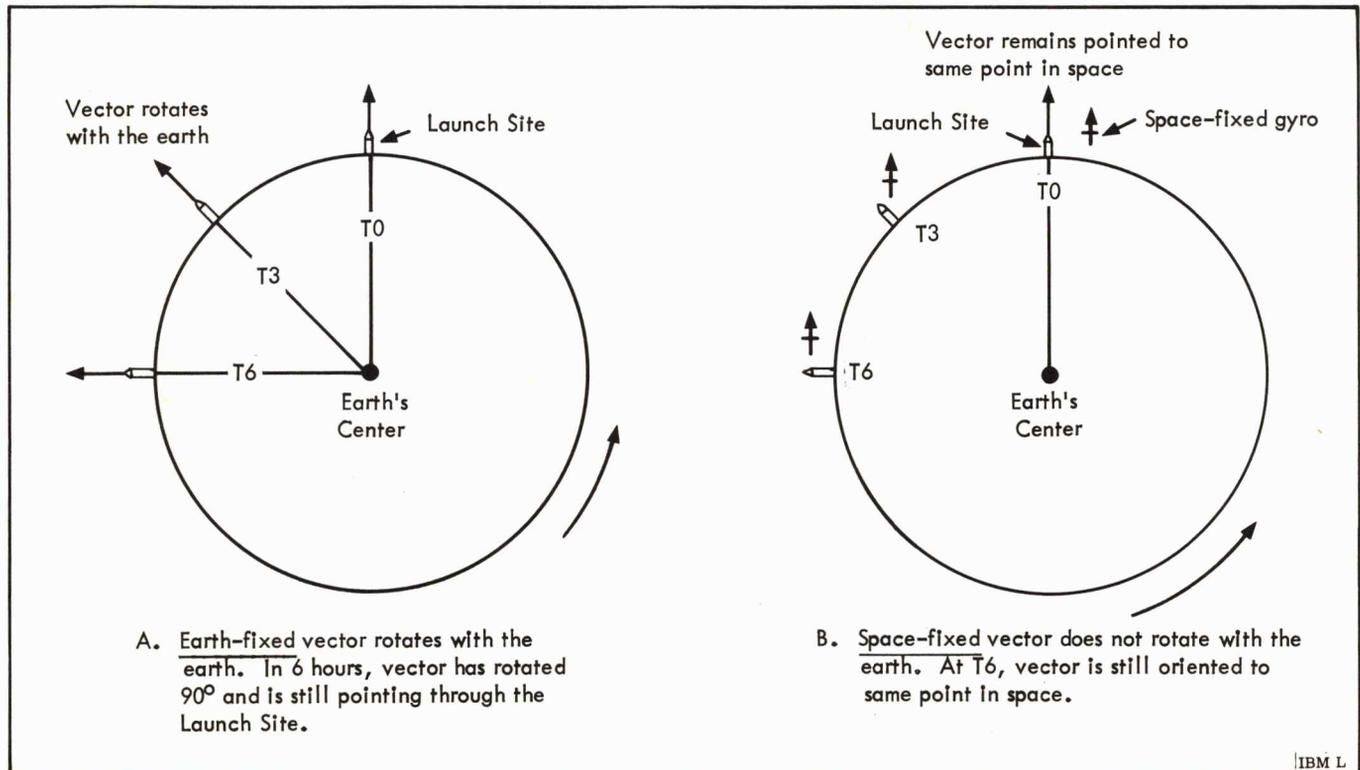


Figure 2-1. Earth-Fixed and Space-Fixed Vectors

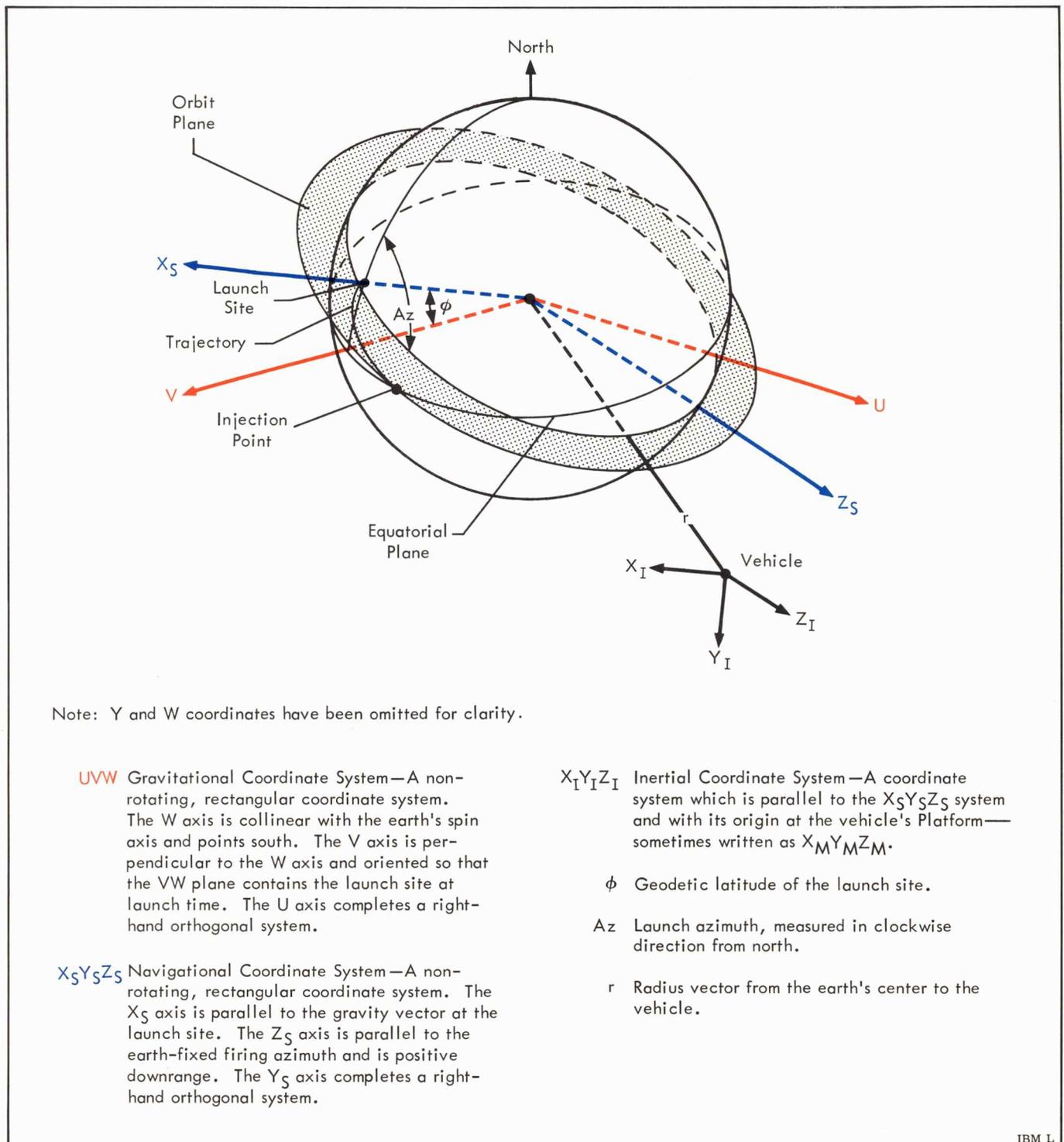


Figure 2-2. Navigation Coordinate Systems

velocity which is "looped back" to the accelerometer readings. Values of Platform velocities are differentiated to obtain components of acceleration. These acceleration values are used in computing thrust acceleration (F/M).

The gravitational acceleration which is acting upon the accelerometers is derived from the gravitational potential of the earth. This gravitational acceleration $g(r)$ varies in relation to position and distance from the earth. A nominal value for $g(r)$ is 32.2 feet/second/second (32.2 ft/s²) at the earth's surface and will decrease as vehicle altitude increases. The components of $g(r)$ are first expressed in the U V W system as $U_g V_g W_g$ and then "rotated" (transformed) to the X Y Z system coordinates where they become $X_g Y_g Z_g$.

2-8 ORBITAL FLIGHT

During orbital coast flight, the navigational program continually computes the vehicle position, velocity, and acceleration from equations of motion which are based on vehicle conditions at the time of orbital insertion. In orbit, navigation and guidance information in the LVDC can be updated by digital data transmission through the radio command system.

Additional navigational computations are used in maintaining vehicle attitude during orbit. These

computations establish a local vertical which is used as a reference for attitude control. Present plans call for the attitude of the vehicle roll axis to be normally maintained at 90 degrees with respect to the local vertical.

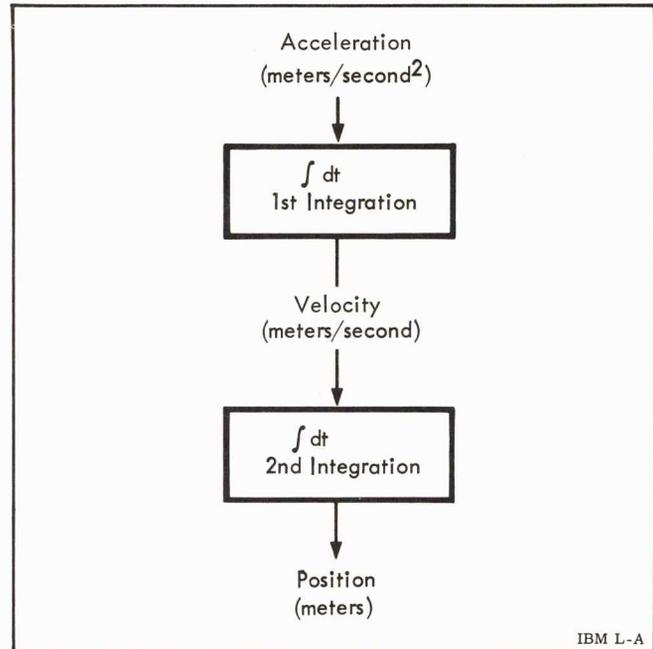


Figure 2-3. Basic Navigation Scheme

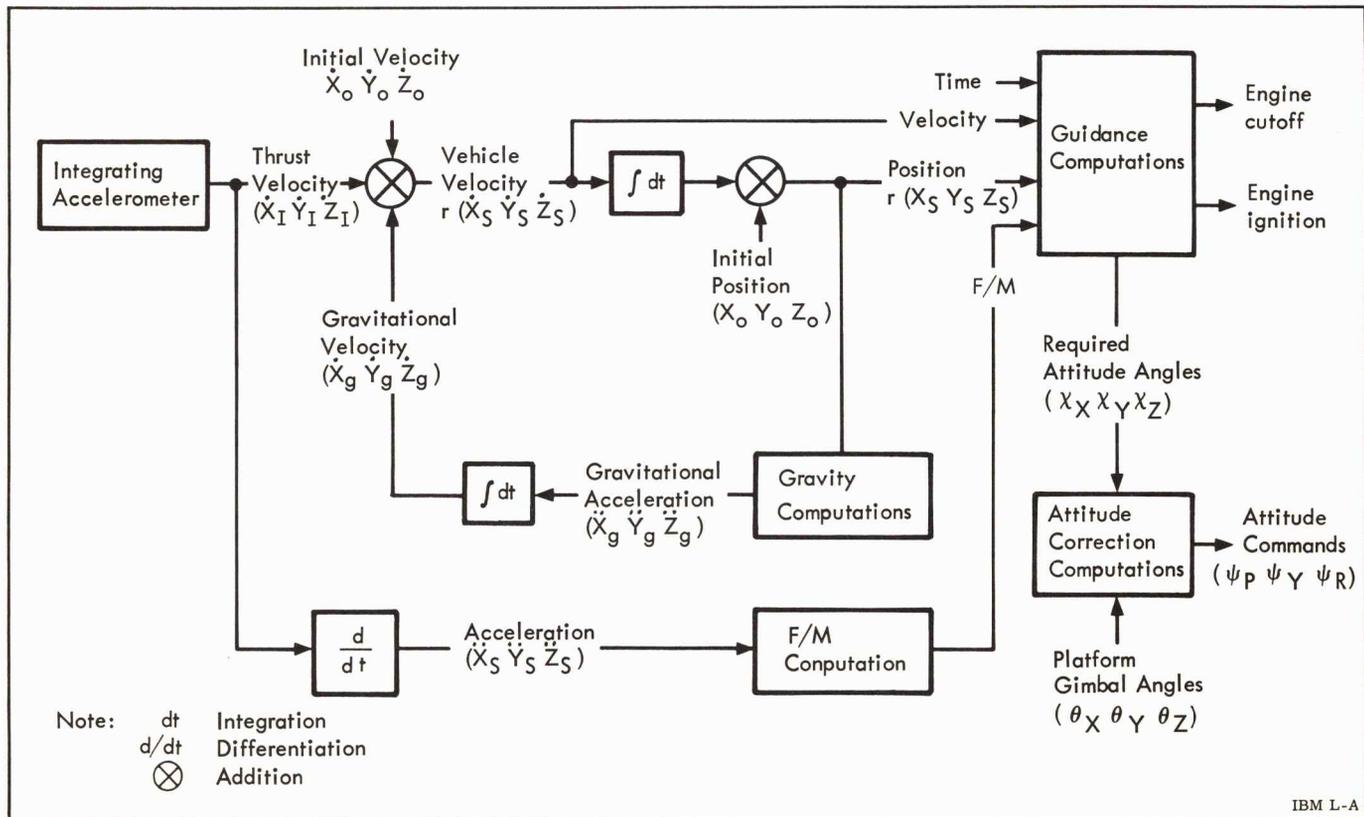


Figure 2-4. Navigation and Guidance Flow Diagram

SECTION III

GUIDANCE

3-1 GENERAL DESCRIPTION

The guidance function of the launch vehicle is accomplished by computing the necessary flight maneuvers to meet the desired end conditions of the flight (e.g., inserting the payload into earth orbit). Guidance computations are performed within the LVDC by programmed guidance equations which use navigation data and mission requirements as their inputs. Simply, the guidance program compares the launch vehicle's present position and heading with the pre-determined "target in space", and the computed differences are issued to the attitude control equipment as maneuvering commands. The control system then alters the vehicle's thrust direction until the vehicle is on its newly computed heading. These guidance computations are performed at an approximate rate of once per second.

Figure 3-1 is a simplified flow diagram of the guidance computations within the LVDC. These computations are actually a logical progression of computed formulas which have a guidance command as their solution. After the desired attitude has been determined by the "best path" program, the guidance computations might be reduced into the following equation:

$$\psi = \chi - \theta$$

Where: ψ is the attitude error command (sometimes written as $\Delta\phi$ in other documentation)

χ is the desired attitude

θ is the vehicle attitude

Calculating these attitude error commands completes the guidance scheme. One final computation, however, involves transforming the attitude commands into the vehicle reference frame from the Platform coordinate references ($\psi_X\psi_Y\psi_Z$ to $\psi_R\psi_P\psi_Y$). These values are then utilized by the Control System to form the engine thrust angle commands.

3-2 PATH ADAPTIVE GUIDANCE

Saturn system requirements for flight maneuvers emphasize minimum fuel consumption and avoidance of excessive attitude changes which could cause vehicle breakup. The guidance calculations for the final flight phase (orbital insertion) must be very

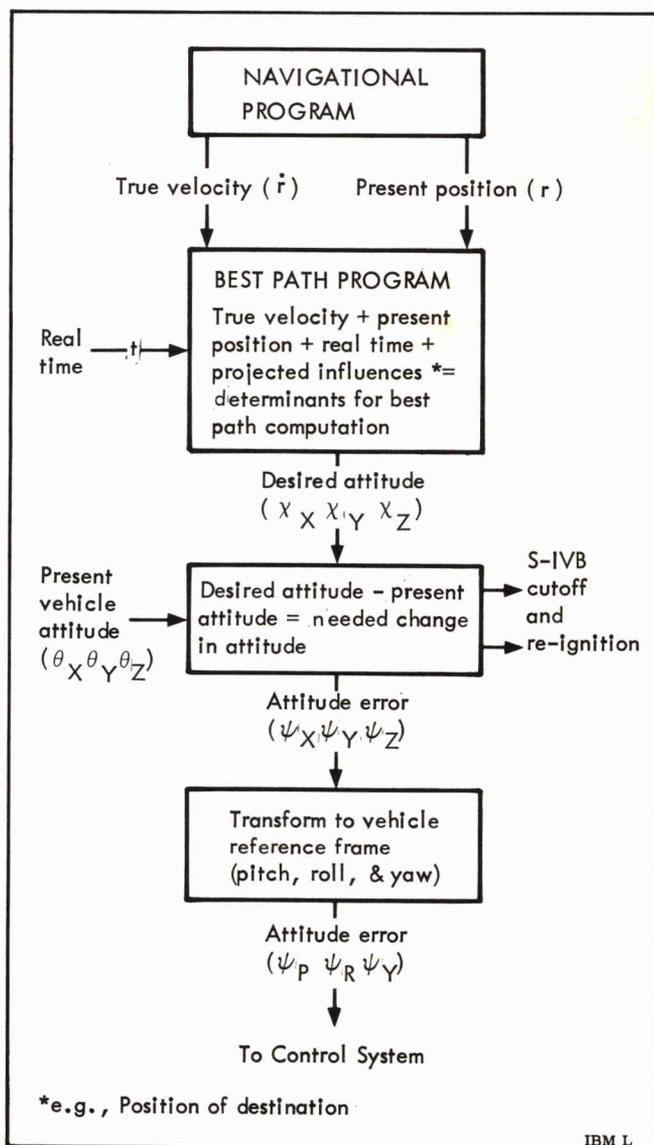


Figure 3-1. LVDC Guidance Functions

accurate to avoid additional propellant-consuming maneuvers.

The guidance system corrects for numerous flight disturbances which include:

- Atmospheric perturbations from wind
- Control inaccuracies
- Unsymmetrical air flow around the vehicle
- Non-standard engine and vehicle characteristics and performance
- Emergency conditions

These disturbances cannot be predicted and, unless compensated for during flight, they could cause the vehicle to miss its cutoff and orbital target in space.

To meet the accuracy of the specifications just outlined, a method of guidance called path adaptive guidance has been developed for Saturn Vehicles. Based on the instantaneous status of the vehicle (position, velocity, etc.), the path adaptive guidance scheme computes a new and optimum flight path at one second intervals. Thus, flight disturbances are corrected or compensated for almost as soon as they occur. Unlike many ballistic missiles which are limited to a definite trajectory, the Saturn Vehicles are "free" to make continued corrections to their course.

NOTE

During first-stage flight, the vehicle transverses the denser portion of the atmosphere where high aerodynamic pressure occurs. To avoid excessive structural loads caused by guidance maneuvers, no guidance constraints are applied during this flight phase. An open-loop guidance, in the form of a time tilt program, is used. Path adaptive guidance begins with the ignition of the second stage (S-IVB Stage for the Uprated Saturn I and S-II Stage for the Saturn V Vehicles).

Several path adaptive guidance schemes were developed for Saturn Launch Vehicles, but only two were used in the Saturn I series. These were the Polynomial Guidance Mode (PGM) and the Iterative

Guidance Mode (IGM). Saturn Vehicles will continue to use the IGM scheme, although both the PGM and IGM schemes were successful. A description of each scheme follows.

3-3 POLYNOMIAL GUIDANCE MODE

Briefly, the polynomial guidance mode utilizes many pre-calculated, minimum-propellant trajectories. These trajectories are based on expected perturbations and characteristics of each vehicle stage (e. g., if at some point in the flight, the vehicle can be expected to yaw a certain number of degrees, a trajectory must then be plotted from that point in space to the target). Approximately 100 to 300 such trajectories are required for a two-stage vehicle. During flight, the vehicle state (position, velocity, etc.) is continually "matched" to one of these pre-calculated trajectories (i. e., the position of the vehicle is mathematically compared with all the predicted trajectories and is then matched with the one it most nearly resembles). Control signals are then generated which will align the vehicle attitude and thrust direction to the newly-selected trajectory.

In summary, the PGM scheme utilizes pre-calculated trajectories to determine commanded attitude angles. Predicted vehicle changes are used in these calculations. During flight, present vehicle attitude and velocity are compared with the predicted changes and proper guidance commands are issued to keep the vehicle on its new "course".

3-4 ITERATIVE GUIDANCE MODE

The iterative guidance mode is a mission-flexible, minimum-propellant guidance scheme which was developed for large space vehicles. The IGM scheme is based on a repetitive computation of trajectories between the present vehicle position and its target (cutoff point) in space. Equations of motion have been derived to approximate the vehicle motion over an oblate earth with a realistic gravity field. These equations are solved during flight to determine the instantaneous range angle to cutoff. Onboard inputs to the guidance computations include vehicle position, velocity, real time, and thrust acceleration.

The IGM equations are of a general nature and are valid for any firing azimuth, vehicle configuration, or mission. Preset values within the flight program are relatively easy to change if a modification to the mission becomes necessary. Therefore, programming the LVDC for an alternate mission, or from

one flight to the next, requires only changing such pre-set input values as launch azimuth, inclination, descending node, aim vector, etc.

In summary, the IGM scheme utilizes explicit guidance equations to operate on preset values and on-board measurements. The scheme provides a flexible flight program with a minimum of preflight calculation.

3-5 COMPARISON OF PGM AND IGM

The PGM and IGM schemes were both developed for use with high-thrust vehicles having one or more guided stages and for various launch vehicle characteristics and configurations. The PGM scheme was designed and flight tested first, with excellent results. The IGM scheme was then developed to provide more flexibility.

Since both schemes were extremely accurate, other characteristics were considered in choosing a "best one"; these include the following:

- Mission and vehicle flexibility. The PGM equations must be recalculated when vehicle or mission changes occur. The IGM equations are usable for most changes; only a few presettings must be altered. This is probably the most significant feature of the IGM scheme.
- Propellant economy. Both the IGM and the PGM schemes have excellent propellant economy.
- Flight computations. Both the IGM and the PGM schemes require the same size, large capacity digital computer.
- Preflight computations. The PGM scheme requires 100 to 300 precalculated trajectories, whereas only one or two precalculated trajectories are required for the IGM scheme. This is a significant factor for consideration as vehicle and mission changes are to be expected in the Saturn Program.

The principal advantages of the IGM scheme over the PGM scheme are the small amount of pre-calculation and the flexibility to mission requirements. The IGM guidance scheme, because of its versatility, comes close to providing a flight program capability for lunar and orbital missions.

3-6 COORDINATE REFERENCE SYSTEMS FOR GUIDANCE

The following paragraphs define the guidance coordinate systems * used in writing the guidance programs for the Saturn Vehicles. These coordinate systems are:

- The navigational or Platform coordinate system ($X_S Y_S Z_S$)
- The target plane coordinate system ($X_4 Y_4 Z_4$)
- The injection coordinate system ($X_V Y_V Z_V$)

Figure 3-2 shows how these systems are oriented and referenced to each other and to the orbital plane.

3-7 NAVIGATIONAL OR PLATFORM COORDINATE SYSTEM

The Platform coordinate system ($X_S Y_S Z_S$) is a space-fixed, rectangular coordinate system with its origin at the center of the earth. The X_S axis is parallel with the local gravity vector at the launch site. The Z_S axis is parallel to the earth-fixed firing azimuth. The Y_S axis completes the right-handed system.

3-8 TARGET PLANE COORDINATE SYSTEM

The target plane coordinate system ($X_4 Y_4 Z_4$) is a space-fixed, rectangular coordinate system with its origin at the center of the earth. The X_4 axis passes through the intersection point of the orbit plane and the equator (descending node). The Z_4 axis lies in the desired orbit plane, 90 degrees downrange from the X_4 axis. The Y_4 axis is perpendicular to the orbit plane.

3-9 INJECTION COORDINATE SYSTEM

The injection coordinate system ($X_V Y_V Z_V$) ($\eta \zeta \xi$) is a right-handed, rectangular coordinate system with its origin at the center of the earth. The X_V axis lies in the orbit plane at an angle ψ_T from the X_4 axis. The Z_V axis lies in the orbit plane 90 degrees downrange from the X_V axis. The Y_V axis is collinear with the Y_4 axis.

* The XYZ Coordinates used in this manual reflect the Project Apollo Coordinate System Standards. This coordinate scheme becomes effective for vehicles AS-206 and AS-502 (and subsequent).

The inertial coordinate system is also shown in the figure. The symbols for this system may be seen in either of two forms, $X_I Y_I Z_I$ or $X_M Y_M Z_M$. Their axes are parallel with $X_S Y_S Z_S$ system.

NOTE

The Platform, not the vehicle, is aligned to the launch azimuth. Prior to launch, it is possible to have a difference of several degrees between the launch azimuth and the vehicle alignment.

3-10 GUIDANCE FUNCTIONS IN FLIGHT

Prior to launch, the Platform is erected with the X_S axis referenced to the local vertical and the Z_S axis pointing in the direction of the launch azimuth. If the launch azimuth is to vary with time, the Platform will be automatically torqued (turned) to maintain this orientation.

Just before liftoff, the Platform is released and becomes space fixed. The Z_S axis then determines the flight azimuth.

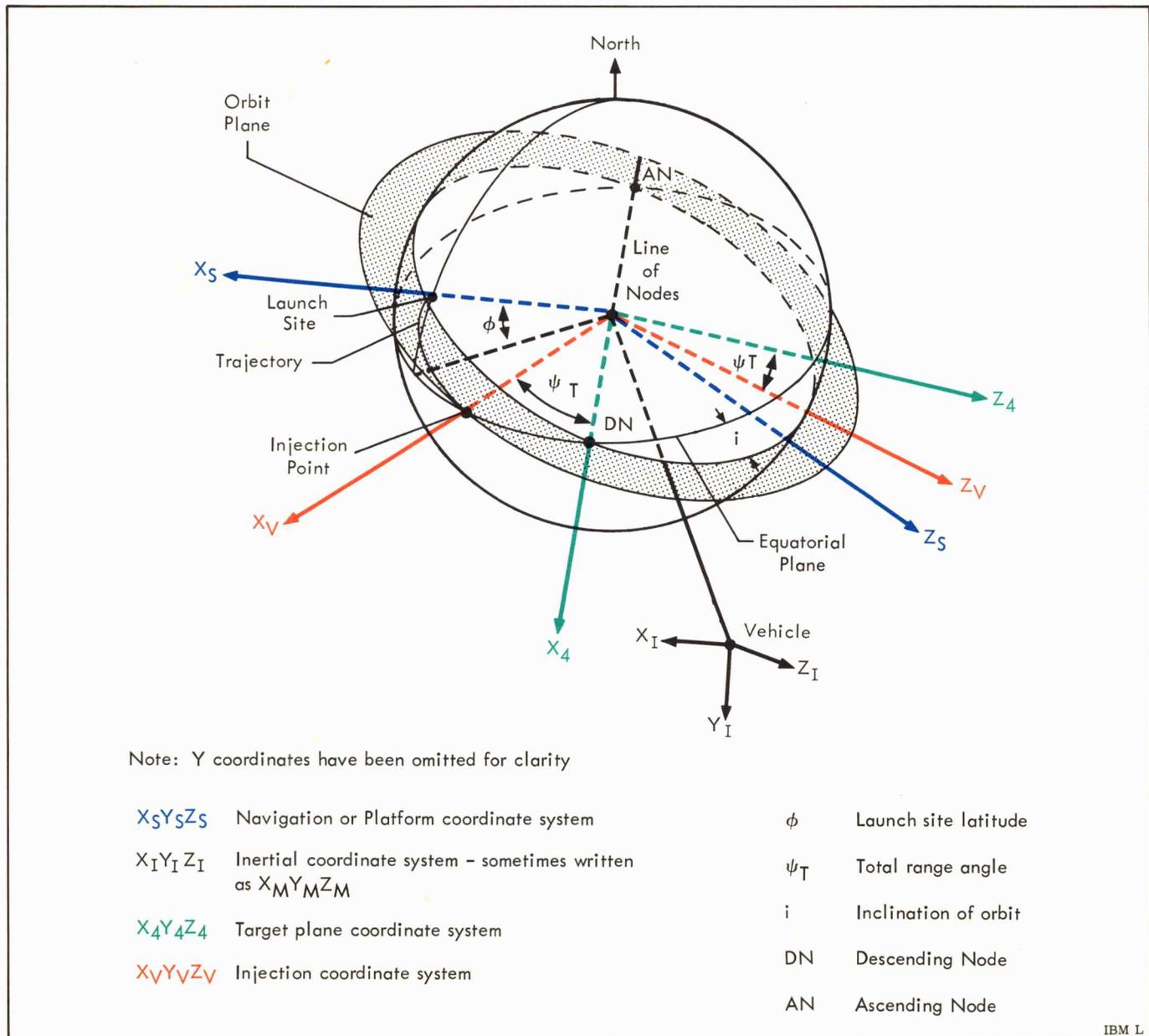


Figure 3-2. Guidance Coordinate Systems

FIRST-STAGE FLIGHT

The vehicle lifts off vertically from the launch pad and maintains its liftoff orientation long enough to clear the ground equipment. It then performs a roll maneuver to align the vehicle with the flight azimuth direction. This maneuver gives the vehicle control axes the correct alignment to the flight plane, thus simplifying the computations in the attitude control loop. On the launch pad, the vehicle always has a roll orientation fixed to the launching site. Table 3-1 specifies the roll error constants presently planned for Uprated Saturn I Missions.

During first-stage propulsion, a time-tilt program, stored in the LVDC, is applied directly after the described roll maneuver has been completed. The pitch angle of the vehicle is commanded according to the tilt program which is a function of time only and is independent of navigation measurements. See Table 3-1 for these pitch angles. However, navigation measurements and computations are performed throughout the flight, beginning at the time the Platform is released (i. e., 5-10 seconds before liftoff). Cutoff of the first-stage engines occurs when the fuel level in the tanks reaches a predetermined level. Thereafter, the first stage is separated from the launch vehicle, and the S-II Stage engine is ignited.

The mission profile for a typical Uprated Saturn I flight was shown in Figure 1-3.

SECOND AND THIRD-STAGE FLIGHT

Boost IGM begins soon after ignition of the S-II engine and jettison of the launch escape system. As described earlier, IGM is a path adaptive system designed to direct the vehicle to its desired end condition in a near-optimum fashion. In this flight phase, the end condition is injection into a parking orbit about the earth. Since IGM is a path adaptive scheme, position, velocity, and acceleration are inputs to the guidance computations. The guidance equations compute the pitch and yaw angles for the required thrust direction. In addition, the Saturn V scheme permits up to three thrust levels to occur during this boost phase.

Boost IGM is terminated when the time for S-IVB cutoff is less than 3 seconds away. At this

time, the attitude commands are frozen, and the flight program enters a high speed loop designed to accurately determine the time of cutoff (TCO). When TCO has been defined, a cutoff command is issued to the S-IVB engine via the S-IVB Switch Selector.

EARTH ORBITAL FLIGHT

During orbital coast flight, vehicle acceleration, velocity, and position are continually computed from equations of motion which are based on insertion conditions. Guidance during this flight phase consists of maintaining predetermined vehicle attitudes. Usually, this attitude will be maintained so that the roll axis is at 90 degrees with respect to the local vertical. This local vertical is determined from navigational computations.

Guidance computations during this flight phase are slowed from the normal 25 times per second to once per second. This slowdown allows more time for check routines and other programs to operate within the LVDC.

TRANSLUNAR FLIGHT

The guidance scheme used for the second S-IVB boost is similar to the IGM scheme used during boost flight into orbit. Again, path-adaptive IGM is used to guide the SC/S-IVB/IU vehicle configuration into a lunar trajectory. TCO is computed from inputs of vehicle motion, and cutoff is commanded when the correct velocity and direction are achieved.

The last flight phase for the launch vehicle is the translunar coast period in which the guidance computations are primarily concerned with maintaining a steady attitude while the transposition and docking maneuvers are accomplished.

THE UPRATED SATURN I FLIGHT GUIDANCE

The guidance scheme for the Uprated Saturn I flights is basically the same as previously described for the Saturn V Vehicles. Since the Uprated Saturn I Vehicle has no intermediate state, IGM begins soon after S-IVB Stage ignition. This guidance mode continues until orbital insertion is achieved. Later in the flight, if another boost flight phase is scheduled, IGM is again used for the guidance computations.

Table 3-1. Time-Tilt and Roll Constants for Uprated Saturn I Missions

Vehicle	Roll Error	Vehicle Alignment	Firing Azimuth	Pitch Angles
AS-202	+ 5°	100°	105°	0° to -57.56° (T ₁ + 10 to T ₁ + 138)
SA-203	-12°	84°	72°	0° to -69.73° (T ₁ + 10 to T ₁ + 138)
AS-204	-28°	100°	72°	0° to -58.46° (T ₁ + 10 to T ₁ + 138)
AS-205	-28°	100°	72°	0° to -61.81° (T ₁ + 10 to T ₁ + 138)
AS-206	-18°	90°	72°	0° to -61.72° (T ₁ + 10 to T ₁ + 134)
AS-207 and subsequent vehicles	(To be supplied)			

Note: T₁ is a time reference base which commences at liftoff (T₁ + 10 refers to 10 seconds after liftoff).

SECTION IV

CONTROL SYSTEM

4-1 GENERAL CONSIDERATIONS OF ATTITUDE CONTROL

The Control Systems of the Saturn Launch Vehicles are designed to maintain and control vehicle attitude by forming the steering commands to be used by the controlling engines of the active stage.

Attitude control of the Saturn Launch Vehicles may be divided into two parts, powered (burn) flight control and coast flight control. Powered flight consists of the two or three stages of propulsion necessary to carry the last stage (S-IVB Stage) and payload into orbit. Coast flight consists of maneuvering the payload and last stage to maintain a predetermined orbital attitude.

Vehicle attitude is achieved by gimbaling the four outboard engines of the S-IB, S-II, or S-IC Stage during their particular burn phase. These control engines are actually moved about their mounting axes by piston-like hydraulic actuators.

During the powered phase of the S-IVB Stage flight, yaw and pitch maneuvers are accomplished by gimbaling its single propulsion engine. Roll maneuvers, which cannot be executed with a single engine, are controlled by an Auxiliary Propulsion System (APS). The APS consists of two Control Relay Packages and six thrust nozzles. These nozzles are arranged in 2 groups of 3 as shown in the cross sectional view of the S-IVB Stage in Figure 4-1. The ON-OFF thrust action of the nozzles produces the desired thrust direction.

NOTE

Firing a combination of either nozzles I_{II} and III_{IV} or I_{IV} and III_{II} will impart a rolling motion to the vehicle.

The APS is used exclusively during the coast flight phase of the S-IVB Stage since the main engine is turned OFF. All three maneuvers (pitch, roll, and yaw) are executed by the APS nozzle configuration during this coast period. More details of the APS operation are contained in Section VII.

4-2 VEHICLE ATTITUDE AXES

Orientation of the launch vehicle's three axes is also shown in Figures 4-1 and 4-2. The axes are best defined by first picturing the vehicle as it will rest on the launching pad. Position I will point "downrange" and in the general direction of the planned flight path. In flight, position I will normally be pointed earthward as shown in the figure. The motion of the fore portion of the vehicle (nose) is used to define polarity of motion.

With position I and the nose as the reference, the attitude axes may be defined as follows:

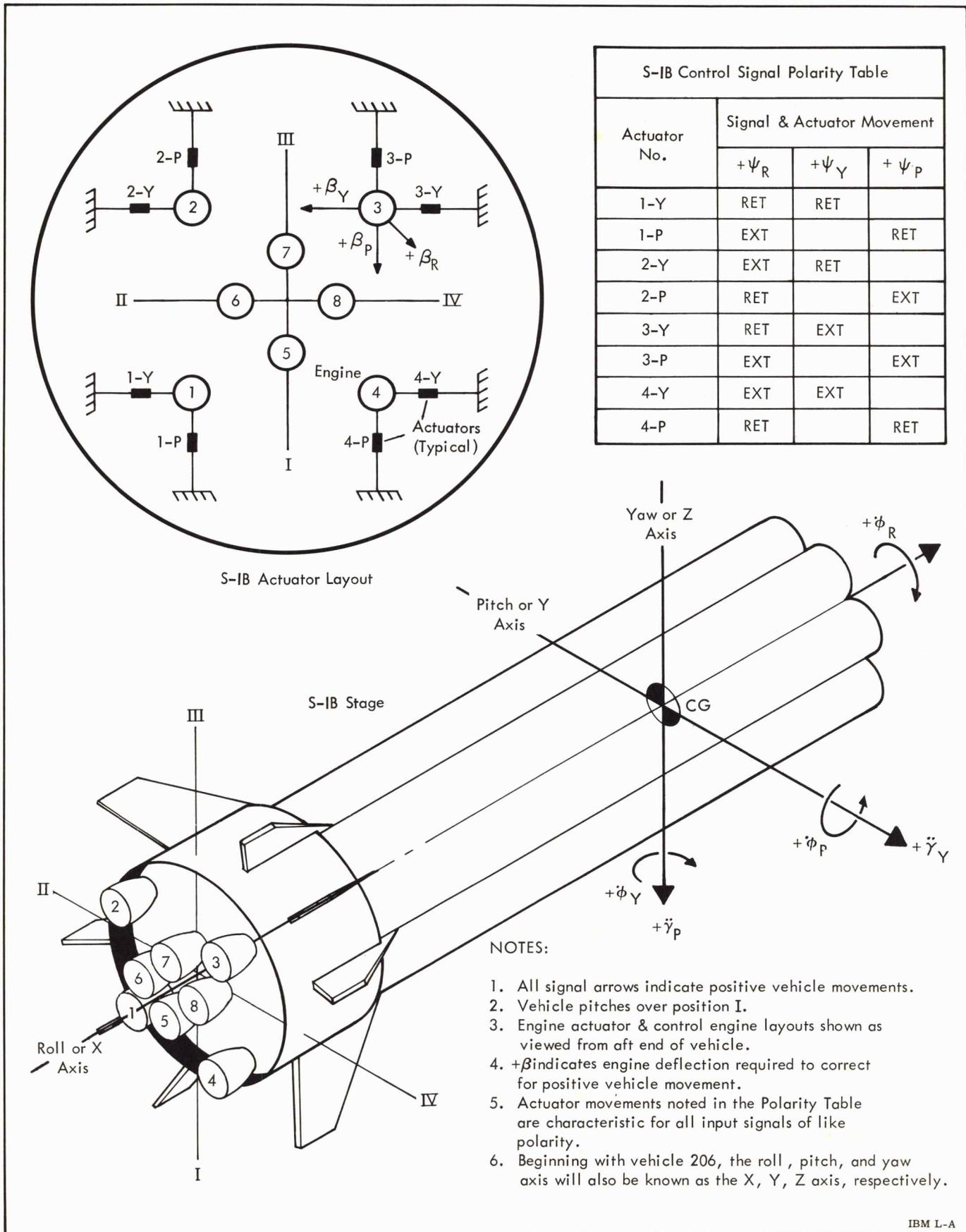
- Pitch (P) The axis on which the vehicle may tilt downrange. In flight, the pitch axis allows "up" and "down" motion of the vehicle. An upward tilt motion is positive (+P); a downward tilt motion is negative (-P).
- Yaw (Y) The axis on which the vehicle turns to the right or left. A turn to the right is positive (+Y); a turn to the left is negative (-Y).
- Roll (R) The roll axis runs longitudinally through the vehicle - "fore and aft" A positive roll (+R) maneuver is in a clockwise direction (looking forward); a negative roll (-R) maneuver is in a counter-clockwise direction (looking forward).

At times, especially in programming, these axes will be referred to in an X Y Z coordinate system. For Vehicles 201 through 205 and 501, X, Y, and Z represent the yaw, roll, and pitch axes, respectively. Coincident with Vehicles 206 and 502, the X, Y, and Z coordinates will change and thereafter represent the roll, pitch, and yaw axes, respectively. Polarities are the same for either system.

4-3 CONTROL SYSTEM OPERATION

4-4 THE UPDATED SATURN I CONTROL SYSTEM

Figure 4-3 shows a simplified block diagram of the Updated Saturn I Control System. The Flight



S-IB Control Signal Polarity Table			
Actuator No.	Signal & Actuator Movement		
	$+\psi_R$	$+\psi_Y$	$+\psi_P$
1-Y	RET	RET	
1-P	EXT		RET
2-Y	EXT	RET	
2-P	RET		EXT
3-Y	RET	EXT	
3-P	EXT		EXT
4-Y	EXT	EXT	
4-P	RET		RET

NOTES:

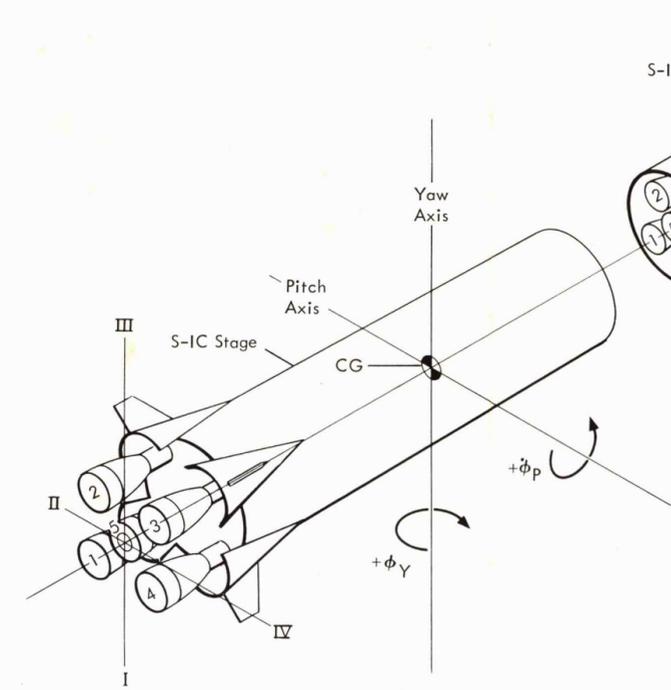
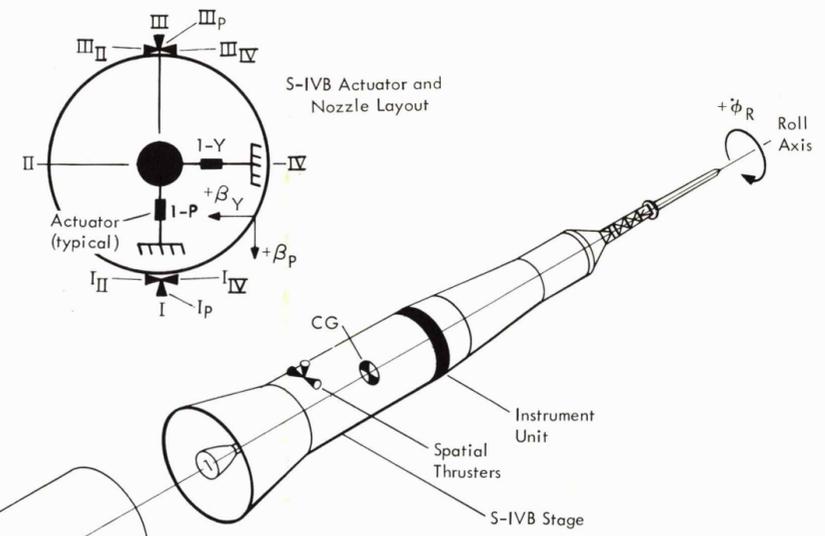
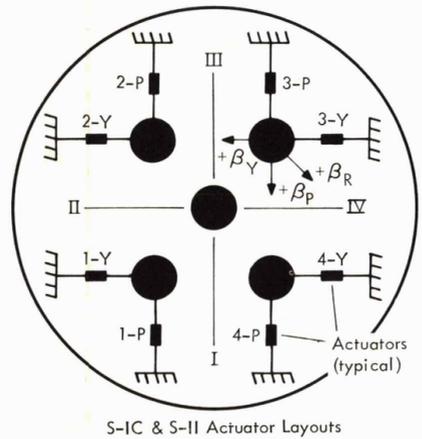
1. All signal arrows indicate positive vehicle movements.
2. Vehicle pitches over position I.
3. Engine actuator & control engine layouts shown as viewed from aft end of vehicle.
4. $+\beta$ indicates engine deflection required to correct for positive vehicle movement.
5. Actuator movements noted in the Polarity Table are characteristic for all input signals of like polarity.
6. Beginning with vehicle 206, the roll, pitch, and yaw axis will also be known as the X, Y, Z axis, respectively.

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Figure 4-1. The Uprated Saturn I Engine and Actuator Configuration

NOTES:

1. All signal arrows indicate positive vehicle movements.
2. Vehicle pitches over position I.
3. Engine actuator layouts shown as viewed from aft end of vehicle.
4. Directions and polarities shown are typical for all stages.
5. $+\beta$ indicates engine deflection required to correct for positive vehicle movement.
6. CG = Center of gravity
F = Nozzles ON
EXT = Actuator extended
RET = Actuator retracted
 β = Thrust vector angular deflection
7. Beginning with vehicle 502, the roll, pitch, and yaw axes will also be known as the X, Y, Z axes, respectively.



Actuator No.	Actuator Movement		
	$+\psi_R$	$+\psi_Y$	$+\psi_P$
1-Y	RET	RET	
1-P	EXT		RET
2-Y	EXT	RET	
2-P	RET		EXT
3-Y	RET	EXT	
3-P	EXT		EXT
4-Y	EXT	EXT	
4-P	RET		RET

Actuator No.	Signal & Action			
	$+\psi_R$	$-\psi_R$	$+\psi_Y$	$+\psi_P$
1-Y			EXT	
1-P				RET
Engine No.				
I IV		F		
I P				
I II	F			
III II		F		
III P				
III IV	F			
Conditions During Coast				
	$+\psi_R$	$-\psi_R$	$+\psi_Y$	$-\psi_Y$
I IV		F		F
I P				F
I II	F		F	
III II		F	F	
III P				F
III IV	F			F

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Figure 4-2
Saturn V Engines, Actuators, and Nozzle Arrangement

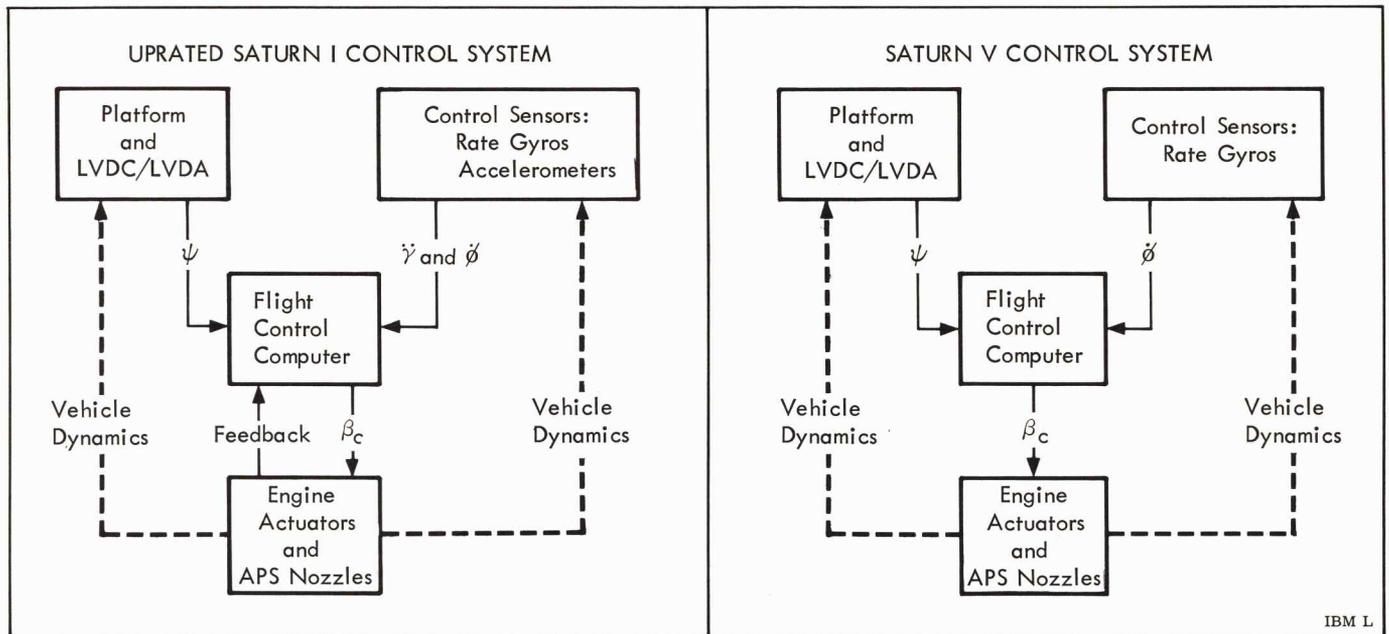


Figure 4-3. Saturn Control Systems Block Diagram

Control Computer, herein referred to as the Control Computer, is the heart of the Control System and accepts signals from 4 sources:

- Attitude error signals (ψ) from the LVDC/LVDA Guidance System.
- Attitude angular rate change signals ($\dot{\phi}$) from Control-EDS Rate Gyros.
- Lateral acceleration rate signals ($\dot{\gamma}$) from Control Accelerometers.
- Electrical feedback signals from the S-IB Stage engine actuators.

The Control Computer uses the angular rate changes to form the angular engine commands (β_c) by modifying the attitude error signals to conform to vehicle limits. These command limits are needed to maintain the rate of vehicle maneuvering and motion within safe, prescribed limits during all phases of the flight.

Because of high aerodynamic loading pressures and jet-stream winds encountered during first-stage burn, lateral acceleration measurements are also used in forming the engine attitude command signals. In the subsequent burn and coast phases of the S-IVB Stage flight, lateral acceleration is so slight that it is disregarded.

The angular thrust direction of the engines is controlled by swivelling the gimbal-mounted propulsion engines. This control is obtained by linear, hydraulic, servo-actuators which are oriented to the pitch and yaw planes.

4-5 SATURN V CONTROL SYSTEM

The Saturn V Control System is essentially the same as the system used on the Saturn IB Vehicle. As shown in Figure 4-3, the Saturn V Flight Control Computer has two less inputs. The Saturn V configuration does not use lateral acceleration values and engine feedback signals in its control scheme. Instead, the acceleration and bending modes are accounted for within the guidance and control computations and filter networks. Mechanical feedback within the actuator assemblies is used exclusively on Saturn V.

As in the Uprated Saturn I Vehicle, attitude command signals (ψ) generated in the LVDC are limited by rate signals ($\dot{\phi}$) from the rate gyros. The commands (β_c), thus formed, are the pitch, yaw, and roll signals for the engine actuators and the APS thrust nozzles.

4-6 FLIGHT CONTROL COMPUTER OPERATION

The following is a simplified explanation of the Control Computer function. The explanation is inserted at this point in the text as an aid in describing the

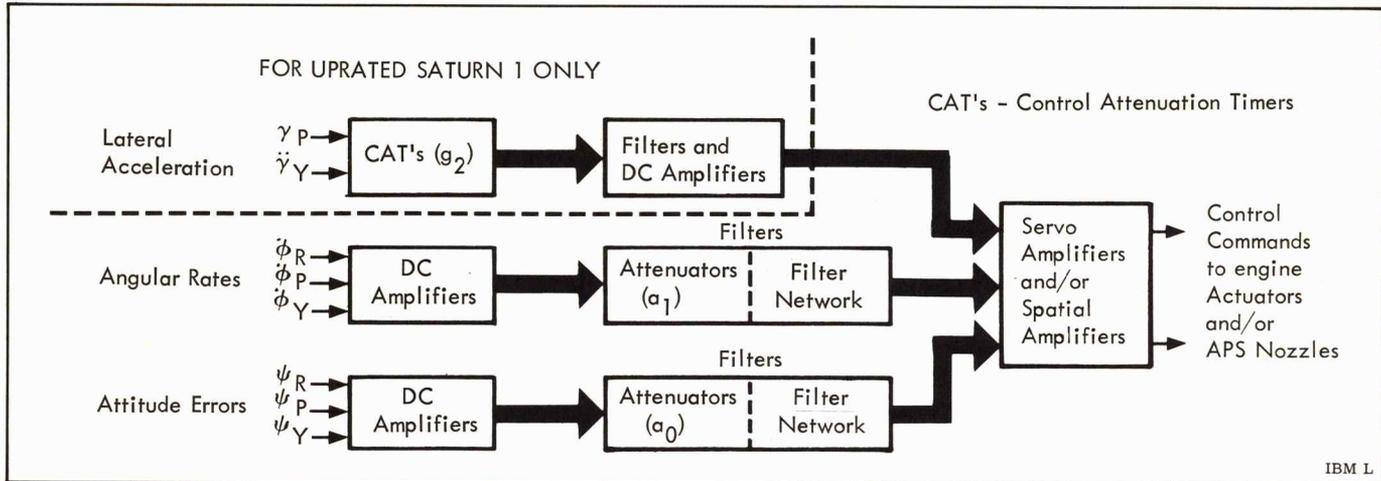


Figure 4-4. Flight Control Computer Simplified Block Diagram

Control System operation. A detailed description of the Control Computer may be found in Section VII.

networks shape the signals to achieve phase and gain stabilization.

The Control Computer is an analog computer which generates the proper control commands for the engine actuators and S-IVB auxiliary propulsion system. To accomplish this, the Control Computer processes and combines analog signals from the LVDC/LVDA or spacecraft and control sensors. In the Uprated Saturn I Vehicles, the Control Computer also provides 60 Vdc to the engine actuators as a power source for the feedback loop mentioned earlier.

Figure 4-4 is a block diagram of the Flight Control Computer. Input channels accept the control signals listed in Table 4-1. Each channel then amplifies, scales, and filters its respective signal according to a predetermined and time-variable gain factors. The symbols for these gain factors are also shown in the table. The processed signals are then summed together and further amplified by either servo or spatial amplifiers. The output signals from the two types of amplifiers are the drive signals for the engine servo actuators and/or auxiliary steering system.

The gains of these channels are controlled by two types of attenuators. One attenuator, the CAT (Control Attenuation Timer), is motor driven. The other type of attenuator consists of relay-switched resistor networks which are controlled by commands from the LVDC. These relay-switched attenuators are often referred to as "switch points". The filter

Table 4-1. Input Signals to the Flight Control Computer

Input Channel	Symbol	Gain** Factor	Signal Sources
Lateral Acceleration*			
Pitch	$\ddot{\gamma}_P$	} g_2	Uprated Saturn I Control Accelerometers
Yaw	$\ddot{\gamma}_Y$		
Angular Rate			
Pitch	$\dot{\phi}_P$	} a_1	Control-EDS Rate Gyros
Yaw	$\dot{\phi}_Y$		
Roll	$\dot{\phi}_R$		
Attitude Error			
Pitch	ψ_P	} a_0	LVDA/LVDC or Spacecraft
Yaw	ψ_Y		
Roll	ψ_R		

* Used only on Uprated Saturn I Vehicles

** Time-varying functions that determine which of the three terms of the control equation will be dominant. The control equation is defined as:

$$\beta_c = a_0 \psi + a_1 \dot{\phi} (+ g_2 \ddot{\gamma} \text{ for Uprated Saturn I})$$

SECTION V

FLIGHT PROGRAM

5-1 GENERAL DESCRIPTION

A flight program is defined as a set of instructions which controls the LVDC operation from seconds before liftoff until the end of the launch vehicle mission. These instructions are stored in core memory within the LVDC.

The flight program performs many primary functions during the launch vehicle mission. These functions include: navigation, guidance, attitude control, event sequencing, data management, ground command processing, and hardware evaluation. The definition for these functions will change with the mission objectives as R and D or operational; lunar or orbital; or manned or unmanned.

The LVDC flight program may be divided into five parts for the purpose of discussion: the powered flight major loop, the orbital-flight program, the minor loop, interrupts, and telemetry. The powered flight major loop contains guidance and navigation calculations, timekeeping, and all repetitive functions which do not occur on an interrupt basis. The orbital flight program consists of an executive routine concerned with IU equipment evaluation during orbit and a telemetry time-sharing routine to be employed while the vehicle is over receiving stations. In addition, in the orbital flight program, all navigation, guidance, and timekeeping computations are carried out on an interrupt basis keyed to the minor loop. The minor loop contains the Platform gimbal angle and accelerometer sampling routines and control system computations. Since the minor loop is involved with the vehicle control, minor loop computations are executed at the rate of 25 times per second during the powered phase of flight. However, in earth orbit, only a rate of 10 executions per second is required for satisfactory vehicle control.

Several subroutines are secondary functions are available to the main program. They are utilized at specific times within the main loop or certain phases of the flight (e.g., boost navigation computations). In addition, an interrupt routine permits interruption of the normal program operation to free the LVDC for

priority work. These interrupt operations may occur at any time within the program. Actually, the minor loop is an interrupt operation which will occur at intervals of 25 times per second (i.e., every 40 milliseconds, the main program is interrupted while gimbal angle readings, accelerometer samplings, and control system routines are processed).

A programmed telemetry feature is also provided as a method of monitoring LVDC and LVDA operations. The telemetry routine transmits specified information and data to the ground via IU telemetry equipment. In orbit, telemetry data must be stored at times when the vehicle is not within electromagnetic range of a ground receiving station. This operation is referred to as data compression. The stored data will be transmitted later on a time-shared basis with real-time telemetry when range conditions are favorable.

The execution time for any given major loop, complete with minor loop computations and interrupts, is not fixed. The average execution time for any given major loop in powered flight, complete with minor loop computation and interrupt processing, is called the nominal computation cycle for that mode. The computation cycle is not fixed for two reasons. First, the various flight modes of the program have different computation cycle lengths. Second, even in a given flight mode, the uncertainties of discrete and interrupt processing and the variety of possible paths in the loop preclude a fixed computation cycle length. Even though the exact length of any given computation cycle is not predictable, the longest nominal computation cycle in boost should be less than 2 seconds. In orbit, the computation cycle will be approximately 1 second for guidance and 8 seconds for navigation. For the second S-IVB burn (out-of-orbit flight), the computation cycle will be approximately 2 seconds in length.

NOTE

The following paragraphs contain a description of the Saturn flight

program for AS-502. In later vehicles, these routines and the timing may vary as refinements and changes become necessary. Therefore, all descriptions and diagrams should be considered as typical and for general information only.

5-2 PRELAUNCH AND INITIALIZATION

The sequence of events which take place prior to launch are referenced to the estimated liftoff time. The sequence begins approximately 20 minutes before estimated liftoff (T-20 minutes). Up to this point in time, the LVDC has been under control of the Ground Control Computer (GCC). Ground routines that perform certain prelaunch functions and prepare the LVDC for the flight program are established. At T-20 minutes, the GCC issues a "Prepare-To-Launch" (PTL) command to the LVDC. The PTL routine performs the following functions:

- Executes an LVDC/LVDA self-test program and telemeters the results.
- Monitors accelerometer inputs and calculates the Platform off-level indications. Telemeters accelerometer outputs and time.
- Performs reasonable checks on particular discrete inputs and alerts.
- Interrogates the error monitor register.
- Keeps all ladder outputs zeroed by issuing ladder outputs.
- Processes the Guidance Reference Release (GRR) interrupt and transfers LVDC control to the flight program.
- Samples Platform gimbals angles.

At T-163 seconds, an automatic launch sequence is started. (This action is not communicated to the LVDC.) At T-15 seconds, the launch sequencer issues a GRR alert signal to the LVDC and GCC. In effect, this signal alerts the program. At T-10 seconds, a GRR interrupt signal is sent to the LVDC and GCC. With the receipt of this signal, the PTL routine transfers control of the LVDC to the flight program.

When the Guidance Reference Release (GRR) interrupt is received by the LVDC, the following events take place:

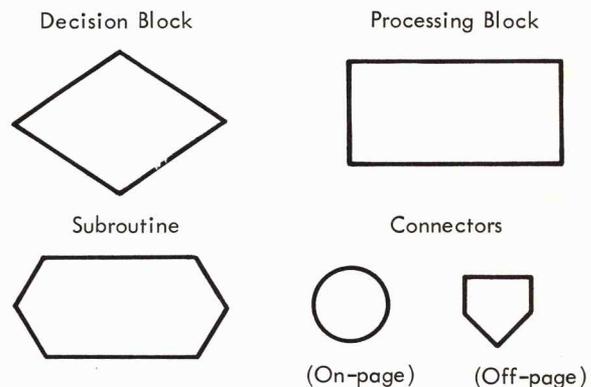
- The computer sets time base zero (T_0).
- Gimbal angles and accelerometer are sampled and stored for use by program routines.
- Time and accelerometer readings are telemetered.
- All flight variables are initialized.
- The ground computer is signaled that the LVDC is under control of the flight program.

During the time period (T_0) between GRR and Liftoff (LO), the LVDC begins to perform navigational calculations and processes the minor loops. At T-8.8 seconds, the engines are ignited. At T=0, liftoff occurs and a new time base (T_1) is initiated. T_1 is used for first-stage flight and for discrete outputs.

5-3 FLIGHT PROGRAM ROUTINES

This section is primarily concerned with the major and minor loops. However, since portions of the program are dependent upon other routines, brief summaries of these are included to give the reader a better understanding of how the flight program routines fit together. A further breakdown of routines, i.e., subroutines, is beyond the scope of this book. *

Simplified "word" flow charts of the program and its routines are included. The following symbols are used to represent program functions:



* For a more detailed explanation of the flight program and its mathematics, refer to the LVDC Equation Defining Document which is published by IBM and updated for each vehicle.

5-4 MAJOR LOOP

The major loop, shown in Figure 5-1, contains the navigation and guidance calculations, timekeeping, and other repetitive operations of the flight program. Its various routines are divided by function and are illustrated by individual blocks in the figure. Depending upon mode of operation and time of flight, the program will follow the appropriate "path".

Assuming that the vehicle has just lifted off and the program has been "running" normally, a boost major loop cycle will operate as follows. Entering block 1 of Figure 5-1, it is determined that it is not time for the orbital scheme. Therefore block 2, which is the accelerometer processing routine, will be the first routine to operate. Following the completion of that routine, the boost major loop will continue operating through blocks 3, 4, 5, 8, 9, 1, 2, etc., in that order. This is a repetitive cycle and will continue until it is time for the IGM mode of operation. The path during IGM operation will then include blocks 1, 2, 3, 4, 6, 7, 8, and 9.

After S-IVB cutoff, the vehicle is assumed to be in orbit so the program will necessarily follow blocks 1, 10, and 11 or 12, etc., respectively. This portion of the program is referred to as the orbital major loop.

It should be noted that the minor loop support routine (block 8) is not the minor loop as previously described. Minor loop support is a processing routine within the major loop which supports the minor loop (interrupt) function.

Block 13 includes the minor loop and other interrupt routines. Figure 5-2 is a general flow diagram of the interrupt and minor loop processing routines which represent the remainder of the flight program. The interrupt function is shown separately because it operates independently of the major loop. An interrupt can occur at any place and time within the operation of the major loop program.

5-5 INTERRUPT AND MINOR LOOP OPERATION

The LVDC/LVDA has a built-in feature which allows priority processing by interrupting the normal flight program. See Figure 5-2. An "interrupt" is generated when such a priority task arises. The interrupt transfers LVDC control to a special subroutine which identifies the interrupt source, performs the necessary subroutines, and then returns to the point in the program where the interruption occurred. For example, during the 50th instruction of the boost

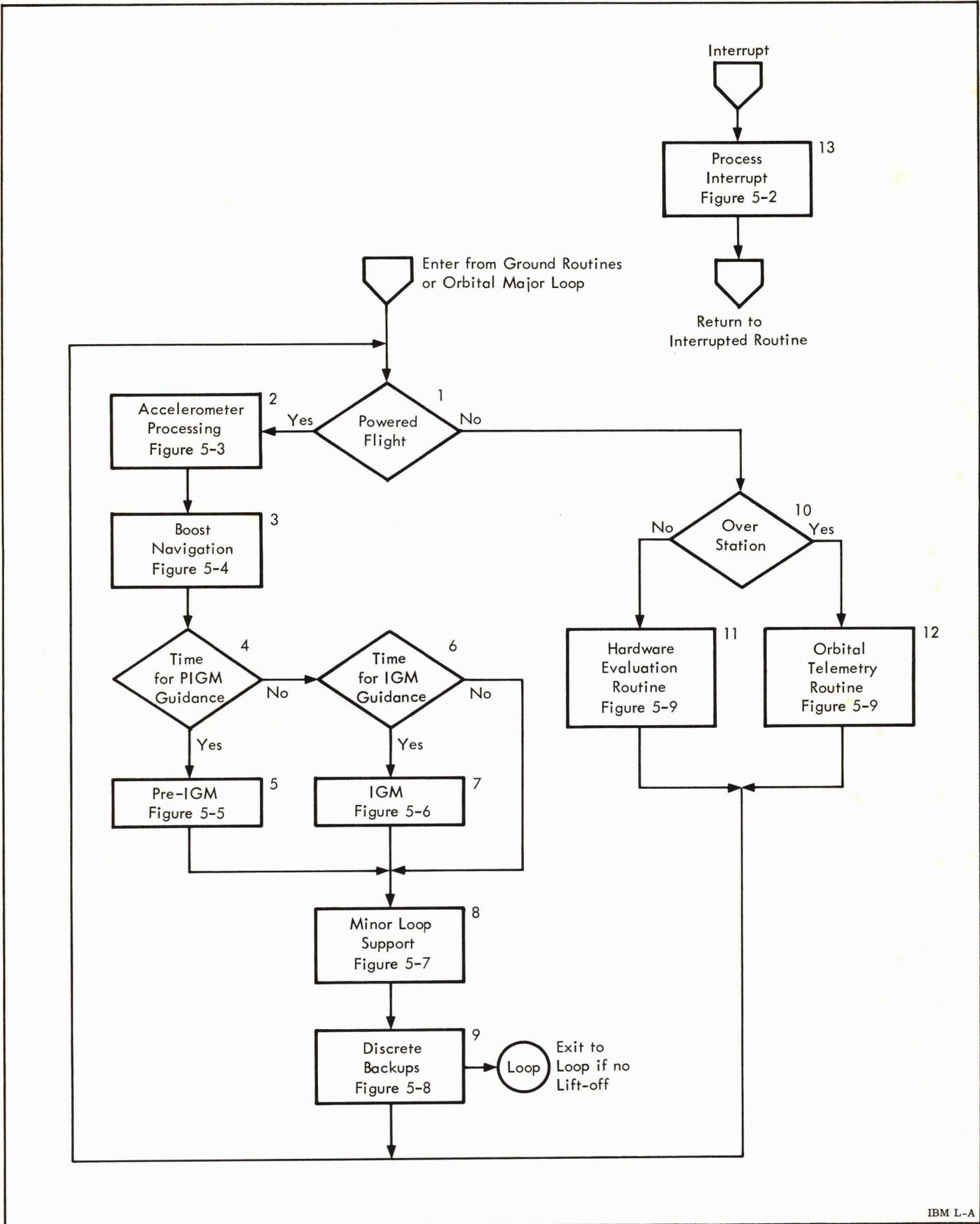
navigation program, an interrupt might occur. At the completion of that instruction, the program control branches to the interrupt routine, performs the indicated operation, and then returns to the 51st instruction step of the boost navigation program. The boost navigation routine itself will not be affected in any way except for the time of delay caused by the interrupt operation.

The LVDC/LVDA has provision for 12 interrupts which are listed in Table 5-1.

The minor loop, which is initiated by the interrupt, is shown on the right of the figure. A built-in timing feature of the LVDC (under program control) causes a minor loop interrupt approximately every 40 milliseconds (25 times per second) during boost flight. Present plans indicate that the minor loop will operate approximately 21 milliseconds. This implies that the major loop will operate for only 19 milliseconds between each minor loop interrupt. During orbit, the frequency of the minor loop interrupt is reduced to 100 millisecond intervals (10 times per second) and can be considered as divided into 2 modes. The first mode is the attitude update mode (1 per second) in which the gimbal angles are sampled and the ladder (attitude) commands are computed. In the second mode, which is the attitude hold mode, the ladder commands are recomputed (9 per second) based on the previous gimbal samples. In either case, ladder commands are issued at the minimum rate of 10 per second. Under this scheme, the time spent in the minor loop is reduced from over 50 percent in powered flight to approximately 10 percent during orbit.

Table 5-1. Interrupts

Decreasing Priority	Function
1	Minor Loop Interrupt
2	Switch Selector Interrupt
3	Computer Interface Unit Interrupt
4	Temporary Loss of Control (TLC)
5	Command Receiver Interrupt
6	Guidance Reference Release
7	S-II Propellant Depletion/Engine Cutoff
8	S-IC Propellant Depletion/Engine Cutoff "A"
9	S-IVB Engine Out "B"
10	Program Re-Cycle (RCA-110A Interrupt)
11	S-IC Inboard Engine Out "A"
12	Command LVDA/RCA-110A Interrupt



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Figure 5-1. Major Loop

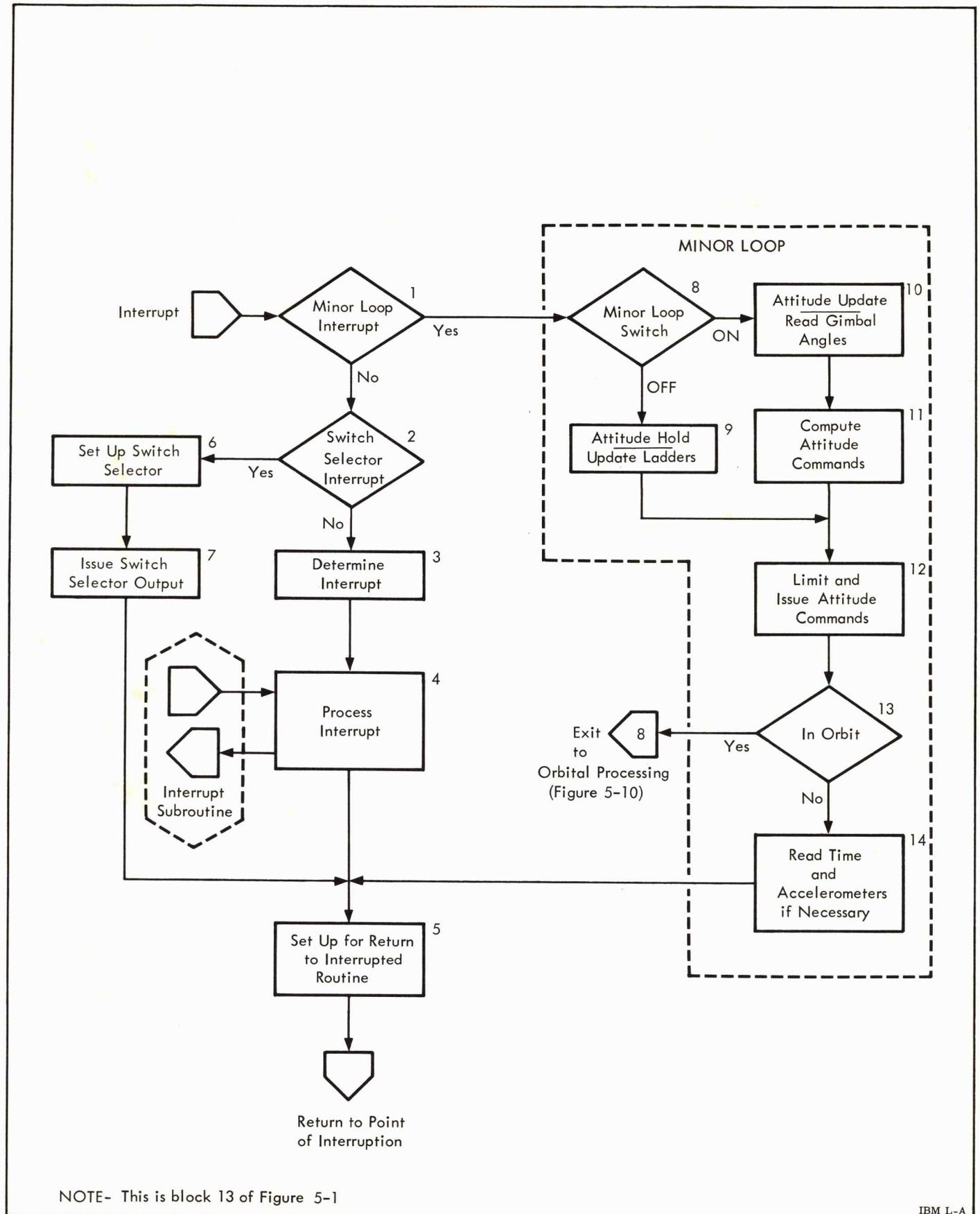


Figure 5-2. Interrupt and Minor Loop Processing

5-6 ACCELERATION PROCESSING

The accelerometer processing routine, shown in Figure 5-3, accomplishes two main objectives: it accumulates velocities as measured by the Platform, and tries to detect velocity measurement errors through "reasonableness" tests.

The quantity F/M (acceleration) is computed from Platform velocities except where such computations are expected to be "noisy". During noisy portions of the program, F/M is set to a predetermined constant. M/F is also computed in this routine for use within the IGM routine.

The reasonableness test is designed to detect large errors in the formation of velocity words. The test serves as a program switch which selects velocity word channel "B" in the event of a failure in velocity word channel "A". A velocity change is considered reasonable if it falls within ± 50 percent of the expected change enlarged by a Reasonable Test Constant (RTC). The RTC serves two purposes. First, it provides leeway in the test when the expected change is near zero (e.g., RTC=5). Secondly, the RTC provides a safety margin during portions of the flight when F/M computations may be questionable (e.g., RTC=30).

Should both readings fail the reasonableness test, an appropriate velocity change is computed from current gimbal angles, time, and pre-stored values of thrust, mass, and mass flow rate. The reasonableness tests will not correct the cause of the error but will attempt to prevent such errors from causing corresponding errors in guidance and navigation quantities.

5-7 BOOST NAVIGATION

The boost navigation routine, shown in Figure 5-4, combines gravitational acceleration with measured Platform data to compute position and velocity in the X_S, Y_S, Z_S coordinate system. Each block in the figure represents the computation of the values given in Table 5-2.

This boost navigation routine is used from GRR until approximately 100 seconds after the first S-IVB cutoff and again from the beginning of restart preparations until 10 seconds after the second S-IVB cutoff.

5-8 PRE-IGM GUIDANCE

Pre-IGM guidance deals with the method of generating attitude commands (χ angles) during the

Table 5-2. Boost Navigation Calculations

Block	Computation Results
1	$\Delta X_g \Delta Y_g \Delta Z_g$
2	$\Delta X_T \Delta Y_T \Delta Z_T$
3	$X_S Y_S Z_S$
4	$X_g Y_g Z_g$
5	$I_{gX} I_{gY} I_{gZ}$
6	$X_S Y_S Z_S$

time from Guidance Reference Release (GRR) to initiation of IGM. The word flow diagram for this period is depicted in Figure 5-5. This portion of the flight program is sometimes referred to as the "time-tilt" program since these early guidance commands are functions of time. It is also referred to as "open loop" guidance since vehicle dynamics do not affect or influence the guidance commands.

Consider a typical Saturn V flight, where position I alignment is offset by -18 degrees. This offset occurs because Position I has an azimuth heading of 90 degrees at liftoff whereas the desired heading for Position I is in the direction of firing azimuth (72 degrees). After liftoff, the vehicle is maintained vertically as the roll angle is commanded to -18 degrees. When the tower has been cleared, the roll error is commanded to zero. After this command, roll and yaw commands remain at zero and the vehicle is gradually pitched (tilted) about the vehicle's Y axis to its predetermined boost heading. Rate limiting of the output commands prevents the χ angles from exceeding 1 degree per second.

Just prior to S-IC engine cutoff, the attitude commands are "frozen" until the initiation of IGM. This freeze continues into the initial portion of the S-II Stage flight to eliminate excessive flight perturbations caused by S-IC burnout and the S-II ignition.

5-9 IGM ROUTINE

The IGM routine (shown in Figure 5-6) is primarily used to compute the steering angle com-

mands and the "time-to-go" for the remaining burn time of the vehicle. Most of the values are computed in the injection coordinate system and are later transformed into the space-fixed coordinate system.

IGM commences after second-stage ignition and continues until the S-IVB engine is cutoff. Cutoff occurs when the desired velocity has been reached.

IGM is started approximately 30 seconds after S-II ignition. During S-II burn, one or more burn modes (engine mixture ratios) may be programmed. At 350 seconds after S-II ignition, S-II thrust will be terminated and stage separation occurs. The S-IVB Stage is then ignited and burns for approximately 180 seconds before injecting the vehicle into a parking orbit.

5-10 MINOR LOOP SUPPORT

Certain processing is required to support the minor loop. The first task performed within this support routine (Figure 5-7) is to check with X Y Z counters which record Platform resolver failures (64:1 or 2:1). The output of these resolvers are used as inputs to the minor loop. The 64:1 resolvers are tested to determine whether the backup resolver should be used instead of the normal resolver. The 2:1 counters are tested to determine if a guidance failure has occurred. If excessive Disagreement Bit (DB) failures are detected, certain counters in the disagreement bit processing routine are not reset.

Values of $D\chi$ are computed in block 6 of this routine and will be used in limiting certain attitude rates (guidance commands) during powered flight. The value of $D\chi$ is a computed increment of the latest guidance command (χ) which is gradually added to the last guidance command. This scheme provides a smooth transition from the old command to the new one. During coast flight, the smooth transition is not required, and entire guidance command is issued when it is first computed.

The (χ) rate of change is limited to values appropriate to the particular flight mode. When this limiting occurs, the Steering Misalignment Correction (SMC) computations are inhibited.

The remainder of the routine is used to compute sine-cosine coefficients needed in attitude control equations. A check of the channel A ladder output register failures is also made, and if it fails more than three times in one major loop cycle it is abandoned in favor of channel B.

5-11 DISCRETE BACKUPS

Certain discrete, outboard events are particularly important to the flight program since they reset the computer time base which is the reference for all sequential events. For Saturn V Vehicles, these significant events (time bases) are:

T ₁	Liftoff (LO)
T ₂	S-IC Inboard Engine Cutoff (IECO)
T ₃	S-IC Outboard Engine Cutoff (OECO)
T ₄	S-II Cutoff
T ₅	S-IVB Cutoff (Boost Phase)
T ₆	S-IVB Restart
T ₇	S-IVB Cutoff (Orbital Phase)

Since Switch Selector outputs are a function of time (relative to one of the time bases), no Switch Selector output could be generated if one of the discrete signals were missed. A backup routine is provided to circumvent such a catastrophic failure. Simply, the discrete backup routine (Figure 5-8) will simulate these critical signals if they do not occur when they are expected. No onboard backup for the initiation of time base six (T₆) is included in the flight program at this time.

In the cases of the backup routines for LO and IECO, special routines are established as a double safety check. In both cases, motion as well as time are confirmed before a backup discrete is issued. For LO, the backup routine is entered 10.5 seconds after GRR. If the X_S acceleration exceeds 2 m/s^2 for 6 computation cycles, the vehicle is assumed to be airborne, and the liftoff discrete is issued. For IECO, an additional safety feature is built into the routine to ensure that an on-the-pad firing of the S-II Stage cannot occur if T₁ is accidentally set. Before T₂ can be initiated, velocity along the Z_S coordinate is tested for a minimum of 500 m/s.

5-12 ORBITAL FLIGHT PROGRAM

The orbital flight program (shown in Figure 5-9) consists of an executive routine concerned with IU equipment evaluation during orbit and a telemetry routine which is employed while the vehicle is over or within range of a receiving station. The orbital navigation routine computes and pinpoints the access areas.

Both real-time and stored (past-history) data are transmitted on a time-shared basis. The stored data is "compressed" before being stored in the LVDC because of limited core capacity. Four types of data will be compressed during a typical flight: (1) LVDC inputs, (2) LVDC internal data, (3) LVDC outputs, and (4) PCM data read into the LVDC through the Computer Interface Unit.

5-13 ORBITAL PROCESSING

The Orbital Processing Routine (OPR) is shown in Figure 5-10. The routine is actually an extension of

the minor loop interrupt but is only used during the orbital phase of the mission.

Navigation, guidance, and attitude control functions are carried out on a regular basis under control of the minor loop interrupt. The OPR thus serves as an executive program which cycles various routines on a timed basis. Among these routines are:

- Orbital Guidance (1 per second)
- Orbital Navigation (1 per 4 seconds)
- Read gimbal angles (1 per 8 seconds)

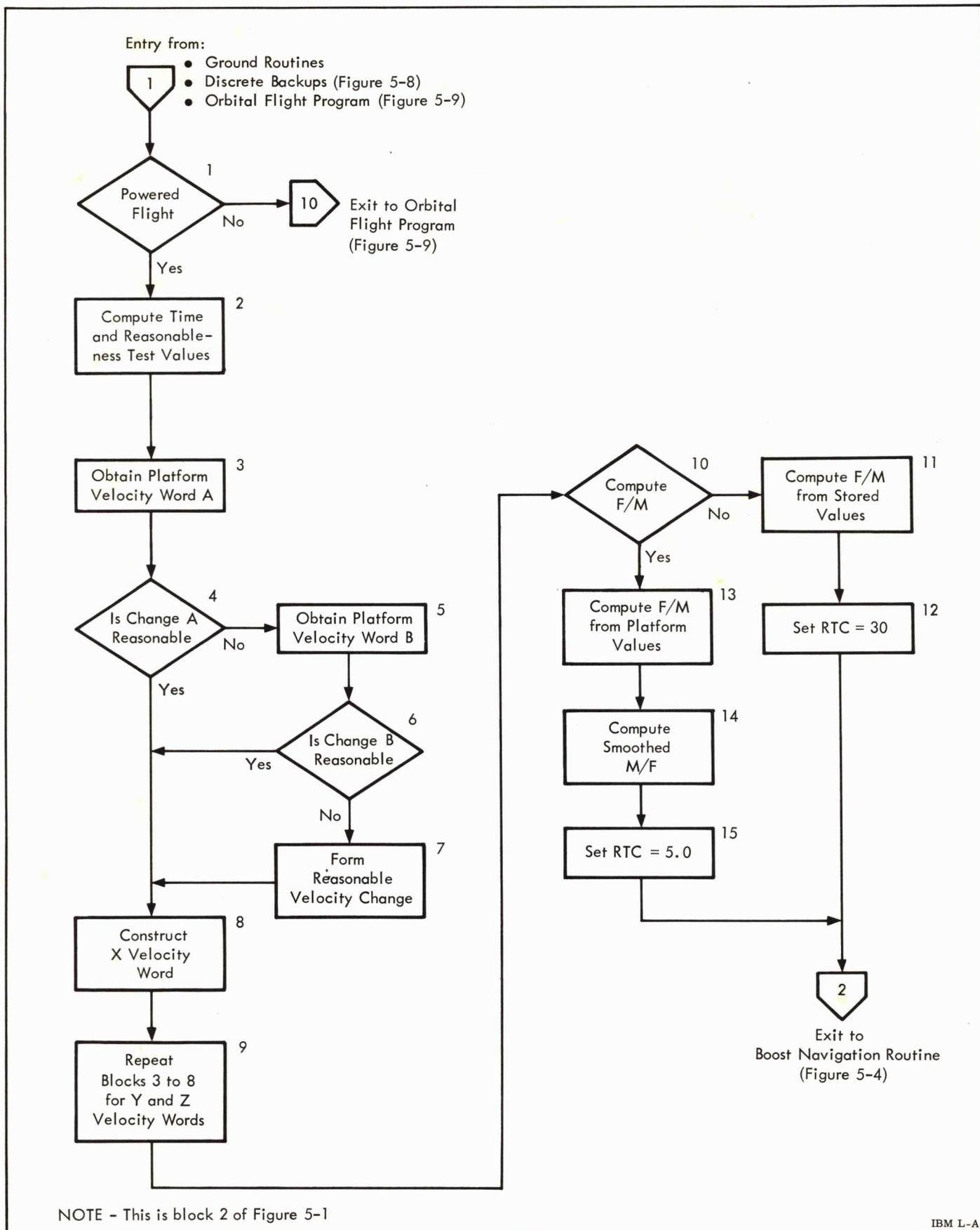


Figure 5-3. Accelerometer Processing

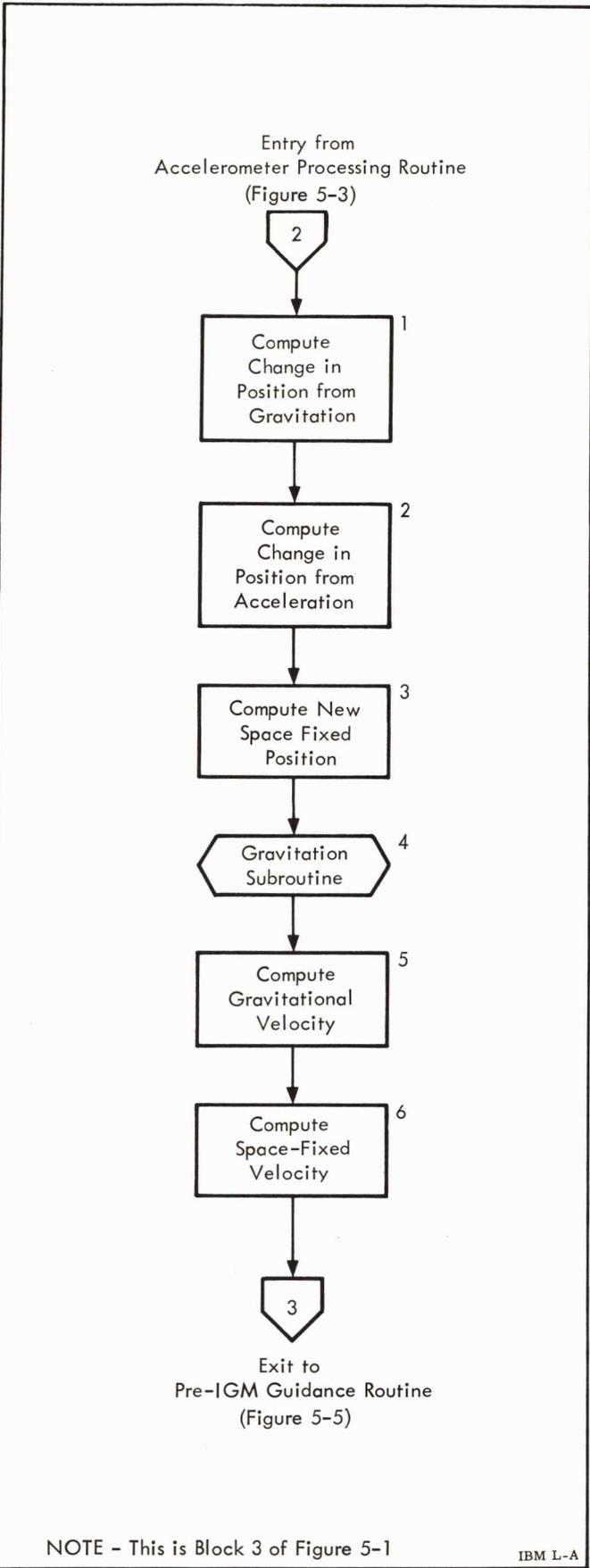


Figure 5-4. Boost Navigation

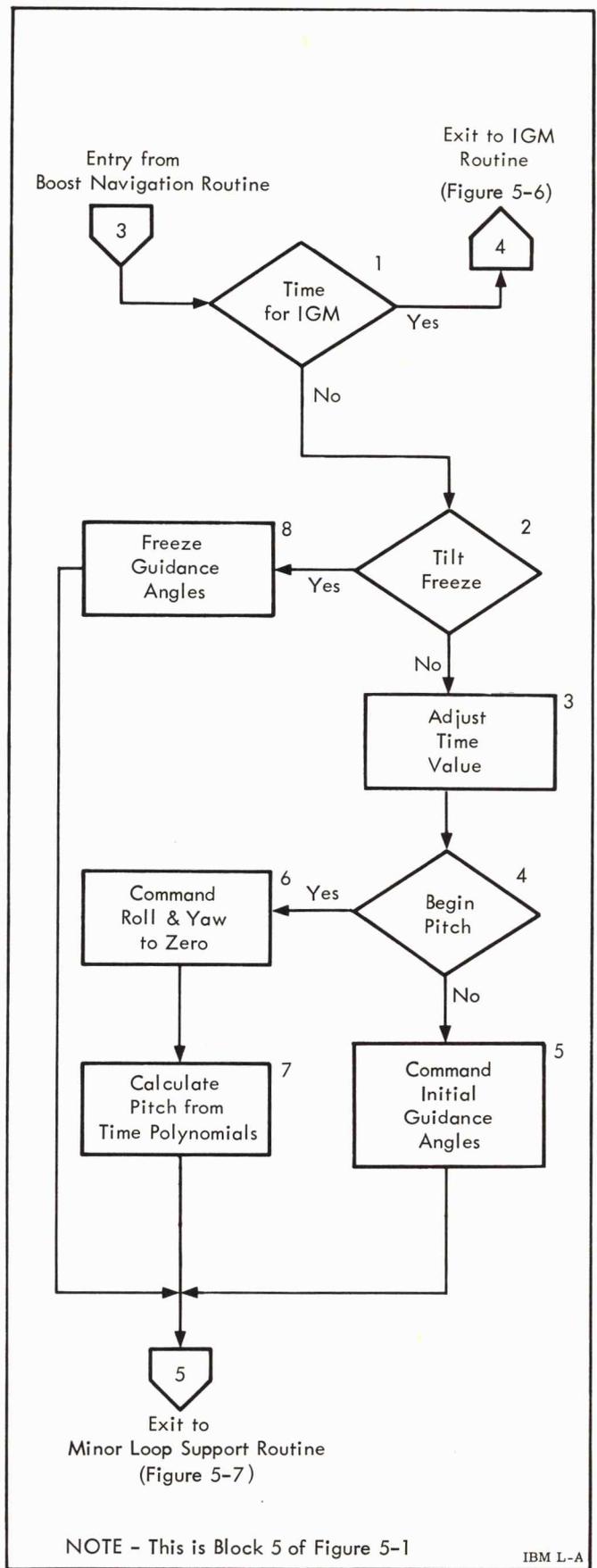
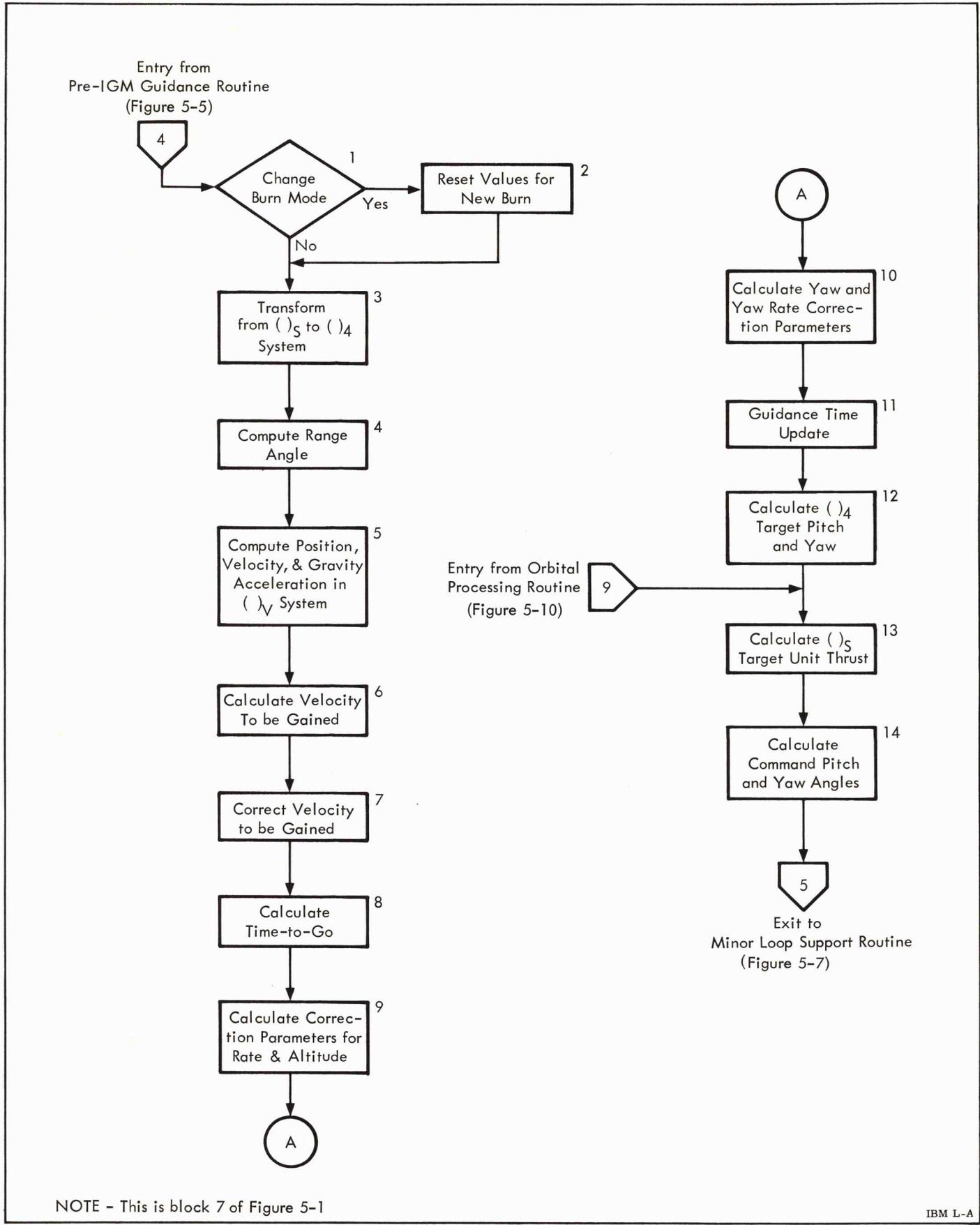


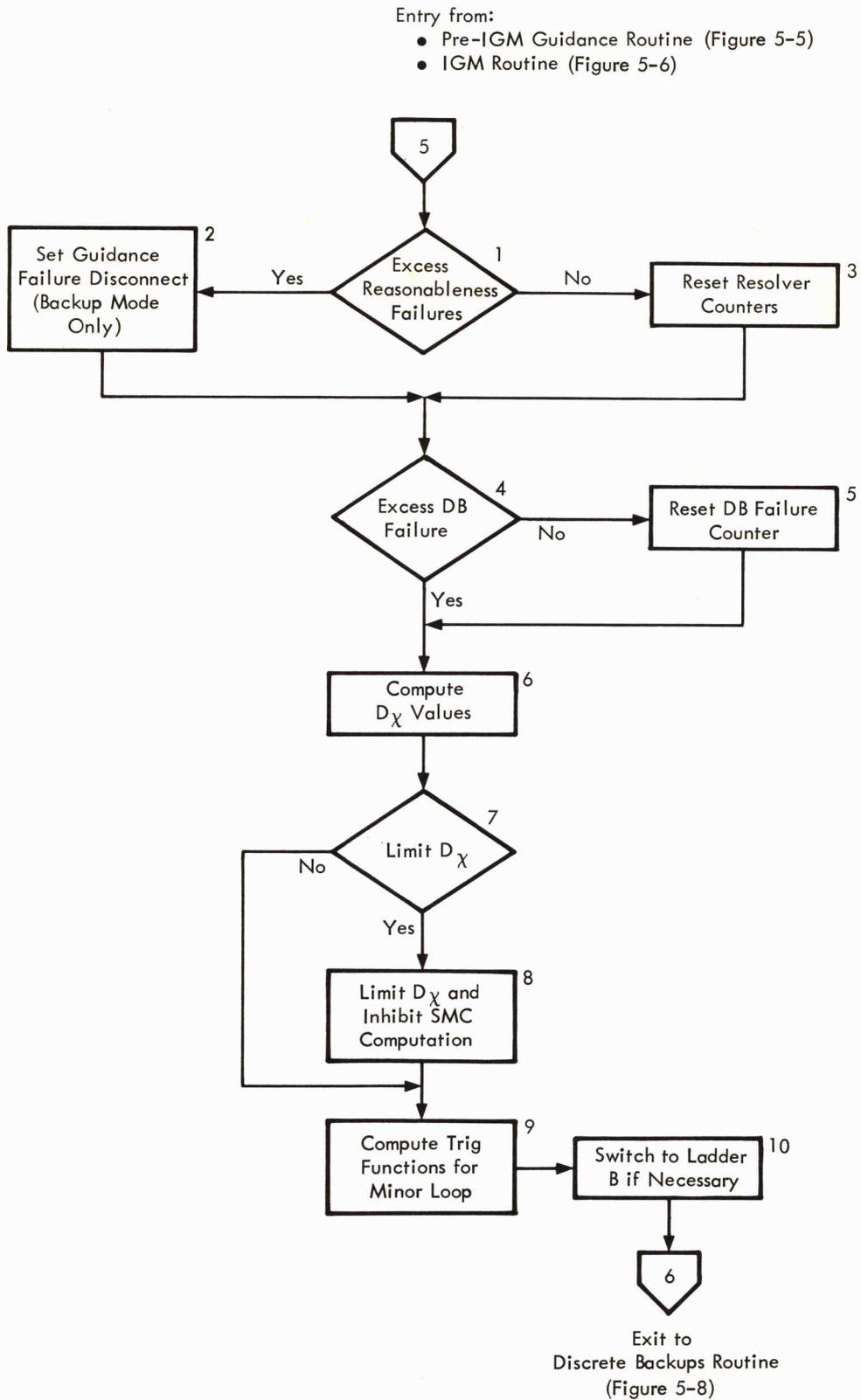
Figure 5-5. Pre-IGM Guidance



NOTE - This is block 7 of Figure 5-1

IBM L-A

Figure 5-6. IGM Flow Diagram

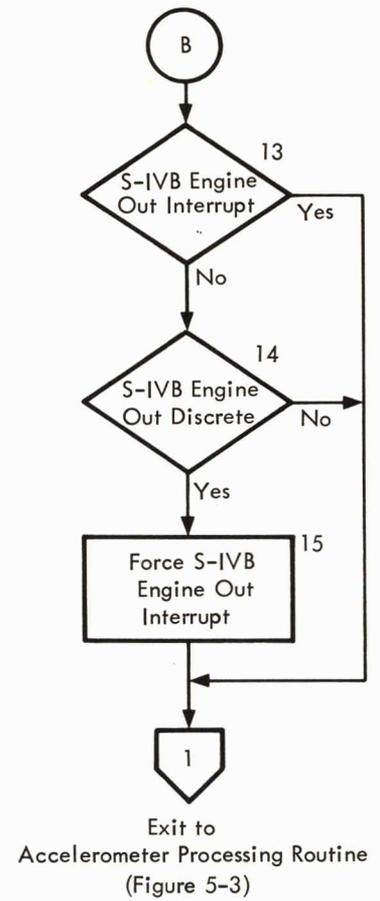
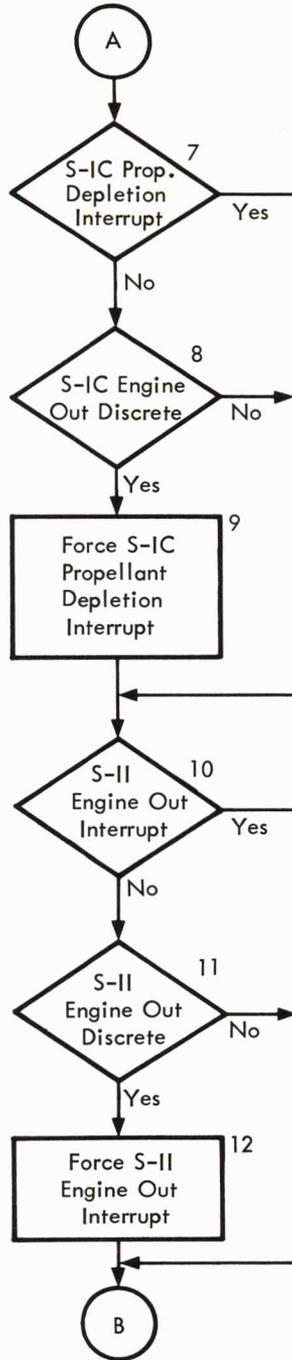
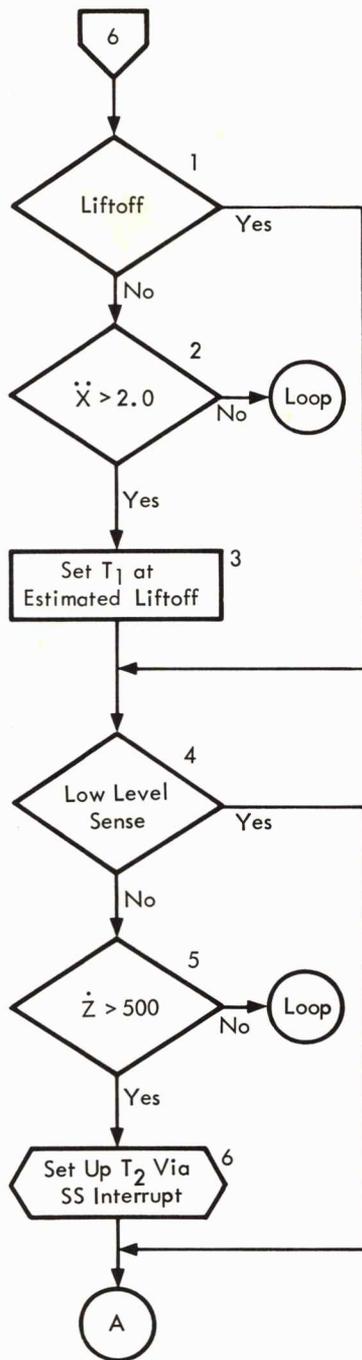


NOTE - This is block 8 of Figure 5-1

IBM L-A

Figure 5-7. Minor Loop Support

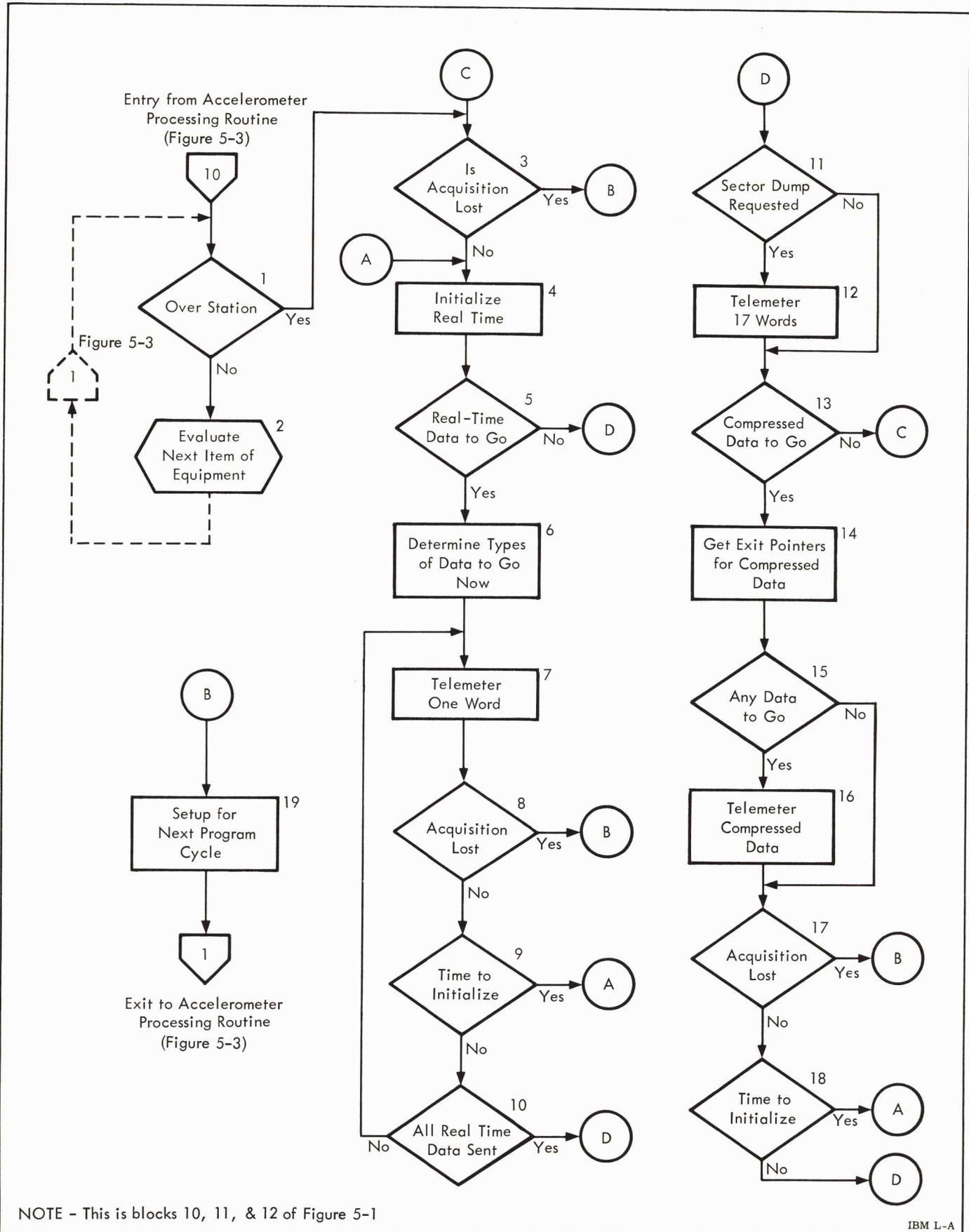
Entry from
Minor Loop Support Routine
(Figure 5-7)



NOTE - This is block 9 of Figure 5-1

IBM L-A

Figure 5-8. Discrete Backups



NOTE - This is blocks 10, 11, & 12 of Figure 5-1

IBM L-A

Figure 5-9. Orbital Flight Program

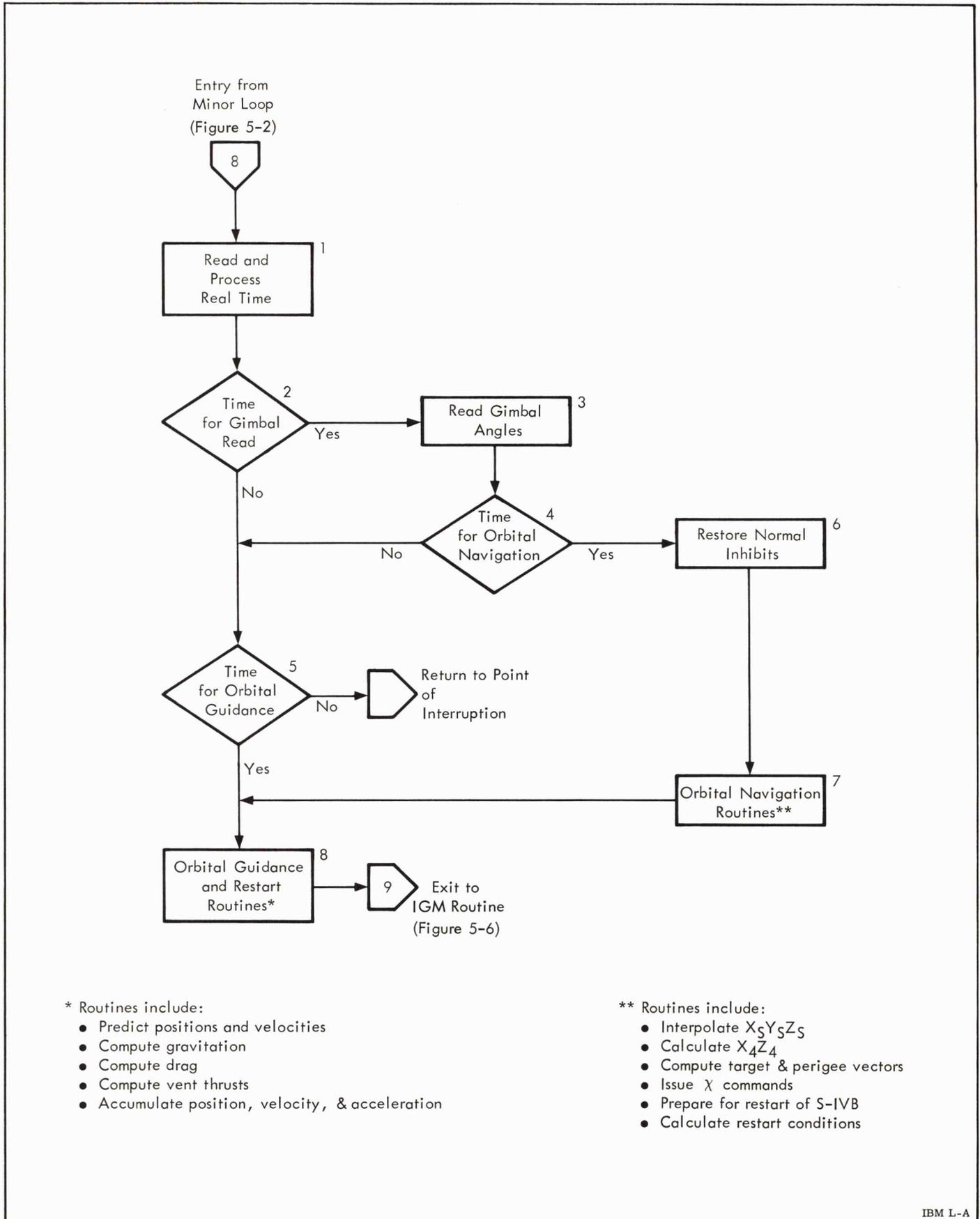


Figure 5-10. Orbital Processing

SECTION VI

MODE AND SEQUENCE

6-1 GENERAL DESCRIPTION

The LVDC memory contains a predetermined number of sets of instructions which, when initiated, induce the entire Astrionics System, or portions of the system, to operate in a particular mode. An example of a mode operation is the solving of guidance equations with interlaced attitude control and sequencing commands during the first-stage flight. Each mode consists of a predetermined sequence of events. The Guidance Computer also generates the appropriate control signals (e. g. , engine cutoff and ignition, stage separation). Such a predetermined sequence of events is initiated by commanding the Guidance Computer to operate in a particular mode.

Mode selection and initiation is accomplished through one of three actions: the successful completion of a previous mode, Guidance Computer switching to a new mode based on real time, or an event occurrence. In addition to these internal mode selections which the system makes, mode switching is also accomplished by commands from the ground checkout equipment (before launch), the IU command system, or the Apollo Spacecraft. A built-in safeguard feature gives the system the capability of refusing conflicting commands or commands that would be detrimental to vehicle safety.

Examples of modes of operation that occur during flight in the Astrionics System are:

- First, second, and third-stage guidance, control, and sequencing.
- Orbital operations –
 - Vehicle attitude stabilization commanded by the IU.
 - Spacecraft command of the vehicle attitude.
- Control of stage sequence functions from ground stations through the IU command system (emergency mode).

- Insertion of data into the LVDC through the IU command system.

The mode and sequence control scheme is very flexible since changes of modes and flight sequences are made by changing the instructions and programs in the LVDC memory, rather than by hardware modifications. The equipment involved in mode and sequence control of the launch vehicle is indicated in Figure 6-1. The LVDC issues flight sequence commands through the LVDA to the Switch Selector of the particular stage where the command must be executed. The Switch Selector of the addressed stage activates the appropriate circuit to perform the commanded function (e. g. , engine cutoff, power ON or OFF). The Switch Selector operation is discussed later in this section.

Mode commands from the spacecraft to the LVDA change the operational mode of the IU guidance and control system. When the Astronaut wants to control the attitude of the vehicle during coast flight or in orbit, he initiates the proper mode command to the LVDA. Control is returned to the IU attitude control system when the Astronaut issues another mode command. In a similar manner, the back-up guidance mode may be selected. In this mode, the navigation and guidance system of the spacecraft guides the vehicle during powered flight.

During coast flight, the IU command system may be used to command mode changes from the ground.

Before launch, the ground checkout equipment exercises all operational modes of the Astrionics System. This includes simulated launch and orbit programs.

Some events of the flight sequence are controlled by "discrete" signals generated by the LVDC according to a time program. Other events of the flight sequence are initiated when a particular event has occurred.

Paragraph 6-3 includes flight operation sequences for typical Uprated Saturn I and Saturn V missions. The sequences include all time bases – liftoff through coast phase.

N, G and C System
Section VI

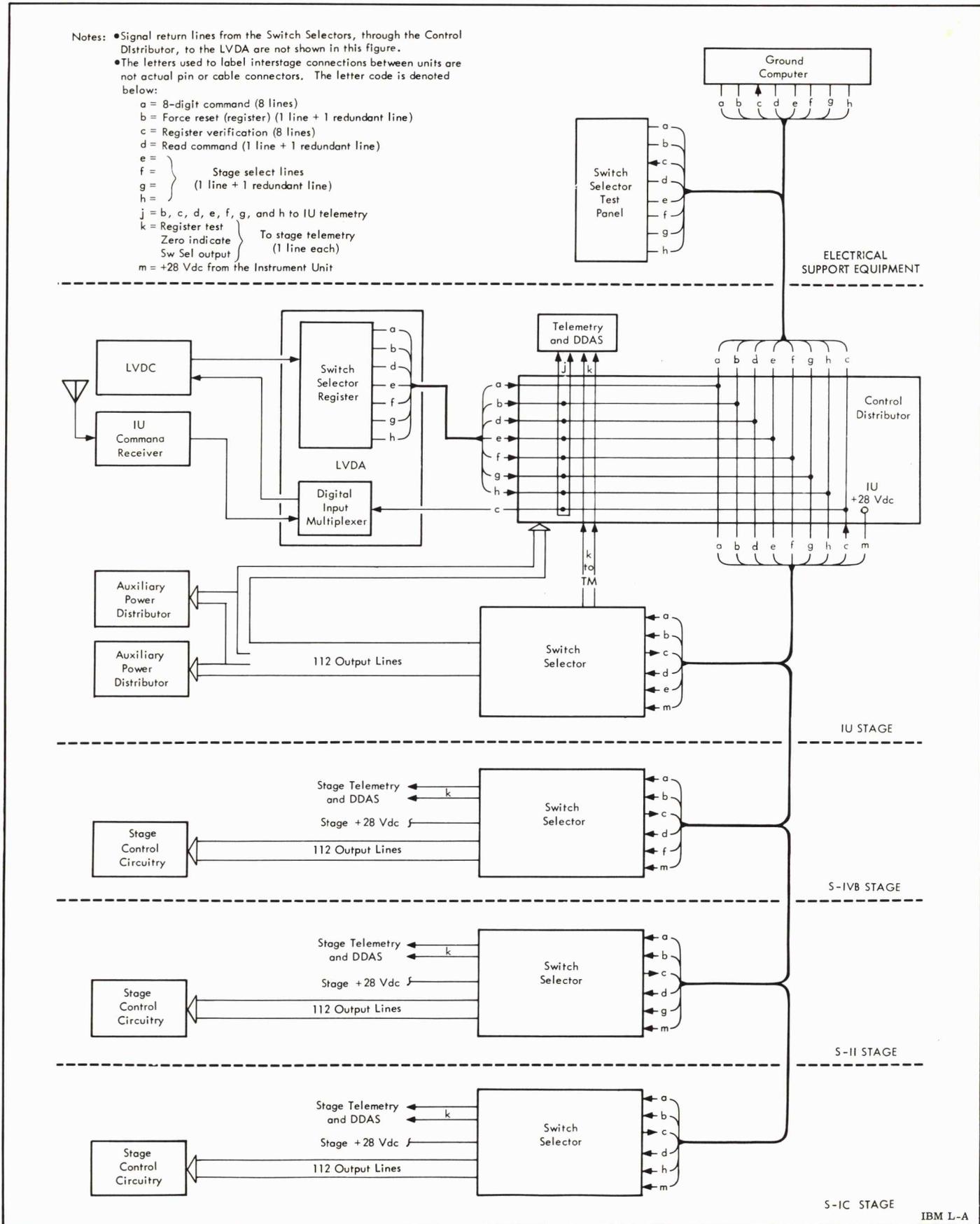


Figure 6-1. Saturn V Mode and Sequence Control Equipment

6-2 SWITCH SELECTORS

The Switch Selector is the connecting link between the LVDA/LVDC (which generates the flight sequence commands) and the circuitry in a vehicle stage where the command is to be executed. Each stage and the Instrument Unit of the Saturn Launch Vehicles contain a Switch Selector. A Switch Selector consists of relay circuits which decode the digital flight sequence command from the LVDA/LVDC and activate the proper stage circuits to execute the command.

Each Switch Selector can activate 112 different circuits in its stage, one at a time. The selection of a particular stage Switch Selector is accomplished through a command code. Coding of flight sequence commands and decoding in the stage Switch Selectors reduces the number of interface lines between stages and increases the flexibility of the system with respect to timing and sequence.

The Switch Selector word format is shown in Figure 6-2. Eight bits represent the flight sequence command; five bits are provided for selection of a particular stage Switch Selector; one bit, the read command, is used to activate the addressed Switch Selector for execution of the command; and the remaining bit is used to reset all Switch Selector relays.

Figure 6-1 illustrates the Saturn V Switch Selector configuration. As shown, all Switch Selector control lines are connected through the Control Distributor in the IU to the LVDA and the electrical support equipment. As shown in the figure, each Switch Selector is connected in parallel to the LVDA through 26 lines:

Stage select lines - 2*
Read command lines - 2*
Reset lines - 2*
IU + 28 Vdc lines - 2*
Signal return lines - 2*
Command lines - 8
Verification lines - 8
(* one line is redundant)

The Uprated Saturn I Switch Selector configuration is almost identical. The most significant difference is in the number of Switch Selectors used. The select lines normally used for the S-II Stage (g on the figure) are spare lines in the Uprated Saturn I. The S-IC Stage Switch Selector lines (h on the figure) are used for the S-IB Stage selection.

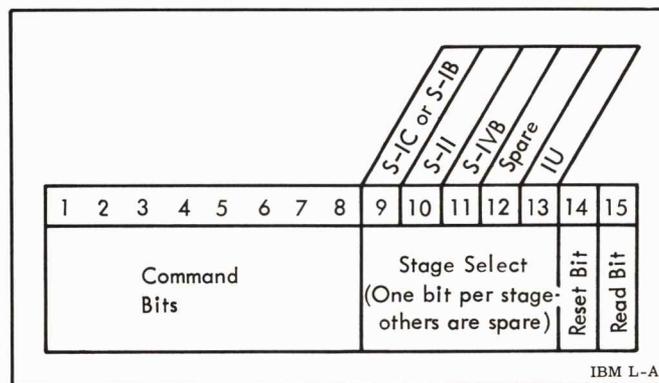


Figure 6-2. Switch Selector Word Format

There are two test methods of controlling the Switch Selectors: manually, from the ground equipment by way of the Switch Selector test panel, or automatically, through the ground control computer.

The flight sequence commands are stored in the LVDC memory and are issued according to the flight program. When a Process Input/Output (PIO) instruction is given, the LVDC sends the flight sequence command, consisting of 15 bits in serial form, to the switch selector register in the LVDA where they are stored. Flight sequence commands may be issued at time intervals of 100 milliseconds.

The output signals of the LVDA switch selector register, with the exception of the 8-bit command, are sampled at the Control Distributor in the IU and sent to the IU PCM telemetry system. Each Switch Selector also has 3 outputs to the telemetry system within its stage.

After setting up the Switch Selector input relays by the 8-bit command, the complement of the received code is sent back to the LVDA/LVDC. The feedback (verification information) is returned to the LVDA and is subsequently compared with the original code in the LVDC. If the feedback agrees with the original information, a read command is given. If the feedback does not agree with the code issued originally, a reset command is given (forced reset), and the LVDC/LVDA reissues the 8-bit command in complement form.

A typical operation cycle, to initiate a given function in a particular stage, is accomplished as follows:

- The 8 verify lines are sampled to ensure that all stage select relays have been

reset, thereby ensuring an unwanted stage is not selected. Zero voltage on all lines indicates that this condition exists. The presence of IU + 28 Vdc on the verify lines indicates that the verify lines are enabled because a stage Switch Selector is not reset. Having detected this situation, the LVDC commands a "force reset" and then rechecks the verify lines.

- The LVDC inserts the 8-bit flight command into the LVDA switch selector register. At the same time, a stage select command is sent to the appropriate Switch Selector. Application of the stage select command completes the signal return path for the input relays and allows the 8-bit command to be stored in the Switch Selector input relays.
- The verification lines are sampled to determine if the command transfer was correct.
- If the verification is correct, the LVDC sends a read command to the Switch Selector, activating it, and causing the proper output to occur.
- If the verification is not correct, the LVDC initiates a reset command to prepare the Switch Selector to receive the complement of the original command.
- After the forced reset is completed, the LVDC loads the stage select command, and the complement of the previously sent command, into the LVDA switch selector register.
- Neglecting the verification information that occurs after the complement command is inserted, the LVDC initiates a read command which produces an output from the selected switch selector channel. The read command also energizes the automatic reset circuitry which returns the Switch Selector to the reset condition to prepare it for a new cycle.

6-3 SATURN OPERATION SEQUENCES

6-4 UPRATED SATURN I SEQUENCE

Four time bases (T_1 , T_2 , T_3 , and T_4)* are used in the Uprated Saturn I flight sequence program in order to achieve an optimum vehicle mission with suitable sequential operation and timing of flight vehicle events. Table 6-1 gives the flight sequence for a typical Uprated Saturn I mission (AS-207).

Proper establishment and initiation of time bases ensures a safe and reliable vehicle on the pad and throughout the flight. Each time base will be established when the required criteria has been received by the LVDC.

Safeguards are used, where necessary, to prevent premature initiation of time bases. If a time base is not established, subsequent time bases cannot be started and the vehicle mission cannot be completed. Therefore, to further increase mission reliability in the absence of the normal time base signals, backup methods are used for establishing time bases.

Both the normal and backup methods for starting each time base are explained in the following paragraphs.

Time Base No. 1

Time base No. 1 (T_1) is initiated by a liftoff signal provided by the deactuation of the liftoff relay in the IU at umbilical disconnect. However, as a safety measure, the LVDC will not recognize the liftoff signal and start T_1 prior to receiving a guidance reference release signal which is initiated and verified 5 seconds prior to scheduled liftoff.

A backup method for starting T_1 is provided should the LVDC fail to receive or recognize the liftoff signal. If T_1 is not initiated within 5.5 seconds after guidance reference release, the LVDC will monitor the vertical accelerometer. If a significant positive acceleration (in excess of 1 g.) exists, the LVDC assumes liftoff has occurred and begins T_1 . A time adjustment is made by the Guidance Computer.

No "negative backup" (i. e., provisions for the LVDC to return to prelaunch conditions) is provided because, in the event T_1 began by error, the Uprated Saturn I Vehicle could safely complete T_1 on the pad without catastrophic results.

* Preflight programming for Uprated Saturn I also recognizes a 5th time base as T_0 which is initiated 5 to 8 seconds prior to liftoff at GRR.

Time Base No. 2

Time base No. 2 (T_2) is initiated by the actuation of the S-IB propellant level sensors. The propellant level sensors are armed 2 seconds prior to calculated actuation time.

A backup method of starting T_2 is available if a failure should occur which would prevent the LVDC from receiving or recognizing this actuation signal. The LVDC will monitor the downrange accelerometer after arming the S-IB propellant level sensors. If T_2 is not started within 1.75 seconds after calculated actuation of the level sensors and significant downrange velocity reading appears, the LVDC will start T_2 .

Use of the accelerometer readings as a backup provides a safeguard against starting T_2 inadvertently. If significant positive readings do not appear, the time backup for T_2 will not be issued. Furthermore, if T_2 is not established, no subsequent time bases can be started. This insures a safe vehicle, even if T_1 is started without liftoff, and requires at least one additional failure to render the vehicle unsafe on the pad.

Time Base No. 3

Time base No. 3 (T_3) is initiated by the S-IB outboard engines cutoff signal from the S-IB Stage at propellant depletion. As a safeguard against trying to separate the S-IB Stage with the thrust of the outboard engines present, a redundant S-IB outboard engines cutoff command is issued at the start of T_3 ($T_3 + 0.0$).

A backup for starting T_3 is available if a failure should prevent the LVDC from receiving or recognizing the S-IB outboard engines cutoff signal. If T_3 is not initiated within 4 seconds after calculated S-IB outboard engines cutoff, the LVDC will issue an S-IB outboard engines cutoff command and start T_3 .

Time Base No. 4

Time base No. 4 (T_4) is initiated by the de-actuation of the S-IVB thrust OK pressure switches at S-IVB cutoff. Redundant signals from the pressure switches are monitored by the LVDC. The LVDC will start T_4 upon receiving either of these signals. As a safeguard against starting T_4 with the thrust of the S-IVB engine present, a redundant S-IVB engine cutoff command is issued at the start of T_4 .

6-5 SATURN V SEQUENCE

Seven time bases (T_1 through T_7)* are used in the Saturn V flight sequence program to achieve an optimum vehicle mission with suitable operation and timing of flight vehicle events. As in Uprated Saturn I Vehicles, safeguards are used where necessary to prevent premature initiation of time bases. Table 6-2 gives the flight sequence for a typical Saturn V mission (AS-503).

Both normal and backup methods for starting each time base are explained in the following paragraphs.

Time Base No. 1

Time base No. 1 (T_1) is initiated by a liftoff signal provided by deactuation of the liftoff relay in the IU at the umbilical disconnect. However, as a safety measure, the LVDC will not recognize the liftoff signal and start T_1 prior to receiving a guidance reference release signal which is initiated and verified 10 seconds prior to scheduled liftoff.

A backup method for starting T_1 is provided should the LVDC fail to receive or recognize the liftoff signal. If T_1 is not initiated within 5.5 seconds after guidance reference release, the LVDC will monitor the vertical accelerometer. If a significant positive acceleration (in excess of 1 g) exists, the LVDC assumes liftoff has occurred and begins T_1 . A time adjustment is made by the computer.

No "negative backup" (i. e., provisions for the LVDC to return to prelaunch conditions) is provided because, in the event T_1 began by error, the Saturn V Vehicle could safely complete T_1 on the pad without catastrophic results.

Time Base No. 2

The S-IC inboard engine will be cutoff by the LVDC through the S-IC Switch Selector at a pre-determined time. At this time, the LVDC will monitor the downrange accelerometer. If sufficient downrange velocity exists, the LVDC will start Time Base No. 2.

Use of the downrange velocity reading provides a safeguard against starting T_2 on the pad should T_1

* Preflight programming for Saturn V also recognizes an 8th time base as T_0 which is initiated 10 seconds prior to liftoff at GRR.

be started without liftoff. Furthermore if T_2 is not established, no subsequent time bases can be started. This insures a safe vehicle requiring at least one additional failure to render the vehicle unsafe on the pad.

Time Base No. 3

Time base No. 3 (T_3) is initiated at S-IC outboard engine cutoff by either of two redundant outboard engines cutoff signals. However, the LVDC must arm outboard engines propellant depletion cutoff prior to starting T_3 . Outboard engines propellant depletion cutoff is armed 1 second prior to calculated outboard engines cutoff.

Time Base No. 4

After arming S-II engines depletion cutoff, the LVDC will initiate Time Base No. 4 (T_4) upon receiving either of two signals; S-II engines depletion cutoff or S-II engines out. The S-II engines depletion cutoff signal is the primary signal for starting T_4 . The S-II engines out signal from the thrust OK circuitry is a backup.

As a safeguard against trying to separate the S-II Stage with the thrust of the engines present, a redundant S-II engines cutoff command is issued by the LVDC at the start of T_4 .

Time Base No. 5

Time base No. 5 (T_5) is initiated by the de-actuation of the S-IVB thrust OK pressure switches at S-IVB cutoff. Redundant signals from the pressure switches are monitored by the LVDC. After sufficient time has elapsed on Time Base No. 4 (to allow "S-IVB thrust OK"), the LVDC will start T_5 upon receiving either of these signals. As a safeguard against starting T_5 with the thrust of the S-IVB engine present, a redundant S-IVB engine cutoff command is issued at the start of T_5 .

Time Base No. 6

Time base No. 6 (T_6) will be initiated by the LVDC (LVDC solves an equation) or by ground command.

Time Base No. 7

Time base No. 7 (T_7) is initiated by the de-actuation of the S-IVB thrust OK pressure switches at S-IVB cutoff. Redundant signals from the pressure switches are monitored by the LVDC. After sufficient time has elapsed on Time Base No. 6, to allow "S-IVB thrust OK", the LVDC will start T_7 upon receiving either of these signals. As a safeguard against starting T_7 with the thrust of the S-IVB engine present, a redundant S-IVB engine cutoff command is issued at the start of T_7 .

Table 6-1. Uprated Saturn I Flight Sequence

The following information includes the time and flight sequence for the AS-207 vehicle (as of the publication date of this manual). The information may be construed as typical for Uprated Saturn I Vehicles and will be changed whenever practicable.

Nominal Flight Time (Min & Secs)	Command	Switch Selector Stage	Time From Base (Seconds)
00:00.0	Liftoff – START OF TIME BASE NO. 1 (T ₁)		T ₁ + 0.0
00:10.0	Multiple Engine Cutoff Enable	S-IB	T ₁ + 10.0
00:25.2	Telemeter Calibration ON	S-IB	T ₁ + 25.2
00:27.0	Telemetry Calibrator In-Flight Calibrate ON	IU	T ₁ + 27.0
00:30.0	LOX Tank Relief Control Valve Enable	S-IB	T ₁ + 30.0
00:30.2	Telemeter Calibration OFF	S-IB	T ₁ + 30.2
00:32.0	Telemetry Calibration In-Flight Calibrate OFF	IU	T ₁ + 32.0
00:40.0	Launch Vehicle Engines EDS Cutoff Enable	IU	T ₁ + 40.0
01:30.2	Telemetry Calibrator In-Flight Calibrate ON	IU	T ₁ + 90.2
01:35.0	Flight Control Computer Switch Point No. 1	IU	T ₁ + 95.0
01:35.2	Telemetry Calibrator In-Flight Calibrate OFF	IU	T ₁ + 95.2
01:45.0	Flight Control Computer Switch Point No. 2	IU	T ₁ + 105.0
01:59.8	Telemeter Calibration ON	S-IB	T ₁ + 119.8
02:00.0	Flight Control Computer Switch Point No. 3	IU	T ₁ + 120.0
02:00.2	IU Control Accelerometer Power OFF	IU	T ₁ + 120.2
02:04.8	Telemeter Calibration OFF	S-IB	T ₁ + 124.8
02:05.3	Regular TM Calibration ON	S-IVB	T ₁ + 125.3
02:09.9	Regular TM Calibration OFF	S-IVB	T ₁ + 129.9
02:12.9	Excess Rate (P, Y, R) Auto-Abort Inhibit Enable	IU	T ₁ + 132.9
02:13.1	Excess Rate (P, Y, R) Auto-Abort Inhibit	IU	T ₁ + 133.1
02:13.3	S-IB Two Engines Out Auto-Abort Inhibit Enable	IU	T ₁ + 133.3
02:13.5	S-IB Two Engines Out Auto-Abort Inhibit	IU	T ₁ + 133.5
02:13.7	Propellant Level Sensors Enable	S-IB	T ₁ + 133.7
02:15.7	S-IB Propellant Level Sensor Actuation – START OF TIME BASE NO. 2 (T ₂)		T ₂ + 0.0
02:18.7	Inboard Engines Cutoff	S-IB	T ₂ + 3.0
02:18.9	Auto-Abort Enable Relays Reset	IU	T ₂ + 3.2
02:19.1	Charge Ullage Ignition EBW Firing Units	S-IVB	T ₂ + 3.4
02:19.7	Q-Ball Power OFF	IU	T ₂ + 4.0
02:20.0	Prevalves Open	S-IVB	T ₂ + 4.3

Table 6-1. Uprated Saturn I Flight Sequence (Cont)

Nominal Flight Time (Min & Secs)	Command	Switch Selector Stage	Time From Base (Seconds)
02:20.2	LOX Depletion Cutoff Enable	S-IB	$T_2 + 4.5$
02:21.2	Fuel Depletion Cutoff Enable	S-IB	$T_2 + 5.5$
02:21.7	S-IB Outboard Engines Cutoff - START OF TIME BASE NO. 3 (T_3)	S-IB	$T_3 + 0.0$
02:22.3	Ullage Rockets Ignition	S-IVB	$T_3 + 0.6$
02:22.5	S-IB/S-IVB Separation	S-IB	$T_3 + 0.8$
02:22.7	Flight Control Computer S-IVB Burn Mode ON	IU	$T_3 + 1.0$
02:22.9	Engine Cutoff Signal OFF	S-IVB	$T_3 + 1.2$
02:23.1	Engine Ready Bypass ON	S-IVB	$T_3 + 1.4$
02:23.3	LH ₂ Chilldown Pump OFF	S-IVB	$T_3 + 1.6$
02:23.5	LOX Chilldown Pump OFF	S-IVB	$T_3 + 1.8$
02:23.7	Chilldown Shutoff Valves Close	S-IVB	$T_3 + 2.0$
02:23.9	Engine Ignition Sequence Start	S-IVB	$T_3 + 2.2$
02:24.1	S-IVB Engine Out Indication "A" Enable	IU	$T_3 + 2.4$
02:24.3	S-IVB Engine Out Indication "B" Enable	IU	$T_3 + 2.6$
02:24.5	Engine Ignition Sequence Start Relay Reset	S-IVB	$T_3 + 2.8$
02:24.7	LOX Tank Flight Pressurization Switch Enable	S-IVB	$T_3 + 3.0$
02:24.9	Fuel Injection Temperature OK Bypass	S-IVB	$T_3 + 3.2$
02:26.7	LH ₂ Tank Pressurization Control Switch Enable	S-IVB	$T_3 + 5.0$
02:29.9	PU System Activate	S-IVB	$T_3 + 8.2$
02:31.4	Charge Ullage Jettison EBW Firing Units	S-IVB	$T_3 + 9.7$
02:34.5	Ullage Rockets Jettison	S-IVB	$T_3 + 12.8$
02:40.5	Ullage EBW Firing Units Charge Relays Reset	S-IVB	$T_3 + 18.8$
02:40.7	Ullage Rockets Ignition and Jettison Relays Reset	S-IVB	$T_3 + 19.0$
02:47.1	Telemetry Calibrator In-Flight Calibrate ON	IU	$T_3 + 25.4$
02:52.1	Telemetry Calibrator In-Flight Calibrate OFF	IU	$T_3 + 30.4$
03:00.0	Water Coolant Valve Open	IU	$T_3 + 38.3$
03:03.7	Flight Control Computer Switch Point No. 4	IU	$T_3 + 42.0$
05:44.7	Flight Control Computer Switch Point No. 5	IU	$T_3 + 203.0$
05:47.1	Telemetry Calibrator In-Flight Calibrate ON	IU	$T_3 + 205.4$
05:51.0	Regular TM Calibration ON	S-IVB	$T_3 + 209.3$
05:52.1	Telemetry Calibrator In-Flight Calibrate OFF	IU	$T_3 + 210.4$
05:55.5	Regular TM Calibration OFF	S-IVB	$T_3 + 213.8$
07:24.1	LH ₂ Tank Pressurization Control Switch Disable	S-IVB	$T_3 + 302.4$

Table 6-1. Uprated Saturn I Flight Sequence (Cont)

Nominal Flight Time (Min & Secs)	Command	Switch Selector Stage	Time From Base (Seconds)
08:17.1	Telemetry Calibrator In-Flight Calibrate ON	IU	$T_3 + 355.4$
08:22.1	Telemetry Calibrator In-Flight Calibrate OFF	IU	$T_3 + 360.4$
09:46.9	Propellant Depletion Cutoff Arm	S-IVB	$T_3 + 445.2$
09:58.9	S-IVB Engine Cutoff – START OF TIME BASE NO. 4 (T_4)	S-IVB	$T_4 + 0.0$
09:59.1	LH ₂ Tank Vent Valve Open	S-IVB	$T_4 + 0.2$
09:59.3	LOX Tank Vent Valve Open	S-IVB	$T_4 + 0.4$
09:59.5	Prevalves Close	S-IVB	$T_4 + 0.6$
09:59.7	LOX Tank Flight Pressurization Switch Disable	S-IVB	$T_4 + 0.8$
09:59.9	LOX Tank Pressurization Shutoff Valves Close	S-IVB	$T_4 + 1.0$
10:00.5	LOX Chilldown Pump Purge OFF	S-IVB	$T_4 + 1.6$
10:00.7	Propellant Depletion Cutoff Disarm	S-IVB	$T_4 + 1.8$
10:01.1	PU System Deactivate	S-IVB	$T_4 + 2.2$
10:01.5	PU Inverter and DC Power OFF	S-IVB	$T_4 + 2.6$
10:03.9	Flight Control Computer S-IVB Burn Mode OFF	IU	$T_4 + 5.0$
10:04.1	Aux Hydraulic Pump Flight Mode OFF	S-IVB	$T_4 + 5.2$
10:13.9	Azusa Transponder Power OFF	IU	$T_4 + 15.0$
TBD	Regular TM Calibration ON	S-IVB	TBD
TBD	Telemetry Calibrator In-Flight Calibrate ON	IU	TBD
TBD	Regular TM Calibration OFF	S-IVB	TBD
TBD	Telemetry Calibrator In-Flight Calibrate OFF	IU	TBD
10:31.5	LOX Tank Vent Valve Close	S-IVB	$T_4 + 32.6$
10:34.5	LOX Tank Vent Valve Boost Close ON	S-IVB	$T_4 + 35.6$
10:36.5	LOX Tank Vent Valve Boost Close OFF	S-IVB	$T_4 + 37.6$
10:58.9	Chilldown Shutoff Valves Open	S-IVB	$T_4 + 60.0$
10:59.1	Prevalves Open	S-IVB	$T_4 + 60.2$
TBD	LH ₂ Tank Vent Valve Close	S-IVB	TBD
TBD	LH ₂ Tank Vent Valve Boost Close ON	S-IVB	TBD
TBD	LH ₂ Tank Vent Valve Boost Close OFF	S-IVB	TBD
TBD	LH ₂ Tank Vent Valve Open	S-IVB	TBD
TBD	LH ₂ Tank Vent Valve Close	S-IVB	TBD
TBD	LH ₂ Tank Vent Valve Boost Close ON	S-IVB	TBD
TBD	LH ₂ Tank Vent Valve Boost Close OFF	S-IVB	TBD

Table 6-2. Saturn V Flight Sequence

The following information includes the time and flight sequence for the AS-503 vehicle (as of the publication date of this manual). The information may be construed as typical for Saturn V vehicles and will be updated whenever practicable.

Nominal Flight Time (Min & Secs)	Command	Switch Selector Stage	Time From Base (Seconds)
00:00.0	Liftoff – START OF TIME BASE NO. 1 (T ₁)		T ₁ + 0.0
00:14.0	Multiple Engine Cutoff Enable	S-IC	T ₁ + 14.0
00:25.0	Telemeter Calibrate ON	S-IC	T ₁ + 25.0
00:27.0	Telemetry Calibrator In-Flight Calibrate ON	IU	T ₁ + 27.0
00:30.0	Telemeter Calibrate OFF	S-IC	T ₁ + 30.0
00:32.0	Telemetry Calibrator In-Flight Calibrate OFF	IU	T ₁ + 32.0
00:40.0	Launch Vehicle Engines EDS Cutoff Enable	IU	T ₁ + 40.0
00:49.5	Fuel Pressurizing Valve No. 2 Open & Tape Recorder Record	S-IC	T ₁ + 49.5
01:30.0	Telemetry Calibrator In-Flight Calibrate ON	IU	T ₁ + 90.0
01:35.0	Telemetry Calibrator In-Flight Calibrate OFF	IU	T ₁ + 95.0
01:35.3	Fuel Pressurizing Valve No. 3 Open	S-IC	T ₁ + 95.3
01:40.0	Flight Control Computer Switch Point No. 1	IU	T ₁ + 100.0
01:55.0	Telemeter Calibrate ON	S-IC	T ₁ + 115.0
01:59.2	Regular Calibrate Relays ON	S-IVB	T ₁ + 119.2
02:00.2	Telemeter Calibrate OFF	S-IC	T ₁ + 120.2
02:04.2	Regular Calibrate Relays OFF	S-IVB	T ₁ + 124.2
02:15.1	Fast Record ON	S-IVB	T ₁ + 135.1
02:15.3	Start Recorders	S-II	T ₁ + 135.3
02:15.5	Fuel Pressurizing Valve No. 4 Open	S-IC	T ₁ + 135.5
02:15.7	Tape Recorder Record ON	IU	T ₁ + 135.7
02:15.9	LOX Tank Strobe Lights OFF	S-IC	T ₁ + 135.9
02:16.1	S-IC Two Engines Out Auto-Abort Inhibit Enable	IU	T ₁ + 136.1
02:16.3	S-IC Two Engines Out Auto-Abort Inhibit	IU	T ₁ + 136.3
02:16.5	Excess Rate (P, Y, R) Auto-Abort Inhibit Enable	IU	T ₁ + 136.5
02:16.7	Excess Rate (P, Y, R) Auto-Abort Inhibit	IU	T ₁ + 136.7
02:16.9	Two Adjacent Outboard Engines Out Cutoff Enable	S-IC	T ₁ + 136.9
02:17.1	Inboard Engines Cutoff – START OF TIME BASE NO. 2 (T ₂)	S-IC	T ₂ + 0.0
02:17.3	Auto-Abort Enable Relays Reset	IU	T ₂ + 0.2
02:17.5	Start First PAM-FM/FM Calibration	S-II	T ₂ + 0.4
02:22.3	Separation Camera ON	S-IC	T ₂ + 5.2

Table 6-2. Saturn V Flight Sequence (Cont)

Nominal Flight Time (Min & Secs)	Command	Switch Selector Stage	Time From Base (Seconds)
02:22.5	Stop First PAM-FM/FM Calibration	S-II	$T_2 + 5.4$
02:22.8	S-II Ordnance Arm	S-II	$T_2 + 5.7$
02:23.0	Separation and Retro EBW Firing Units Arm	S-IC	$T_2 + 5.9$
02:23.5	Q-Ball Power OFF	IU	$T_2 + 6.4$
02:23.9	Telemetry Measurement Switch Over	S-IC	$T_2 + 6.8$
02:24.1	Outboard Engines Cutoff Enable	S-IC	$T_2 + 7.0$
02:29.1	Outboard Engines Cutoff - START OF TIME BASE NO. 3 (T_3)		$T_3 + 0.0$
02:29.3	S-II Recirculation OFF	S-II	$T_3 + 0.2$
02:29.5	S-II Ullage Trigger	S-II	$T_3 + 0.4$
02:29.7	S-IC/S-II Separation	S-IC	$T_3 + 0.6$
02:29.8	S-II Engines Cutoff Reset	S-II	$T_3 + 0.7$
02:29.9	Engines Ready Bypass	S-II	$T_3 + 0.8$
02:30.0	Prevalves Lockout Reset	S-II	$T_3 + 0.9$
02:30.2	Switch Engine Control From S-IC to S-II	IU	$T_3 + 1.1$
02:30.4	S-II Engine Start	S-II	$T_3 + 1.3$
02:30.6	S-II Engine Out Indication "A" Enable; S-II Second Separation Indication "A" Enable	IU	$T_3 + 1.5$
02:30.8	S-II Engine Out Indication "B" Enable; S-II Second Separation Indication "B" Enable	IU	$T_3 + 1.7$
02:31.0	Engines Ready Bypass Reset	S-II	$T_3 + 1.9$
02:32.0	S-II Hydraulic Accumulators Unlock	S-II	$T_3 + 2.9$
02:35.7	S-II Start Phase Limiter Cutoff Arm	S-II	$T_3 + 6.6$
02:35.9	Activate PU System	S-II	$T_3 + 6.8$
02:36.7	S-II Start Phase Limiter Cutoff Arm Reset	S-II	$T_3 + 7.6$
02:40.2	Tape Recorder Record OFF	IU	$T_3 + 11.1$
02:40.4	Stop Recorders	S-II	$T_3 + 11.3$
02:40.6	Fast Record OFF	S-IVB	$T_3 + 11.5$
02:59.6	S-II Second Plane Separation	S-II	$T_3 + 30.5$
03:00.0	Water Coolant Valve Open	IU	$T_3 + 30.9$
03:30.4	Flight Control Computer Switch Point No. 3	IU	$T_3 + 61.3$
05:31.8	Start Second PAM-FM/FM Calibration	S-II	$T_3 + 182.7$
05:36.8	Stop Second PAM-FM/FM Calibration	S-II	$T_3 + 187.7$
05:40.4	Flight Control Computer Switch Point No. 4	IU	$T_3 + 191.3$

Table 6-2. Saturn V Flight Sequence (Cont)

Nominal Flight Time (Min & Secs)	Command	Switch Selector Stage	Time From Base (Seconds)
05:51.8	Telemetry Calibrator In-Flight Calibrate ON	IU	$T_3 + 202.7$
05:56.8	Telemetry Calibrator In-Flight Calibrate OFF	IU	$T_3 + 207.7$
06:01.8	Measurement Control Switch No. 2 Activate	S-II	$T_3 + 212.7$
06:40.0	S-II, LH ₂ Step Pressurization	S-II	$T_3 + 250.9$
07:02.5	Start Third PAM-FM/FM Calibration	S-II	$T_3 + 273.4$
07:07.5	Stop Third PAM-FM/FM Calibration	S-II	$T_3 + 278.4$
07:22.8	Regular Calibrate Relays ON	S-IVB	$T_3 + 293.7$
07:23.0	Telemetry Calibrator In-Flight Calibrate ON	IU	$T_3 + 293.9$
07:27.8	Regular Calibrate Relays OFF	S-IVB	$T_3 + 298.7$
07:28.0	Telemetry Calibrator In-Flight Calibrate OFF	IU	$T_3 + 298.9$
07:28.6	Rate Gyros OFF	S-IVB	$T_3 + 299.5$
07:28.8	Charge Ullage Ignition ON	S-IVB	$T_3 + 299.7$
07:29.0	S-II/S-IVB Ordnance Arm	S-II	$T_3 + 299.9$
07:29.2	Tape Recorder Record ON	IU	$T_3 + 300.1$
07:29.4	Fast Record ON	S-IVB	$T_3 + 300.3$
07:30.0	S-IVB Engine Cutoff OFF	S-IVB	$T_3 + 300.9$
07:30.2	Engine Ready Bypass	S-IVB	$T_3 + 301.1$
07:30.4	S-II LOX Depletion Sensors Cutoff Arm	S-II	$T_3 + 301.3$
07:30.6	S-II LH ₂ Depletion Sensors Cutoff Arm	S-II	$T_3 + 301.5$
TBD	Start Recorders	S-II	TBD
TBD	Start Recorder Timers	S-II	TBD
08:42.8	Cutoff S-II J2 Engines – START OF TIME BASE NO. 4 (T_4)	S-II	$T_4 + 0.0$
08:42.9	Prevalves Close OFF	S-IVB	$T_4 + 0.1$
08:43.0	Fire Ullage Ignition ON	S-IVB	$T_4 + 0.2$
08:43.1	S-II/S-IVB Separation	S-II	$T_4 + 0.3$
08:43.3	S-IVB Engine Start ON	S-IVB	$T_4 + 0.5$
08:43.5	Flight Control Computer S-IVB Burn Mode ON	IU	$T_4 + 0.7$
08:43.7	LOX Chilldown Pump OFF	S-IVB	$T_4 + 0.9$
08:44.5	Chilldown Shutoff Pilot Valve Close ON	S-IVB	$T_4 + 1.7$
08:44.7	Fuel Chilldown Pump OFF	S-IVB	$T_4 + 1.9$
08:45.3	S-IVB Engine Out Indication "A" Enable	IU	$T_4 + 2.5$
08:45.5	S-IVB Engine Out Indication "B" Enable	IU	$T_4 + 2.7$
08:46.1	LOX Tank Flight Pressure System ON	S-IVB	$T_4 + 3.3$

Table 6-2. Saturn V Flight Sequence (Cont)

Nominal Flight Time (Min & Secs)	Command	Switch Selector Stage	Time From Base (Seconds)
08:46.3	Fuel Injection Temperature OK Bypass	S-IVB	T ₄ + 3.5
08:46.5	Engine Start OFF	S-IVB	T ₄ + 3.7
08:48.1	First Burn Relay ON	S-IVB	T ₄ + 5.3
08:50.1	Emergency Playback Enable ON	S-IVB	T ₄ + 7.3
08:50.3	Fast Record OFF	S-IVB	T ₄ + 7.5
08:51.3	PU Activate ON	S-IVB	T ₄ + 8.5
08:52.6	Charge Ullage Jettison ON	S-IVB	T ₄ + 9.8
08:55.1	Fire Ullage Jettison ON	S-IVB	T ₄ + 12.3
08:58.4	Ullage Charging Reset	S-IVB	T ₄ + 15.6
08:58.6	Ullage Firing Reset	S-IVB	T ₄ + 15.8
09:01.7	Tape Recorder Record OFF	IU	T ₄ + 18.9
09:05.2	Telemetry Calibrator In-Flight Calibrate ON	IU	T ₄ + 22.4
09:10.2	Telemetry Calibrator In-Flight Calibrate OFF	IU	T ₄ + 27.4
09:14.6	Regular Calibrate Relays ON	S-IVB	T ₄ + 31.8
09:15.6	Emergency Playback Enable OFF	S-IVB	T ₄ + 32.8
09:19.6	Regular Calibrate Relays OFF	S-IVB	T ₄ + 36.8
Variable	Engine Pump Purge Control Valve Enable ON	S-IVB	Cutoff -7.0
11:33.7	Cutoff S-IVB Engine - START OF TIME BASE NO. 5 (T ₅)	S-IVB	T ₅ + 0.0
11:34.0	70 lb. Ullage Engines ON	S-IVB	T ₅ + 0.3
11:34.1	S-IVB Ullage Thrust Present ON	IU	T ₅ + 0.4
11:34.2	Prevalves Close ON	S-IVB	T ₅ + 0.5
11:34.4	First Burn Relay OFF	S-IVB	T ₅ + 0.7
11:34.6	PU Activate OFF	S-IVB	T ₅ + 0.9
11:34.8	LOX Tank Flight Pressure System OFF	S-IVB	T ₅ + 1.1
11:35.0	Coast Period ON	S-IVB	T ₅ + 1.3
11:35.2	Engine Pump Purge Control Valve Enable ON	S-IVB	T ₅ + 1.5
11:36.5	PU Inverter and DC Power OFF	S-IVB	T ₅ + 2.8
11:38.7	Flight Control Computer S-IVB Burn Mode OFF	IU	T ₅ + 5.0
TBD	S/S FM Transmitter OFF	S-IVB	TBD
TBD	S/S FM Transmitter Group OFF	S-IVB	TBD
11:38.9	Aux Hydraulic Pump Coast Mode ON	S-IVB	T ₅ + 5.2
11:39.1	Aux Hydraulic Pump Flight Mode OFF	S-IVB	T ₅ + 5.4
11:43.7	S-IVB Engine Out Indication "A" Enable OFF	IU	T ₅ + 10.0

Table 6-2. Saturn V Flight Sequence (Cont)

Nominal Flight Time (Min & Secs)	Command	Switch Selector Stage	Time From Base (Seconds)
11:43.9	S-IVB Engine Out Indication "B" Enable OFF	IU	T ₅ + 10.2
11:44.1	S1 RF Assembly Power OFF	IU	T ₅ + 10.4
12:24.0	S-IVB Ullage Thrust Present OFF	IU	T ₅ + 50.3
12:32.2	Prevalves Close OFF	S-IVB	T ₅ + 60.5
12:34.4	Chiltdown Shutoff Pilot Valve Close OFF	S-IVB	T ₅ + 60.7
12:34.6	Azusa Transponder Power OFF	IU	T ₅ + 60.9
14:01.7	Continuous Vent Valve Open ON	S-IVB	T ₅ + 88.0
14:03.7	70 lb Ullage Engines OFF	S-IVB	T ₅ + 90.0
14:03.9	Continuous Vent Valve Open OFF	S-IVB	T ₅ + 90.2
TBD	Tape Recorder Playback Reverse ON	IU	TBD
TBD	Emergency Playback Enable ON	S-IVB	TBD
TBD	Emergency Playback Enable OFF	S-IVB	TBD
TBD	Tape Recorder Playback Reverse OFF	IU	TBD
TBD	Slow Record ON	S-IVB	TBD
TBD	Flight Transmitter Group OFF	S-IVB	TBD
TBD	Flight SCO Group OFF	S-IVB	TBD
TBD	Orbit Transmitter Group OFF	S-IVB	TBD
21:36.3	Engine Pump Purge Control Valve Enable OFF	S-IVB	T ₅ + 602.6
TBD	PU Inverter and DC Power ON	S-IVB	TBD
TBD	Begin Restart Preparations – START OF TIME BASE NO. 6 (T ₆)		T ₆ + 0.0
TBD	70 lb Ullage Engines ON	S-IVB	T ₆ + 0.2
TBD	S-IVB Ullage Thrust Present ON	IU	T ₆ + 0.3
TBD	Aux Hydraulic Pump Flight Mode ON	S-IVB	T ₆ + 0.4
TBD	Aux Hydraulic Pump Coast Mode OFF	S-IVB	T ₆ + 0.6
TBD	Continuous Vent Valve Close ON	S-IVB	T ₆ + 1.2
TBD	LH ₂ Repressurization Control Valve Open ON	S-IVB	T ₆ + 2.2
TBD	LOX Chiltdown Pump ON	S-IVB	T ₆ + 2.4
TBD	Continuous Vent Valve Close OFF	S-IVB	T ₆ + 3.2
TBD	Fuel Chiltdown Pump ON	S-IVB	T ₆ + 5.0
TBD	Prevalves Close ON	S-IVB	T ₆ + 15.0
TBD	Prevalves Close OFF	S-IVB	T ₆ + 305.0
TBD	LOX Repressurization Control Valve Open ON	S-IVB	T ₆ + 305.2
TBD	PU Fuel Boil Off Bias Cutoff ON	S-IVB	T ₆ + 325.0

Table 6-2. Saturn V Flight Sequence (Cont)

Nominal Flight Time (Min & Secs)	Command	Switch Selector Stage	Time From Base (Seconds)
TBD	S-IVB Engine Cutoff OFF	S-IVB	$T_6 + 325.6$
TBD	Engine Ready Bypass	S-IVB	$T_6 + 325.8$
TBD	LH ₂ Repressurization Control Valve Open OFF	S-IVB	$T_6 + 326.0$
TBD	Fuel Chilldown Pump OFF	S-IVB	$T_6 + 326.2$
TBD	LOX Chilldown Pump OFF	S-IVB	$T_6 + 326.4$
TBD	Chilldown Shutoff Pilot Valve Close ON	S-IVB	$T_6 + 326.6$
TBD	LOX Tank Repressurization Control Valve Open OFF	S-IVB	$T_6 + 326.8$
TBD	Engine Start ON	S-IVB	$T_6 + 327.0$
TBD	LOX Tank Flight Pressurization System ON	S-IVB	$T_6 + 327.4$
TBD	Coast Period OFF	S-IVB	$T_6 + 327.6$
TBD	S-IVB Engine Out Indication "A" Enable	IU	$T_6 + 327.8$
TBD	S-IVB Engine Out Indication "B" Enable	IU	$T_6 + 328.0$
TBD	Flight Control Computer S-IVB Burn Mode ON	IU	$T_6 + 334.8$
TBD	Fuel Injection Temperature OK Bypass	S-IVB	$T_6 + 335.0$
TBD	Engine Start OFF	S-IVB	$T_6 + 335.2$
TBD	70 lb Ullage Engines OFF	S-IVB	$T_6 + 337.2$
TBD	S-IVB Ullage Thrust Present OFF	IU	$T_6 + 337.4$
TBD	Second Burn Relay ON	S-IVB	$T_6 + 337.6$
TBD	PU Activate ON	S-IVB	$T_6 + 340.0$
TBD	Flight Control Computer Switch Point No. 5	IU	$T_6 + 597.0$
TBD	Point Level Sensor Arming	S-IVB	$T_6 + 652.9$
TBD	Cutoff S-IVB Engine - START OF TIME BASE NO. 7 (T_7)	S-IVB	$T_7 + 0.0$
TBD	Point Level Sensors Disarming	S-IVB	$T_7 + 0.3$
TBD	Prevalves Close ON	S-IVB	$T_7 + 0.5$
TBD	Second Burn Relay OFF	S-IVB	$T_7 + 0.7$
TBD	PU Activate OFF	S-IVB	$T_7 + 0.9$
TBD	PU Inverter and DC Power OFF	S-IVB	$T_7 + 1.3$
TBD	LOX Chilldown Pump Purge Control Valve Open OFF	S-IVB	$T_7 + 1.6$
TBD	LOX Tank Flight Pressurization System OFF	S-IVB	$T_7 + 1.8$
TBD	Coast Period ON	S-IVB	$T_7 + 2.0$
TBD	Flight Control Computer S-IVB Burn Mode OFF	IU	$T_7 + 5.0$
TBD	Aux Hydraulic Pump Flight Mode OFF	S-IVB	$T_7 + 5.2$
TBD	Prevalves Close OFF	S-IVB	$T_7 + 60.5$

Table 6-2. Saturn V Flight Sequence (Cont)

Nominal Flight Time (Min & Secs)	Command	Switch Selector Stage	Time From Base (Seconds)
TBD	Chiltdown Shutoff Pilot Valve Close OFF	S-IVB	$T_7 + 60.7$
TBD	LH ₂ Tank Vent Valve Open ON	S-IVB	TBD
TBD	LOX Tank Vent Valve Open ON	S-IVB	TBD
TBD	LOX Tank Vent Valve Open OFF	S-IVB	TBD
TBD	LOX Tank Vent Valve Close ON	S-IVB	TBD
TBD	LOX Tank Vent Valve Close OFF	S-IVB	TBD
TBD	LH ₂ Tank Vent Valve Open OFF	S-IVB	TBD
TBD	LH ₂ Tank Vent Valve Close ON	S-IVB	TBD
TBD	LH ₂ Tank Vent Valve Close OFF	S-IVB	TBD
	EVENTS TO BE SEQUENCED BY LVDC ON GROUND COMMAND		
	CCS Transmitter ON	IU	
	CCS Transmitter OFF	IU	
	PCM Coax Switch-Fail Safe & Low Gain Antenna	IU	
	PCM Coax Switch-OMNI Antenna	IU	
	PCM Coax Switch-High Gain Antenna	IU	
	CCS Coax Switch-Fail Safe & High Gain Antenna	IU	
	CCS Coax Switch-OMNI Antenna	IU	
	CCS Coax Switch-Low Gain Antenna	IU	
	EVENTS TO OCCUR OVER TRACKING STATIONS		
TBD	Orbit Transmitter Group ON	S-IVB	TBD
TBD	Flight SCO Group ON	S-IVB	TBD
TBD	Flight Transmitter Group ON	S-IVB	TBD
TBD	Slow Record ON	S-IVB	TBD
TBD	Slow Record OFF	S-IVB	TBD
TBD	Recorder Playback ON	S-IVB	TBD
TBD	Recorder Playback OFF	S-IVB	TBD
TBD	Slow Record ON	S-IVB	TBD
TBD	Slow Record ON	S-IVB	TBD
TBD	Regular Calibrate Relays ON	S-IVB	TBD
TBD	Telemetry Calibrator In-Flight Calibrate ON	IU	TBD
TBD	Regular Calibrate Relays OFF	S-IVB	TBD
TBD	Telemetry Calibrator In-Flight Calibrate OFF	IU	TBD
TBD	Flight Transmitter Group OFF	S-IVB	TBD
TBD	Flight SCO Group OFF	S-IVB	TBD
TBD	Orbit Transmitter Group OFF	S-IVB	TBD

SECTION VII

COMPONENT DESCRIPTION

The following paragraphs contain a general description of each of the components which make up the Navigation, Guidance, and Control System. For detailed descriptions, refer to the documents which are listed in the List of Related Documents.

The flight equipment presented in this section is in the following order:

Inertial Components

- ST-124M-3 Inertial Platform Assembly
- ST-124M-3 Platform Electronics Assembly
- ST-124M-3 Platform Signal Conditioner
- Accelerometer Signal Conditioner

Digital Components

- Launch Vehicle Digital Computer
- Launch Vehicle Data Adapter

Attitude Control Components

- Control Sensors
- Control Signal Processor
- Flight Control Computer
- Engine Actuators*
- Auxiliary Propulsion System*
- Switch Selector, Model II*

7-1 INERTIAL COMPONENTS

The ST-124M-3 Inertial Platform system provides the inertial reference coordinates, integrated acceleration data, and vehicle attitude measurements for the navigation, guidance, and control functions of the Saturn Launch Vehicles. The Platform system consists of the following four main components:

- ST-124M-3 Inertial Platform Assembly
- ST-124M-3 Platform Electronic Assembly
- ST-124M-3 Platform AC Power Supply
- Accelerometer Signal Conditioner

Figure 7-1 is a block diagram of the Platform system. The 56 Volt Power Supply and Gas Bearing

*By definition the engine actuators, Switch Selector, and auxiliary propulsion system are not actually components of the NG&C System but are explained here for a better understanding of the overall system operation.

Supply are also shown even though they are not considered as a direct part of the system. The ESE equipment is located at the launch site and launching control center. The physical characteristics of the inertial components are given in Table 7-1.

7-2 ST-124M-3 INERTIAL PLATFORM ASSEMBLY

The ST-124M-3 Inertial Platform Assembly (Figure 7-2) hereinafter referred to as the Platform, will be used on the Saturn IB and V Vehicles for the Apollo mission.

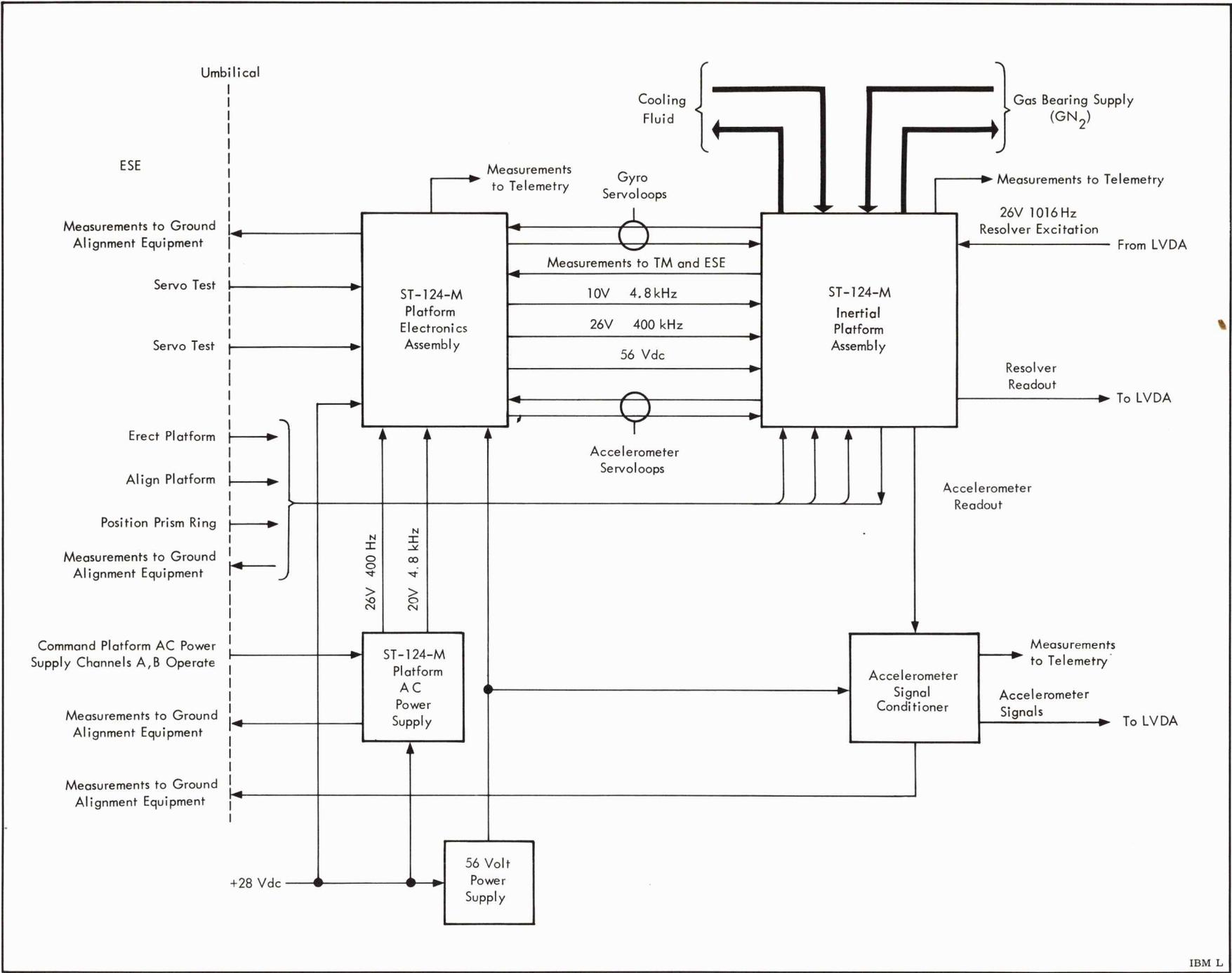
The gimbal configuration of the Inertial Platform is shown in Figure 7-3. The gimbals are:

- Outer gimbal (X axis)
- Middle gimbal (Y axis)
- Inner gimbal (Z axis)

The X and Y axes have unlimited freedom about their reference axes while the Z axis is limited to ± 45 degrees of rotation (vehicle yaw at launch).

The inertial, or inner, gimbal provides a rotationally-stabilized table upon which three integrating accelerometers are mounted. The gimbal system allows the inertial gimbal rotational freedom. Three single-degree-of-freedom gyroscopes provide the reference for the stabilized table. The gyros have their input axes aligned along an orthogonal coordinate system X_I , Y_I , and Z_I of the inertial gimbal as shown in Figure 7-4. The signal generator, which is fixed to the output axis of the gyro, generates electrical signals proportional to torque disturbances. These signals are transmitted to the servo-electronics which terminate in the gimbal pivot servotorque motors. The servoloops maintain the inner gimbal rotationally fixed in inertial space.

The inner gimbal has three integrating gyro accelerometers oriented along the inertial coordinates X_I , Y_I , and Z_I (Figure 7-5). Each accelerometer measuring head contains a single-degree-of-freedom gyro; the rotation of the measuring head is a measure of integrated acceleration along the input axis of the accelerometer. The Y accelerometer measures



IBM L

Figure 7-1. ST-124M-3 Platform System Block Diagram

acceleration perpendicular to the thrust vector (cross-range acceleration). The outputs of the X and Z accelerometers are used to compute the pitch angle of the vehicle acceleration vector and the required cut-off velocity.

The coordinate erection and orientation system of the Platform aligns the X_I coordinate along the launch local vertical, parallel to the gravity vector and aligns the Y_I coordinate perpendicular to the desired flight plane. The coordinate orientation is accomplished by use of an automatic alignment system which is a part of the ESE on the ground. The leveling alignment servoloops (Y and Z) generate torquing voltages which are a function of the earth's angular velocity, the latitude of the launch site, and the azimuth of the Z_I coordinate (launch azimuth). These voltages are applied to the Y and Z gyro torquers and cause the gyros to torque its respective gimbal until the servos are nulled. Platform coordinates are established in azimuth with the roll alignment servoloop. The output of the roll alignment servoloop is a function of the earth's angular velocity and the latitude of the launch site. Azimuth alignment being a commanded function, is accomplished by injecting azimuth alignment signals directly into the roll alignment loop and torquing the roll gimbal with the X gyro. The azimuth alignment position can be updated at any time by the launch control computer.

The reference coordinate frame of the Platform maintains a fixed relationship to the inner gimbal. This coordinate frame is accurately positioned prior to vehicle liftoff and remains space-direction

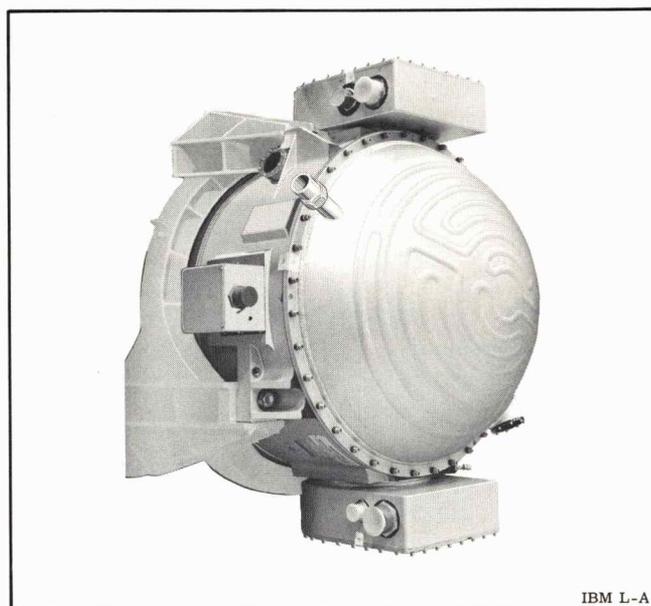


Figure 7-2. ST-124M-3 Inertial Platform Assembly

fixed after vehicle liftoff. The gimbals of the Platform allow the inner gimbal rotational freedom with respect to the vehicle. The gimbal pivots are the axes about which the gimbals turn with respect to each other. The $\pm Y$ pivots couple the inner (stabilized) gimbal to the middle gimbal; the Y pivot axis is normally along the vehicle pitch axis. The $\pm Z$ pivots couple the middle gimbal to the outer gimbal; the Z pivot axis is normally along the vehicle yaw axis. The $\pm X$ pivots couple the outer gimbal to the platform mounting base; the X pivot axis is along the vehicle roll axis. The X, Y, and Z pivots are controlled by dc torque motors; the X pivot torquer has approxi-

Table 7-1. Physical Characteristics of Inertial Platform Components

Item No.	Component	Part No.	Reference Designation	Dimensions L x W x D (inches)	Weight (pounds)	Pwr Consumption (watts)
1	ST-124M-3 Inertial Platform Assembly	50M22100	603A19	28 (w) x 21 (dia)	107	(Included with Item No. 2)
2	ST-124M-3 Platform Electronic Assembly	50M22102	603A20	13 x 19 x 9.4	50	70
3	ST-124M-3 Platform AC Power Supply	50M22106	603A13	13.6 x 12.8 x 7.65	30	110
4	Accelerometer Signal Conditioner	50M22107	603A21	9.2 x 8.9 x 9.4	12	7

mately twice the torque capacity of the other pivot torquers. This accommodates the reflected torque when the middle gimbal is not orthogonal with the outer gimbal. For transfer of electrical signals across the $\pm X$ and $\pm Y$ pivots, slip-ring capsules are used. A flex cable is used on the $\pm Z$ pivot because of its limited freedom.

Dual-speed resolvers (32:1) are used as shaft angle encoders on the $+X$, $+Y$, and $+Z$ pivots. The output of these resolvers is converted into a digital code in the LVDA. The system also has an analog resolver chain which utilizes single-speed resolvers on each pivot and three program resolvers

in the inertial data box. This is used with the ground electrical support equipment only to facilitate check-out and test. If required, the resolver chain system can be used as flight equipment to measure the gimbal angles and to provide the vehicle attitude signals.

7-3 ST-124M-3 PLATFORM ELECTRONIC ASSEMBLY

The ST-124M-3 Platform Electronic Assembly (Figure 7-6) (PEA) contains the electronics required for the Platform axis and accelerometer stabilization. Switching electronics for controlling Platform system power and checkout functions are also located in the PEA.

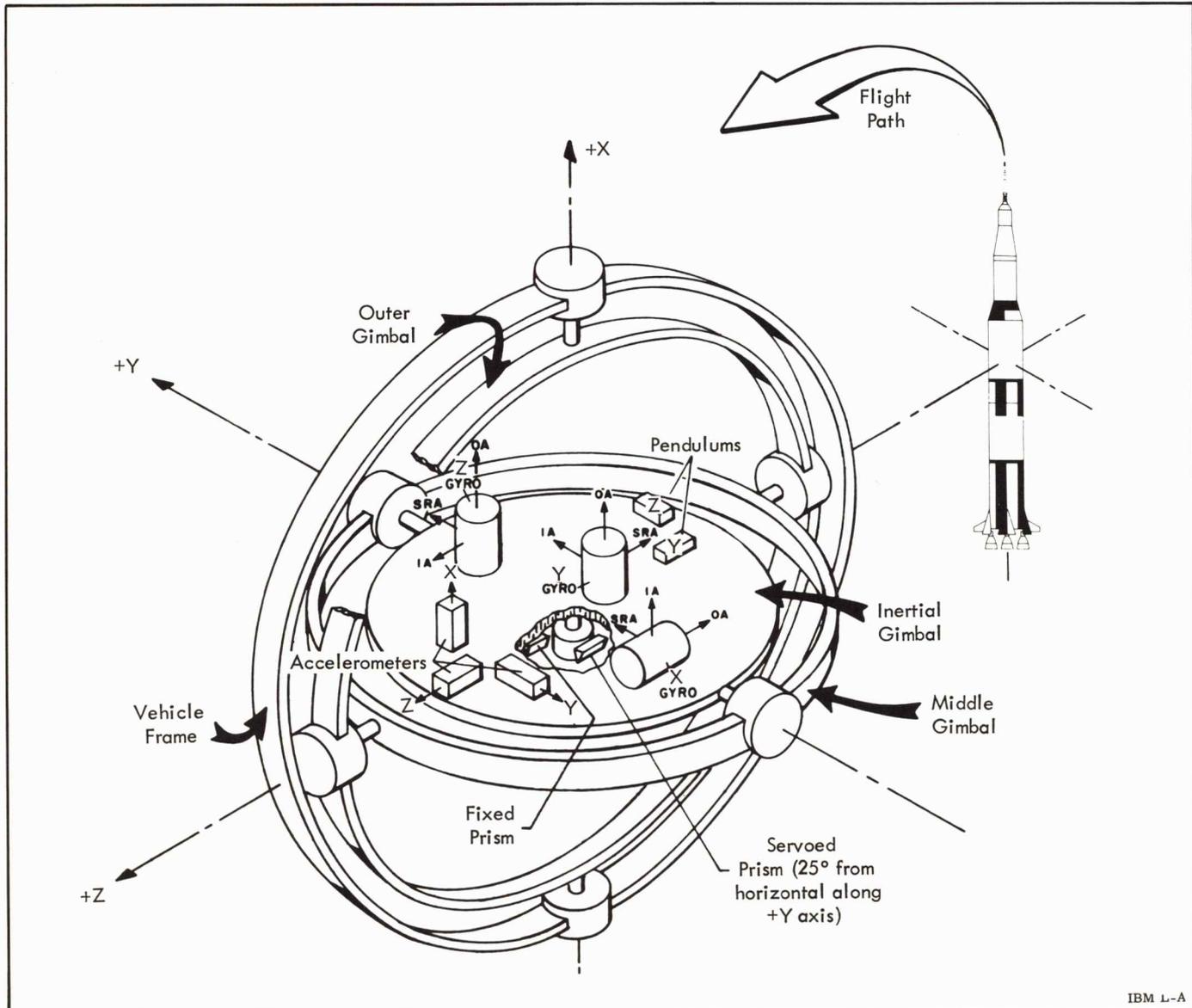


Figure 7-3. Platform Gimbal Configuration

The PEA includes the following circuitry:

- Amplifiers, modulators, and stabilization networks for the Platform gimbal and accelerometer servo loops.
- Relay logic for signal and power control.
- Amplifiers for the gyro and accelerometer pick-off coil excitation.
- Automatic checkout selection and test circuitry for servo loops.
- Control circuitry for the heaters and gas supply.

The PEA has numerous inputs and outputs. However, some input signals have no purpose in the PEA and flow directly from input to output. Inputs to the PEA are as follows:

- +28 Vdc power
- +56 Vdc power
- Three gyro and three accelerometer pick-off signals

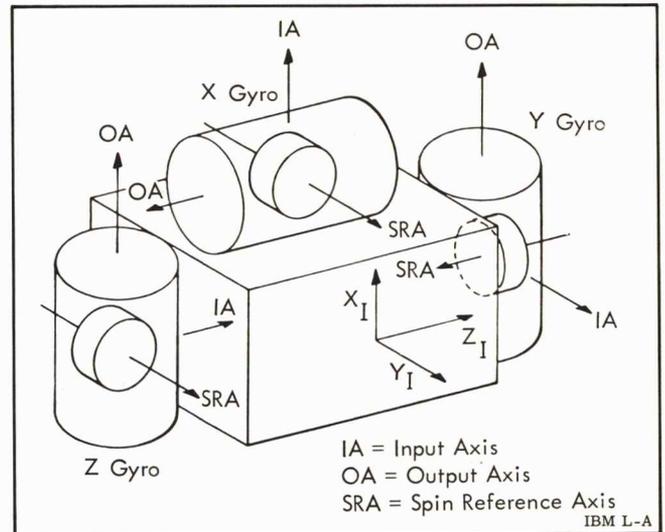


Figure 7-4. Orientation of Gyro Axes

- Gyro and accelerometer wheel power
- Gyro and accelerometer pick-off sensor excitation
- Automatic servo loop checkout control
- Platform gas and temperature sensors signals

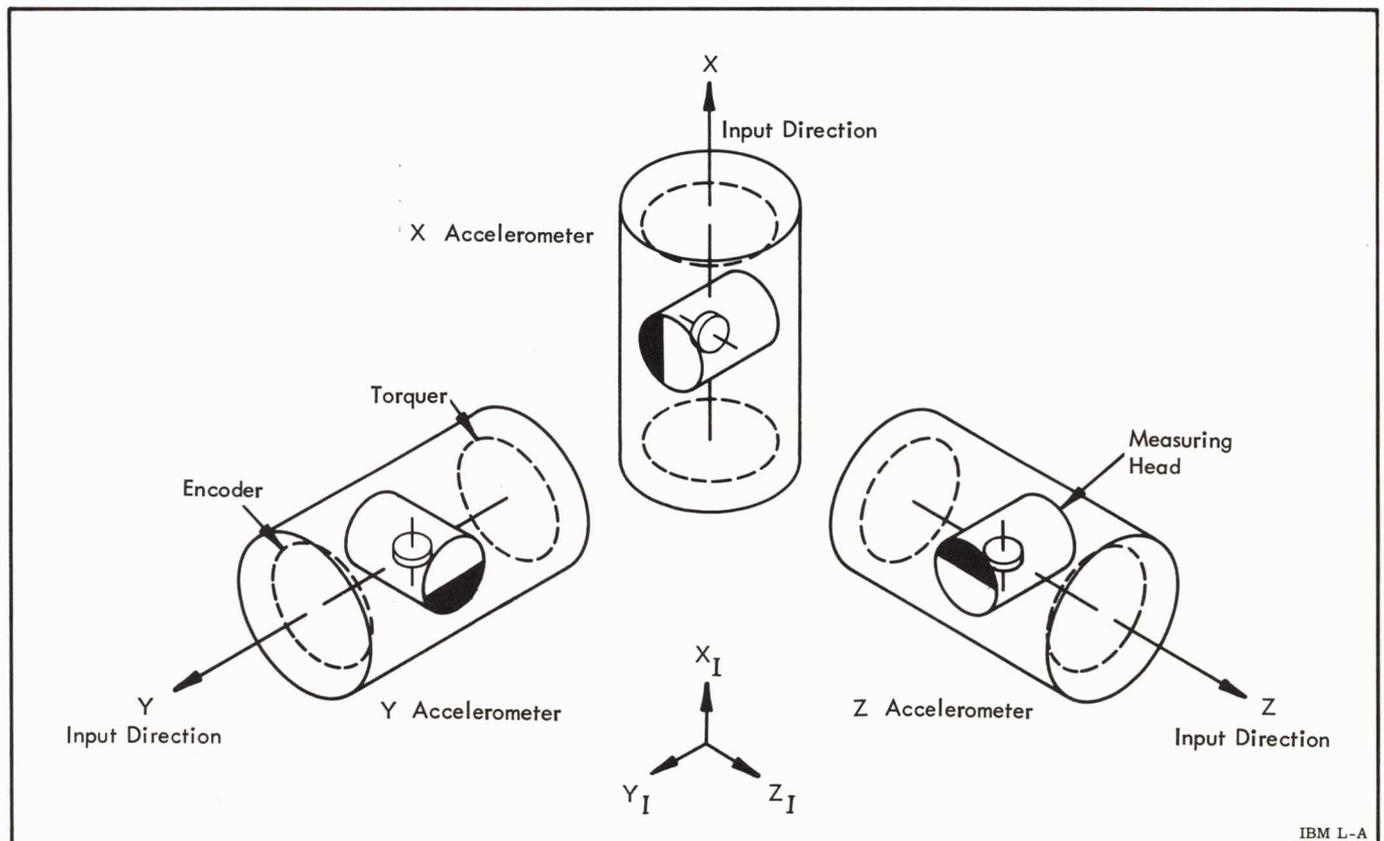


Figure 7-5. Orientation of Accelerometer Axes

Some outputs of the PEA are only controlled versions of the inputs. Outputs are as follows:

- +28 Vdc (controlled) to the Platform
- +56 Vdc (controlled) to the Platform electronics
- Three gimbal and three accelerometer drive motor control signals
- Gyro and accelerometer wheel power (controlled)
- Gyro and accelerometer pick-off sensor excitation (controlled)
- Platform synchro and resolver excitation (controlled)
- Platform heater control
- Telemetry signals

7-4 ST-124M-3 PLATFORM AC POWER SUPPLY

The ST-124M-3 Platform AC Power Supply (Figure 7-7) furnishes the power required to run the gyro wheels. It also supplies the excitation for the Platform gimbal synchros and is the frequency source for the resolver chain references and for gyro and accelerometer servo systems carrier.

The supply produces a three-phase, sine wave output which is fixed at 26 volts (rms) line-to-line at a frequency of 400 ± 0.01 Hertz. Three single-phase, 20-volt reference outputs (square wave) of 4.8 kilohertz, 1.92 kilohertz, and 1.6 kilohertz are also provided. With a normal input voltage of 28 Vdc,



Figure 7-6. ST-124M-3 Platform Electronic Assembly

the supply is capable of producing a continuous 250 VA output.

7-5 ACCELEROMETER SIGNAL CONDITIONER

The Accelerometer Signal Conditioner (Figure 7-8) accepts the velocity signals from the accelerometer optical encoders and shapes them before they are passed on the the LVDA/LVDC.

Each accelerometer requires four shapers (a sine shaper and cosine shaper for the active channel and a sine shaper and cosine shaper for the redundant channel). Also included are four buffer amplifiers for each accelerometer (one for each sine and cosine output).

Accelerometer outputs are provided for telemetry and ground checkout in addition to the outputs to the LVDA.

7-6 DIGITAL COMPONENTS

The digital components described in this section are the LVDC and LVDA. Together, they represent a modern electronic digital computer system. The LVDC is a relatively high-speed computer with the LVDA serving as its Input/Output (I/O) device. Any signal to or from the computer is routed through the LVDA. The LVDA also serves as "central equipment" for interconnection and signal flow between the various systems in the Instrument Unit.

The LVDA and LVDC are involved in the following main operations:

- Prelaunch checkout
- Navigation and guidance computations
- Vehicle sequencing
- Orbital checkout



Figure 7-7. ST-124M-3 Platform AC Power Supply

The interconnections between the LVDC, LVDA, and other equipment is shown in Figure 7-9.

7-7 LAUNCH VEHICLE DIGITAL COMPUTER

General Characteristics

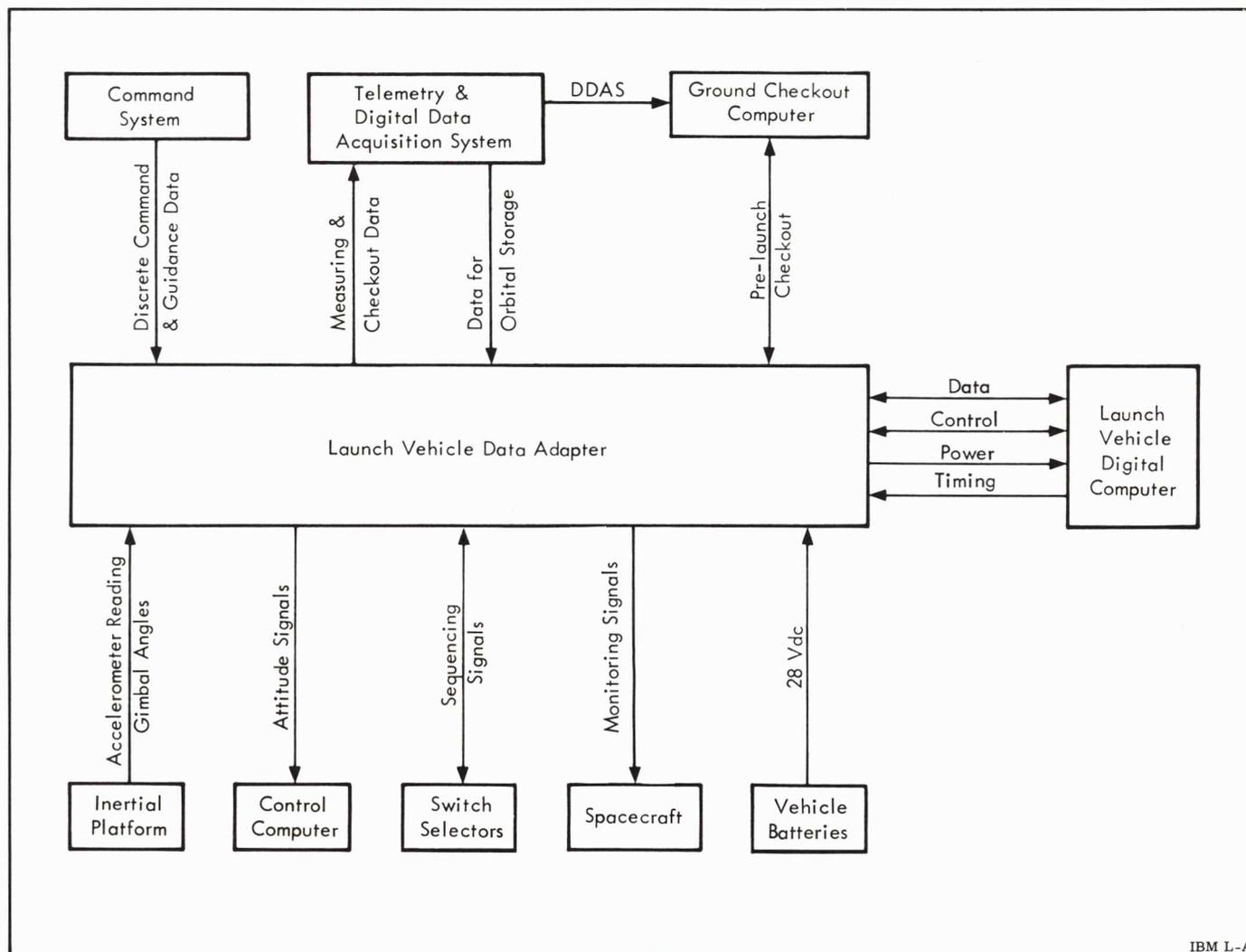
The Launch Vehicle Digital Computer (Figure 7-10) is a general purpose computer which processes data under control of a stored program. The computer uses fixed-point, two's complement arithmetic. Data is processed serially in two arithmetic sections which can, if desired, operate concurrently. Addition, subtraction, and logical extractions are performed in one arithmetic section while multiplication and division are performed in the other.

The principal storage device is a random access, ferrite-core memory with separate controls for data and instruction addressing. The memory



IBM L-A

Figure 7-8. Accelerometer Signal Conditioner



IBM L-A

Figure 7-9. Connections between the LVDC, LVDA, and Associated Equipment

can be operated in either a simplex or duplex mode. In duplex operation, memory modules are operated in pairs with the same data being stored in each module. Readout errors in one module are corrected by using data from its mate to restore the defective location. In simplex operation, each module contains different data which doubles the capacity of the memory. However, simplex operation decreases the reliability of the LVDC because the ability to correct readout errors is sacrificed. The memory operating mode is program controlled. Temporary storage is provided by static registers composed of latches and by shift registers composed of delay lines and latches.

Characteristics of the triple modular redundant LVDC are summarized in Table 7-2. The LVDC is composed of the following eight functional elements:

- Timing
- Memory
- Memory Control
- Data Control
- Program Control
- Arithmetic
- Multiply-Divide
- Voting

LVDC Elements

Figure 7-11 is a block diagram of the LVDC showing the major parts of each functional element

(except the voting element) and how they are interconnected. The heavy lines on the diagram show major paths of information flow.

Timing Element - This element develops three levels of standard timing signals which synchronize and control logic operations in the remaining seven elements (see Figure 7-12). The primary timing is provided by a 2.048 MHz crystal oscillator. The 2.048 MHz signal is used to derive four clock pulses W, X, Y, and Z, each with a repetition rate of 512 kHz.

A bit time is defined as four clock pulses. There are 14-bit times per phase time. A computer cycle is defined as three phase times. A phase time is 27.3 microseconds. Generally, the three phase times A, B, and C provide the following operation:

- | | |
|---------------|--|
| Phase A | Instruction Time
(This is when the instruction is read from memory and decoded.) |
| Phase B and C | Operation Time
(This is when the operand is read from memory and the desired function performed.) |

Memory Element - The element provides the necessary storage medium in the LVDC. The memory is divided into memory modules. The number of memory modules may vary from one to eight. Each module consists of 14 planes with 128 by 64 cores in each plane (a total of 114,688). The basic module contains 4,096 non-redundant 28-bit words (one bit per core). The memory modules operate independently and may be used in either a simplex or duplex mode. In the simplex mode, each memory module is usable for programming. Duplex operation requires pairs of memory modules to function in parallel. Each pair of modules containing the same information, effectively halves the amount of storage that would be available if the same number of modules were operated simplex. With 8 memory modules operating in simplex, the computer has a memory capacity of 32,768 words (of 28 bits each) which is equivalent to the basic memory capability of the IBM 7090 commercial machine. Storage external to the memory is located predominantly in glass delay lines and latches to provide temporary storage for the accumulator, PQ registers, etc.

The organization of the memory modules is indicated in Figure 7-13. For addressing, the 128-core dimension is divided into two equal 64-core

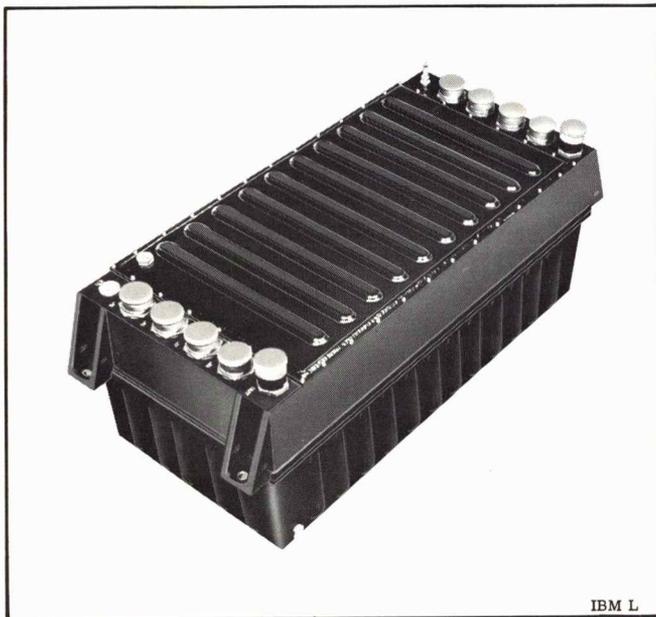
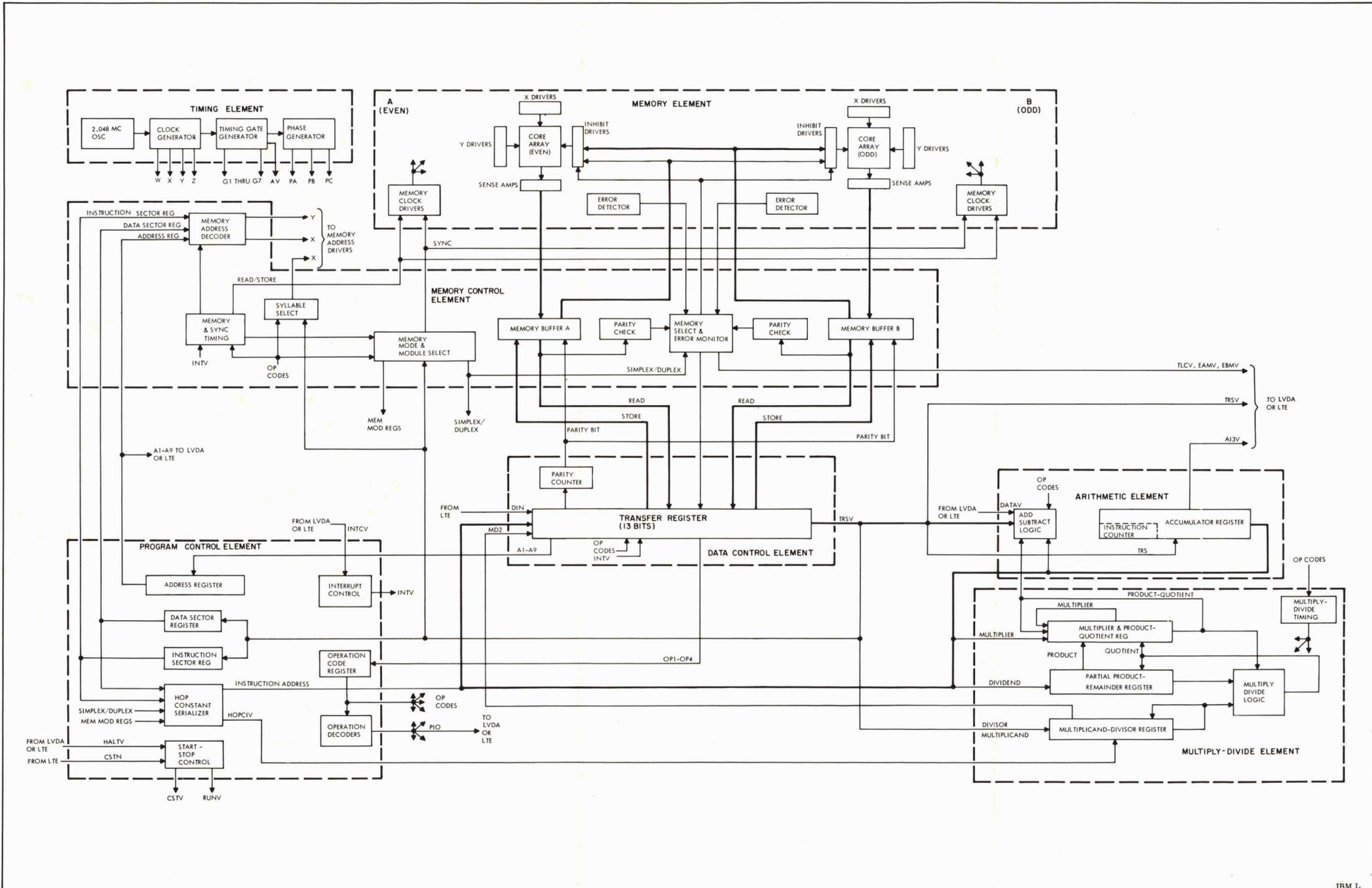


Figure 7-10. Launch Vehicle Digital Computer



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Figure 7-11
Launch Vehicle Digital Computer Block Diagram

Table 7-2. LVDC Characteristics

Characteristic	Description
Type	Stored program, general purpose, serial, fixed-point, binary
Clock	2.048 MHz clock, 4 clocks per bit, 512 kilobits per second
Speed	Add-subtract and multiply-divide simultaneously
Add time (accuracy)	82 us (26 bits)
Multiply time (accuracy)	328 us (24 bits)
Mult-hold time (accuracy)	410 us (24 bits)
Divide time (accuracy)	656 us (24 bits)
Memory	Random access toroidal core
Storage Capacity	Up to a maximum of 32, 768 twenty eight-bit words in 4096-word modules
Word Length	Memory word 28 bits: 2 instructions may be stored in one memory word
Data	26 bits plus 2 parity bits
Instruction	13 bits plus 1 parity bit
Input/Output	External: computer-programmed I/O control: external interrupt provided
Component Count*	40, 800 silicon semiconductors and film resistors (cermet). Up to 917, 504 toroid cores
Reliability*	0.996 probability of success for 250 hours using TMR logic and duplex memory modules
Packaging	Structure constructed of magnesium-lithium material, designed to house 73 electronic pages and 8 memory modules
Weight	88 pounds (6 memory modules)
Dimensions	31 inches by 13.1 inches by 13 inches (L by W by D)
Power*	Included with LVDA
*Figures given here are estimated values	

sections to produce the syllable 0 and syllable 1 portions. Each syllable is then divided into 16 sectors (with 8 by 32 cores in each sector). The last sector in each syllable is called residual memory. It provides a common storage area within the module (for constants, frequently used formulas, etc.) and allows efficient programming. Thirteen of the fourteen memory planes in the memory are for data and instructions and one plane for parity bits.

Each sector will have 256 addresses ranging from 0 through 377 (octal). Addresses of sector 17 (residual storage) will be 400 to 777 (octal). The selection of memory modules is program controlled. The LVDC has the capability of using instructions from one module and data from another, or both from the same module.

To enable the memory to function with a serial arithmetic unit, a serial-by-bit operating mode is

used. This is accomplished by taking two 13-bit memory words (syllable 0 and syllable 1) and producing a 26-bit computer word. The central computer logic then utilizes the serialized computer word. Odd parity is assigned to each half, or 13 bits, of a computer word when it is written into memory. A parity check is made on all information read from memory.

Memory Control Element - The memory control element determines when a transfer will occur and the mode (simplex or duplex) of operation for the memory element. The control element then selects the direction of transfer and the memory location to be exercised. Odd parity is assigned to each half of a word (13 bits) when it is written into memory. A parity check is made on all data transferred from memory. In duplex operation, the control element monitors the output from memories A and B and determines which memory will be used.

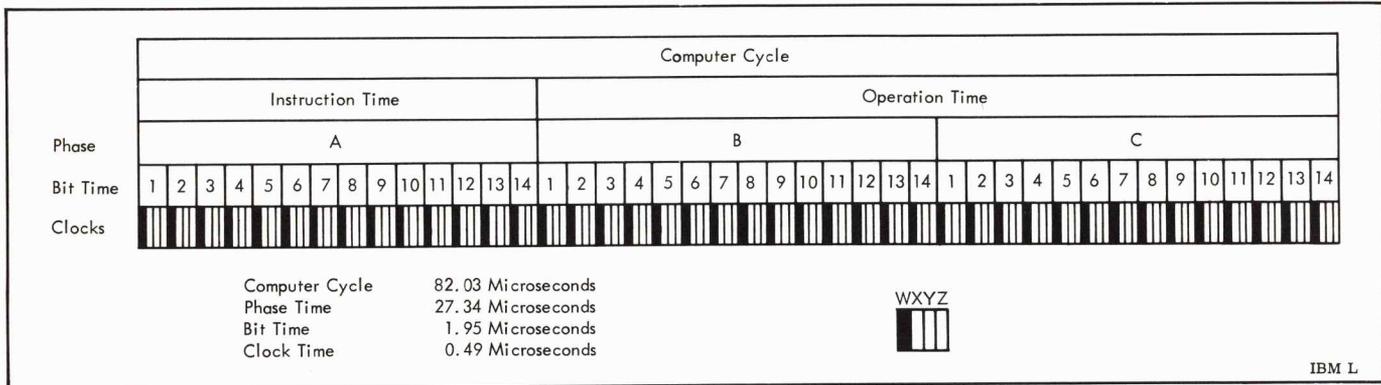


Figure 7-12. Computer Timing

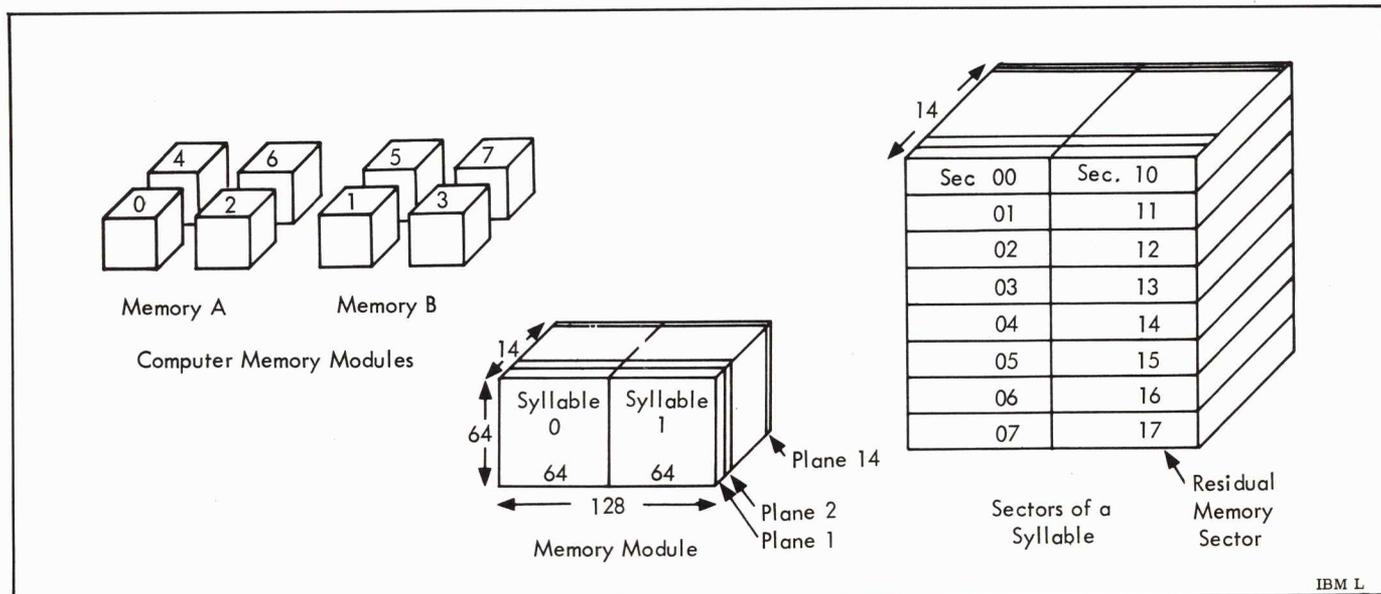


Figure 7-13. Memory Module Arrangement

Data and constants are stored in the memory in two equal segments called syllables. One syllable of data is read at a time. The syllable select circuit determines which syllable will be read. The memory control element sends a sync pulse to the selected memory module. Once pulsed, the module generates all timing signals and drive currents to complete its cycle.

Data Control Element - In the data control element, data words and constants enter the transfer register from the memory in two syllables. Each syllable enters the transfer register in parallel and is then serialized and distributed to the arithmetic element, the multiply-divide element, or the LVDA. Data words which are bound for the memory enter the transfer register in serial form. The transfer register divides the data words into syllables and forwards each syllable to the memory buffer register in parallel. The parity counter assigns odd parity to the number entering the buffer register. The contents of the instruction counter enter the transfer register serially. Before a new instruction is required, the contents of the instruction counter is shifted into the transfer register and transferred in parallel to the address register in the program element.

Program Control Element - This element stores and decodes the programmed instructions. In addition, it controls sequencing of the program through the memory. The operation code register and the address register store their respective parts of the instruction. Outputs of the operation code register, and those of the operation decoders, control the arithmetic and multiply-divide elements, the data and memory control elements, and parts of the program control elements.

Arithmetic and Multiply-Divide Elements - These elements encompass the machine's total computing ability. The arithmetic element performs addition, subtraction, shifts, and logical extractions. The multiply-divide element performs the iterative processes of multiplication and division. The two elements are independent but can be operated concurrently. Once a multiply or divide operation has been started, it runs automatically to completion. During this time, the arithmetic element is available for parallel use. A program option for multiplication stops the program until the product of the multiplication is available.

Voting Element - The voting element is comprised of voter and disagreement detectors located between modules of the LVDC and between the central computer and the memory. The voters resolve differences

between the outputs of triple redundant circuits before the outputs are passed on to succeeding circuits. The disagreement detectors monitor inputs to the voters and provide output signals which indicate when a failure has occurred.

Disagreement detectors are used on module outputs as shown in Figure 7-14 to indicate a failure in the system. Approximately 13 disagreement detectors are logically combined and fed to a register in the LVDA. These signals are then fed to the

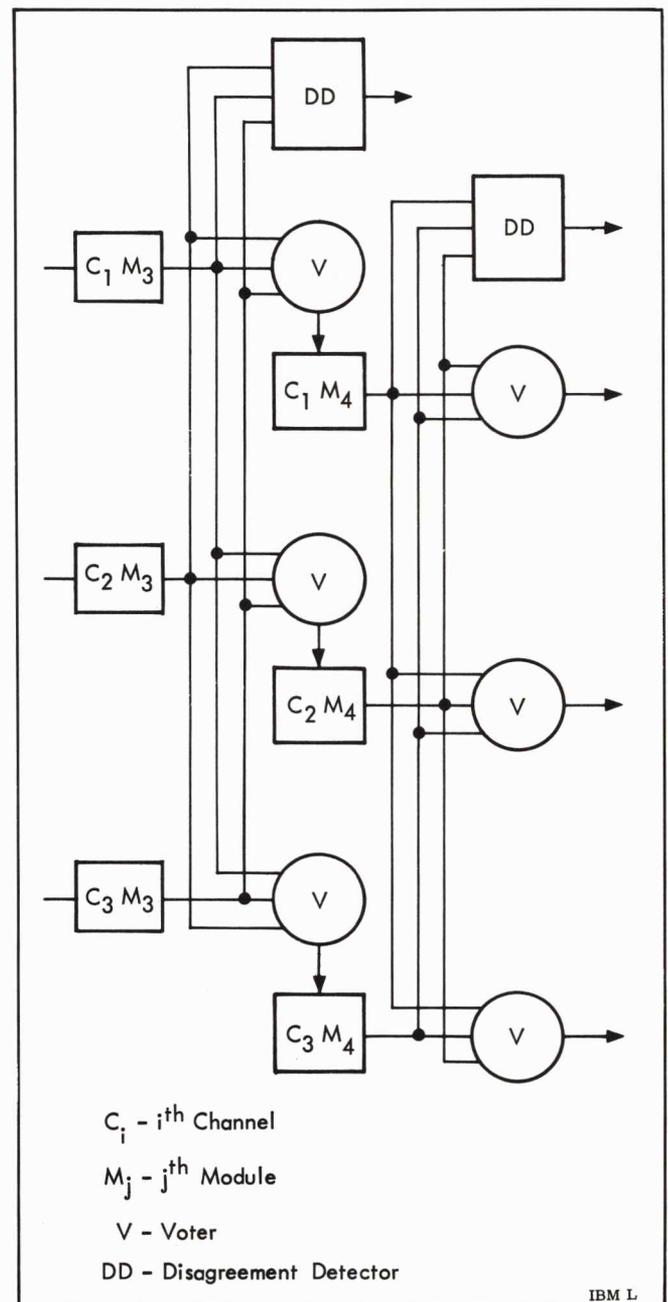


Figure 7-14. Triple Modular Redundancy

telemetry buffer register for monitoring either before launch or in flight.

Computer Word Organization

The LVDC uses a 28-bit word consisting of two 14-bit syllables. Each syllable includes 13 data bits and 1 parity bit. Each syllable is stored separately in the memory. The parity bits are used only to check the accuracy of transfers to and from the memory which leaves a data word 26 bits in length (Figure 7-15).

The use of the data word is at the discretion of the programmer. Each of the 26 bits may be used as an indicator to show the presence or absence of some condition, or the word may be used as a binary number for arithmetic computations. Binary numbers are represented by a sign bit and 25 magnitude bits; negative numbers are shown in two's complement form.

The computer word is also used to store the instructions of the computer program. Instructions are 13 bits in length with one instruction stored in each syllable of the computer word. An instruction consists of a 4-bit operation code (OP1-OP4) and a 9-bit address (A9, A1-A8). Two instruction words may occupy one 28-bit memory word.

Figure 7-15 also shows how the instructions are placed in the computer words.

Computer Instructions

The computer uses a complement of 18 single-address instructions which are composed of a 4-bit operation code and a 9-bit operand address. The 4-bit operation code can select 1 of 16 different instructions to be executed; this range is extended to 18 by grouping 3 instructions under one operation code, then using bits A8 and A9 of the address to discriminate between them. Bits A8 and A9 serve no other function for the instructions which are grouped. A list of the 18 instructions available is given in Table 7-3 with the operation code and a brief description of each.

The 9-bit operand address permits selection of 512 memory addresses for use as operands or data storage locations. The memory is divided into a number of sectors, each containing 256 addresses. Address bits A1 through A8 select one of the addresses within the sector. Bit A9 determines whether the address will be in a sector previously selected by the program or in a special sector called "residual memory". Consequently, bit A9 is called the residual bit; residual memory is selected when A9 is a "1".

Instructions which do not require that data be read from the memory frequently use the operand address for special purposes. For example, the shift instructions (SHF) always manipulate the contents of the accumulator and thus require no operand

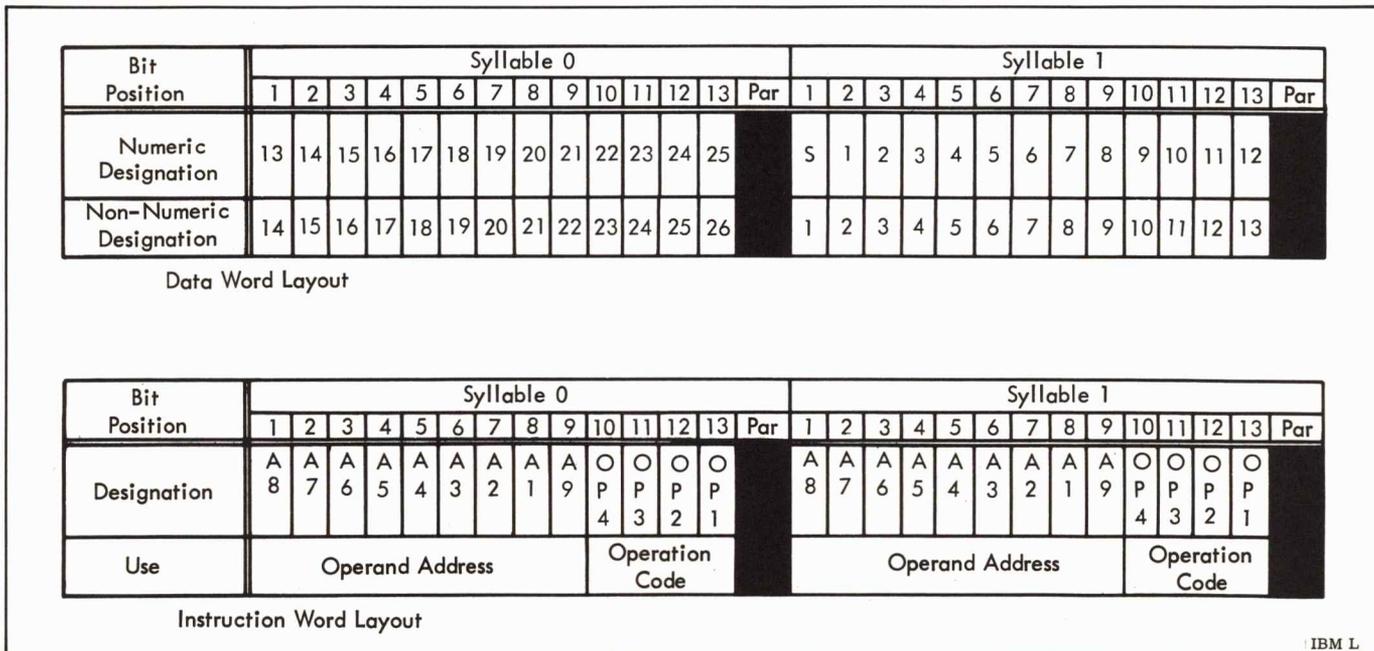


Figure 7-15. LVDC Word Organization

Table 7-3. Computer Instructions

Instruction	Description
ADD (Add)	The contents of the memory location specified by the operand address are added to the contents of the accumulator.
SUB (Subtract)	The contents of the memory location specified by the operand address are subtracted from the contents of the accumulator. The result is retained in the accumulator.
MPY (Multiply)	The contents of the memory location specified by the operand address are multiplied by the contents of the accumulator. The result is retained in the product quotient register.
HOP (Branch)	The contents of the memory address specified by the operand address are used to load the module, sector, syllable, duplex, and instruction counter registers. The contents of the instruction register determine the next instruction to be executed. A full HOP constant must be specified each time since all the registers are loaded each time.
DIV (Divide)	The contents of the accumulator will be divided by the contents of the memory location specified by the operand address. The 24-bit quotient is available in the product quotient register at the eighth computer cycle following the divide.
TRA (Unconditional Transfer)	The eight bits of the operand address (bit A1 through A8) are transferred to the eight low order bits of the instruction counter. Bit A9 of the operand address is transferred to the syllable control latch. Module and sector latches are unchanged. A HOP constant containing the values of the various latches before transferring will be constructed and placed in the multiplicand delay line.
TNZ (Transfer Non-Zero)	A transfer occurs when the accumulator contains a nonzero number. The operand address is used in the same way as for a TRA.
TMI (Transfer Minus)	A transfer occurs if the accumulator sign is minus. The operand address is used in the same way as for the TRA.
SHF (Shift)	The contents of the accumulator will be shifted left or right a maximum of two bit positions as specified by the operand address.
STO (Store)	The contents of the accumulator are stored into the memory location specified by the operand address. The accumulator remains unchanged. The PQ register may be addressed by the STO using 775, A STO 776 or 777 will cause the multiplicand delay line to be stored into the specified (776-777) location. This is used in conjunction with the "HOP save" feature.
PIO* (Process Input or Output)	The address bit A1 through A9 specify: (1) The I/O function to be performed. (2) The Launch Vehicle Data Adapter (LVDA) register to address. (3) The computer address to obtain data from, if required.

Table 7-3. Computer Instructions (Cont)

Instruction	Description
XOR (Exclusive OR)	The contents of the memory location specified by the operand address are exclusively OR'ed, bit-by-bit, with the contents of the accumulator.
AND (Logical AND)	The contents of the memory location specified by the operand address are logically AND'ed, bit-by-bit, with the contents of the accumulator. The result is retained in the accumulator.
CLA (Clear and Add)	The contents of the memory location specified are transferred to cleared accumulator.
RSU (Reverse Subtract)	The contents of the accumulator are subtracted from the contents of the memory location specified by the operand address. The result is retained in the accumulator.
CDS (Change Data Selector)	The operand address will be treated as a constant and will be used to replace the values in the data module, data sector, and data SIM/SUPX latches.
EXM (Execute Modified) A9 through A8	This instruction will: (1) Execute the instruction in a specified memory location. (2) Modify addressing prior to execution. (3) Select the syllable to be executed.
MPH (Multiply and Hold)	The contents of the memory location specified by the operand address are multiplied by the contents of the accumulator. The 24 high order bits of each are multiplied together to form a 26-bit product. The product is available in the accumulator and PQ register at the instruction following the MPH.

* Input-Output Requirements

The computer input-output capability is controlled by the process input-output (PIO) instruction. Each PIO instruction initiates the serial transfer of one 26-bit data word. The data words can be transferred at the rate of 512 kilo bits per second to or from the LVDA.

The computer data is derived from: the main memory, the residual memory, and the accumulator. The computer data inputs have numerous origins. The data adapter system data sampler is the only direct input. This data sampler is used to sample numerous types of data from other systems in the vehicle. All inputs to and outputs from the LVDC are redundant.

address; this frees the operand address for use as a shift control. One instruction which makes extensive use of its operand address is PIO.

Interrupt

A limited program interrupt feature is provided to aid the input-output processing. An external signal can interrupt the computer program and cause a transfer to a subprogram. A computer interrupt occurs when the instruction in progress is completed. All interrupts automatically generate a HOP 400 (octal) instruction. The HOP constant designates the start of the subprogram. Storage of the contents of the instruction counter, sector and module registers, syllable latch, accumulator, and product-quotient registers must be accomplished by the subroutine itself. These values are stored for an eventual return to the interrupted program. Protection against multiple interrupts and interrupts during MPY and DIV operations is also provided.

The interrupt signal may be generated by a timed source. The rate at which it is generated is controlled by changing the magnitude of a number which is being continually summed. When the summed number reaches a predetermined value, the interrupt signal is generated. This is accomplished in the LVDA.

Certain discrete input signals are allowed to cause an interrupt. These are useful in causing the input-output subprogram to give immediate attention to an input or output operation.

The interrupt feature facilitates the timing of input-output operations by causing a transfer to an input-output subprogram. The interrupt signal is generated in the LVDA and may be set to interrupt at the highest rate at which any input-output quantity must be handled. This method avoids the necessity of keeping track of time expired since last entering the input-output subprogram.

The automatic interrupt also makes it possible to permit certain discrete inputs to cause an interrupt. Allowing discrete inputs to interrupt makes it possible to demand that the program give attention to an important discrete input. Communications between LVDC and the vehicle telemetry monitoring system are thus facilitated.

Computer Reliability

Reliability of the LVDC is insured by the use of triple modular redundancy in the central computer and duplex modules in the memory section. This reliability has been calculated to be 0.996 for 250 hours of operation or 0.99996 for a 6-hour mission.

Central Computer Reliability

The triple modular redundant logic system of the LVDC uses three identical simplex logic channels and subdivides each channel into seven functional modules. The outputs from corresponding modules are voted upon in voter circuits before the signal is sent to the next modules. Figure 7-13 shows typical modules and voters. The output of the voter circuit is equal to the majority of the inputs to the circuit. Thus, even if one of the three inputs is incorrect, the output to the next module will be correct.

An average of 13 output signals from each module are voted on. The voter circuit outputs may go to any of the other subdivided modules of the LVDC. This allows correct computations to be obtained, even with several malfunctions in the LVDC, provided two identical modules of a triple redundant set are not in error.

This method provides greater reliability than using three independent computers. If the outputs from three independent computers were compared, any malfunction in two of the computers would cause the computation to be in error.

Memory Reliability

The memory system has two individual memories which can be used in parallel (duplex) for increased reliability or completely independent (simplex) for increased capacity. In the duplex mode, information is read out of both memories from corresponding cores, and by means of a selection network, just one memory output will be used. If the selected memory should contain an error (parity or timing), the information from the other memory would be used with the correct information being read back into both memories. Thus, the computer can correct memory errors.

7-8 LAUNCH VEHICLE DATA ADAPTER

General Characteristics

The Launch Vehicle Data Adapter (Figure 7-16) is the input/output device for the Launch Vehicle

Digital Computer and the central station for the signal flow in the Instrument Unit equipment.

The LVDA includes the following circuits:

- Various registers for buffering input and output signals.
- Delay lines for real time, accumulating accelerometer pulses, storing interrupts, line interrupt counters, and switch selector interrupt counters.
- Power supplies for the LVDA and LVDC.
- Digital-to-analog and analog-to-digital converters.
- Redundancy checkout circuit including channel switching, discrete output switching, and power supply switching.

The LVDA transforms input and output signals to a form that is compatible with the characteristics of the receiving equipment, controls the data flow in the IU, performs certain simple computation and logical operations on data, and provides temporary storage of data.

Communication with the computer is carried out through 512-kilobit per second serial transmission. The PIO instruction permits the specification of either input or output operations and addresses the

device to be affected. A single 26-bit word is transferred to the computer accumulator or from the accumulator or memory.

The characteristics of the LVDA are listed in Table 7-4.

LVDA Input/Output Connections

The interconnections between the LVDA and associated equipment in the IU may be seen in Figure 7-17.

The LVDA accepts discrete input signals from the stage Switch Selectors, IU Command Receiver, Ground Launch Computer, Telemetry Computer Interface Unit, Telemetry Data Multiplexer, Control Distributor, and other vehicle equipment. It has output registers to provide discrete output signals to the above mentioned equipment. It also accepts and processes LVDC interrupt signals from the ground launch computer and the IU equipment.

The LVDA accepts two-phase resolver analog signals from the ST-124M-3 Inertial Platform Assembly and converts these signals to a digital number proportional to the electrical rotation of the resolver. It accepts and accumulates incremental velocity inputs from gray code incremental encoders on the Platform accelerometers and converts digital signals to analog signals for use in the Flight Control Computer.

The LVDA interface has been standardized as much as possible. Digital inputs and outputs will be 0 and 28 Vdc, except for inputs from the optisyns, telemetry transmitter, and Computer Interface Unit.

LVDA Functions

Typical functions performed in the LVDA are the following:

- | | |
|--------------|---|
| Category I | Control data flow, including temporary storage. |
| Category II | Transform data into a form which is compatible with the characteristics of the receiving equipment. |
| Category III | Performs certain simple computational and logical operations on the data. |

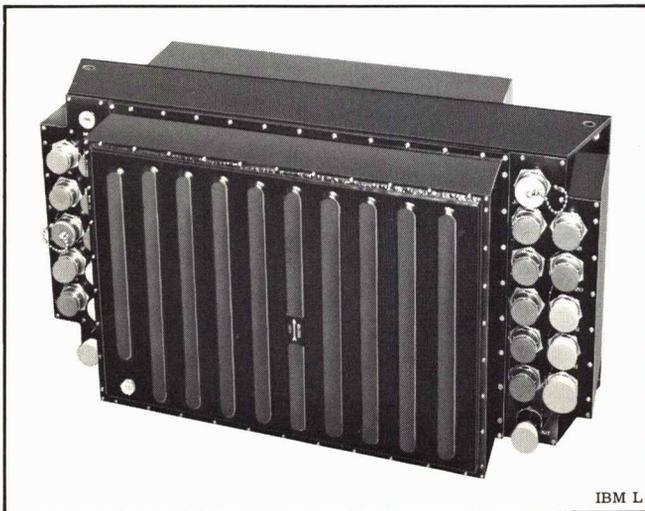
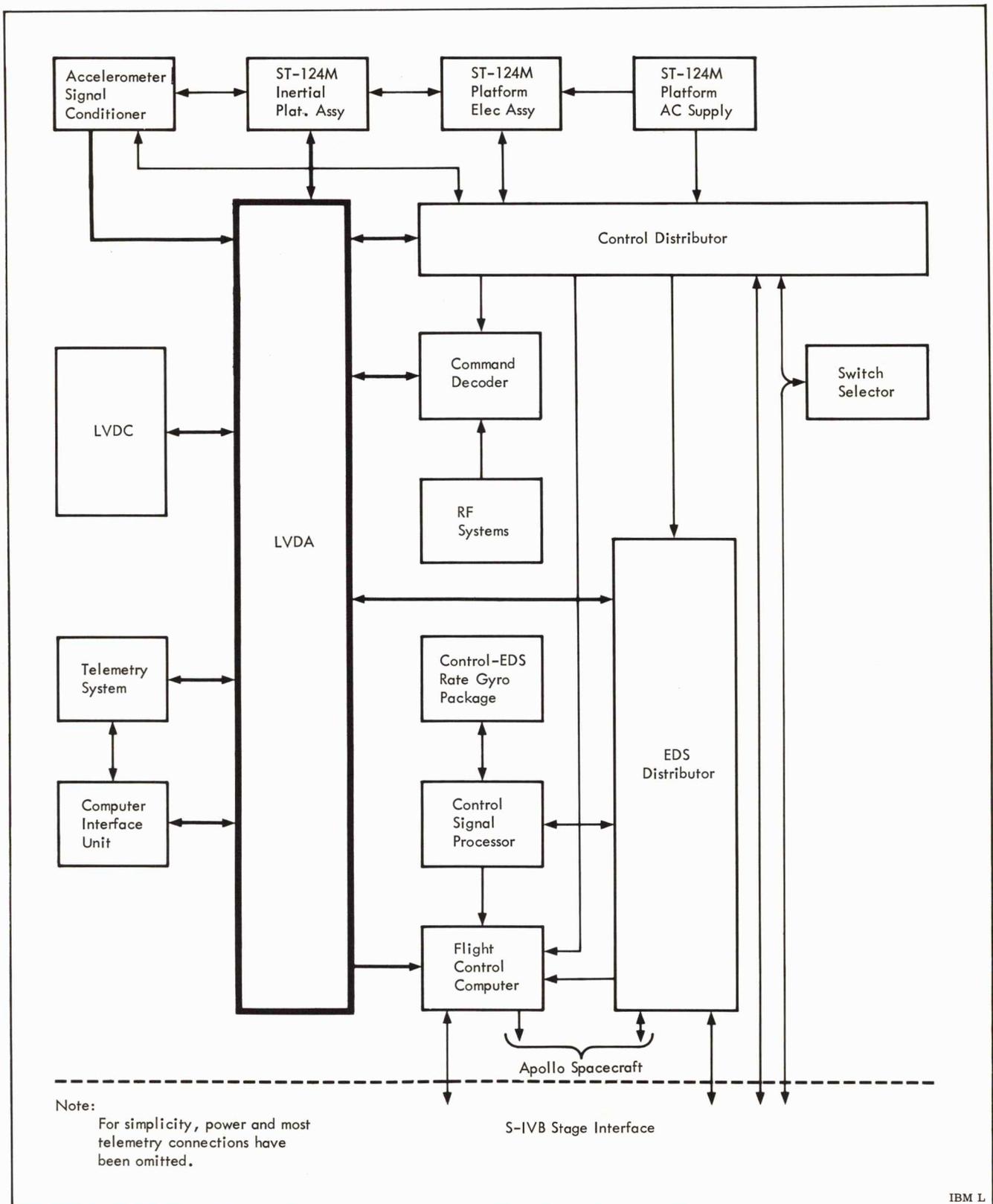


Figure 7-16. Launch Vehicle Data Adapter



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Figure 7-17. LVDA-IU Interconnection for Saturn V

Table 7-4. Data Adapter Characteristics

Item	Description
Computer input-output rate	512 kHz serial
Power supplies	6 duplexed regulated dc supplies 2 ac resolver power supplies
Switch Selector	8-bit Switch Selector input 15-bit Switch Selector output
Discretes	7 interrupt inputs from the IU 13 discrete outputs 32 discrete inputs
Buffer register	26 bits
Tab register	8 bits
Mode register	6 bits
Digital-to-analog converter	Provide communication with the RCA-110 Ground Contr Control Computer, telemetry transmitter, and DDAS 8 bits plus sign, 2.5 millisecond operation, three attitude commands, and two spare outputs
Analog-to-digital converter Platform Spares	Equivalent of 17 bits from a 2-speed resolver 4 two-speed gimbal angle resolver inputs 10 single-speed resolver inputs
Delay lines	3 four-channel delay lines for normal operations 1 four-channel delay line for telemetry operations (DOM)
Telemetry Command Receiver data transmitter Computer Interface Unit	14 bits for input data 38 bits and identification bits plus validity bit and parity bit 15 bits address plus a data requires bit for output data 10 bits for input data plus data ready interrupt
Output to launch computer	41 data and identification bits for output data plus discrete outputs
Input from RCA-110 Ground Control Computer	14 bits for input data plus interrupt
Number of components (estimated)	38,000 silicon semiconductors, cermet resistors, and other special components
Reliability	0.99 probability of success for 250 hours of operation; uses TMR logic, duplex special circuits, duplex power supplies
Packaging	125 electronic page assemblies, plus special electronic assemblies
Weight	190 pounds
Dimensions	32 inches by 16.3 inches by 14.9 inches (L by W by D)
Power (with LVDC)	785 watts

The following functions are typical of those included in Category I:

- The storage of telemetry data from the LVDC and LVDA in the buffer registers.
- The temporary storage of CIU addresses during orbital checkout.
- The transmission of guidance data from the LVDC to the analog Flight Control Computer.

Operations which require a change in the form of the data include (typical of those in Category II):

- Digital-to-analog, analog-to-digital, and signal level conversions.
- The formation of 40-bit launch computer and telemetry words from 26-bit LVDC words.
- Buffering of communications between the LVDC and the ground-based launch computer to reconcile the difference in clock rates.

The LVDA contributes to the efficient operation of the LVDC by performing many simple, though time consuming, logical and computational tasks such as (typical of those functions performed in Category III):

- Keeping track of real time.
- Decoding of operand address in PIO operations.

Power Supplies

The LVDA contains six duplexed dc power supplies and one pair of ac resolver supplies. Associated with the power supplies are controls to:

- Provide channel switching (method of selecting one of the TMR channels for checkout) in the LVDA and LVDC.
- Provide power sequencing where required under ground equipment control.

The regulated voltage supplies are: one +20 Vdc supply, one +12 Vdc supply, two +6 Vdc supplies, one -3 Vdc supply, and one -20 Vdc supply. For

greater reliability, the supplies are duplexed, i.e., two regulated power supplies are connected in parallel. To further increase reliability, the two dc-to-dc power converters within the same duplex supply are connected to different +28 Vdc vehicle supplies. This design feature allows one +28 Vdc vehicle supply to fail without a duplex supply failure.

The ac power supply generates a well-filtered sine wave for excitation of various resolvers in the IU. The 1016-hertz frequency needed to drive the resolvers is obtained by counting down from computer timing pulses.

The resolver frequency sources are also duplexed in that each source supplies power for half of the resolver inputs (i.e., fine and coarse resolver excitation for any input parameter is not supplied by the same source). Since fine and coarse inputs serve as a backup for each other (under the proper program control), duplex redundancy is used for the excitation source.

7-9 CONTROL SYSTEM COMPONENTS

The Control System accepts guidance computations from the LVDC/LVDA Guidance System. These guidance commands, which are actually attitude error signals, are then combined with measured data from the various control sensors. The resultant output is the command signal to the various engine actuators and APS nozzles.

The final computations (analog) are performed within the Flight Control Computer, herein referred to as Control Computer. This computer is also the central switching point for command signals. From this point, the signals are routed to their associated active stages and to the appropriate attitude control devices.

Figure 7-18 shows the Uprated Saturn I Control System in block diagram form. No major changes in flight hardware are anticipated throughout the Saturn program. The Saturn V Control System is very similar except, as explained in Section IV, the Saturn V scheme does not include Control Accelerometer readings and electrical feedback from the engine actuators.

7-10 CONTROL ACCELEROMETERS

Two body-mounted Control Accelerometers (one is shown in Figure 7-19) are used on the Uprated

Saturn I Vehicle to sense lateral acceleration of the vehicle. The accelerations sensed by the Control Accelerometers differ from that measured by the guidance accelerometers. The guidance accelerometers are mounted on the ST-124M Inertial Platform Assembly and measure accelerations with respect to an inertial space coordinate system, while the Control Accelerometers measure lateral acceleration which is perpendicular to the vehicle's longitudinal axis.

The output signals of the accelerometers are used in angle-of-attack control to aid in:

- Reducing the steady state drift of the vehicle's trajectory
- Minimizing the bending moments on the vehicle structure by reducing the angle of attack and lateral component of thrust.

A typical trajectory program for an Up-rated Saturn I Vehicle will utilize these Control Accelerometers for 30 to 120 seconds after liftoff – all within the S-IB Stage flight time – when aerodynamic pressures are greatest. Once free of the atmosphere, this angle-of-attack control scheme is no longer needed.

The Control Accelerometers are physically mounted in segments 601 and 603 of the Instrument Unit. They are oriented at 90 degrees with respect to each other and are referenced to the vehicle pitch and yaw axes.

These accelerometers are force-balance, mass-type and are capable of sensing accelerations of up to 10 meters/second² with a scale factor of 1 volt/meter/second². The output signal, represented by gamma-double dot ($\ddot{\gamma}$), is the accelerometer input signal to the Flight Control Computer which was shown in Figure 7-18. Table 7-5 gives the characteristics of the Control Accelerometer.

Figure 7-20 is a block diagram of a Control Accelerometer. Battery power (28 Vdc) is regulated and converted to 115-volt, 400 cps to power a 45 Vdc power supply, a sensor device, and to act as a reference for a demodulation circuit.

The sensor device converts any lateral acceleration in its sensitive axis to a modulated 400-cycle ac signal. The modulated signal is then amplified and demodulated to a pulsating dc signal. The output signal from the demodulator is then filtered and further amplified in an output amplifier buffer stage.

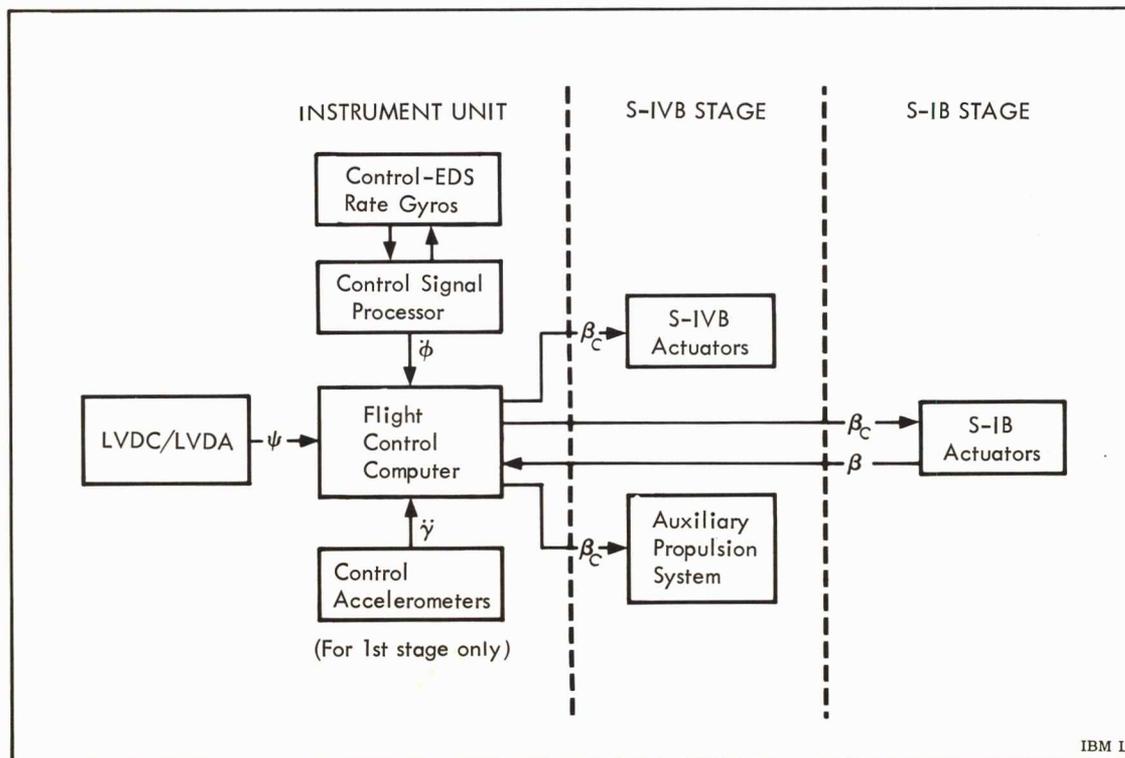


Figure 7-18. Up-rated Saturn I Control System Block Diagram

Table 7-5. Control Accelerometer
Package Characteristics

Reference Designations:	
Pitch	601A25
Yaw	603A26
Size:	
Length	5.5 inches
Width	4 inches
Height	3.5 inches
Weight	5 pounds
Range	10 meters/second ²
Input Voltage	28 ± 4 Vdc
Output (scale factor)	1 Vdc/meters/second ²
Force Coil:	
Scale factor	17 ma dc/meter/ second ²
Accuracy	8% of reading with zero g input
Input Power	15 watts

During test operations, lateral acceleration is simulated by utilizing a force coil or torquer which is built into each sensor device. The force coil produces a calibrated deflection of the mass which is then measured by the sensor in the normal way. The coil is also used for checking polarities in the thrust vector by the Control System in the last minutes prior to launch. The coil is energized by the output of an operational amplifier which is part of the ESE equipment.

7-11 CONTROL-EDS RATE GYRO PACKAGE

Single degree of freedom rate gyros (Figure 7-21) are used on the Saturn vehicles to sense the angular rate of vehicle movement about its roll, pitch, and yaw axes. The Control-EDS Rate Gyro Package, hereinafter referred to as the Rate Gyro Package, houses nine rate gyros - three for each axis - in a triple redundant, "pair and spare" configuration.

Angular rate about the gyro input axis is translated to an ac voltage output signal by using a microsyn differential transformer pickoff which is coupled to the gimbal. The amplitude of this output signal has a definite relationship to the angular rate. This relationship, called the scale factor, is approxi-

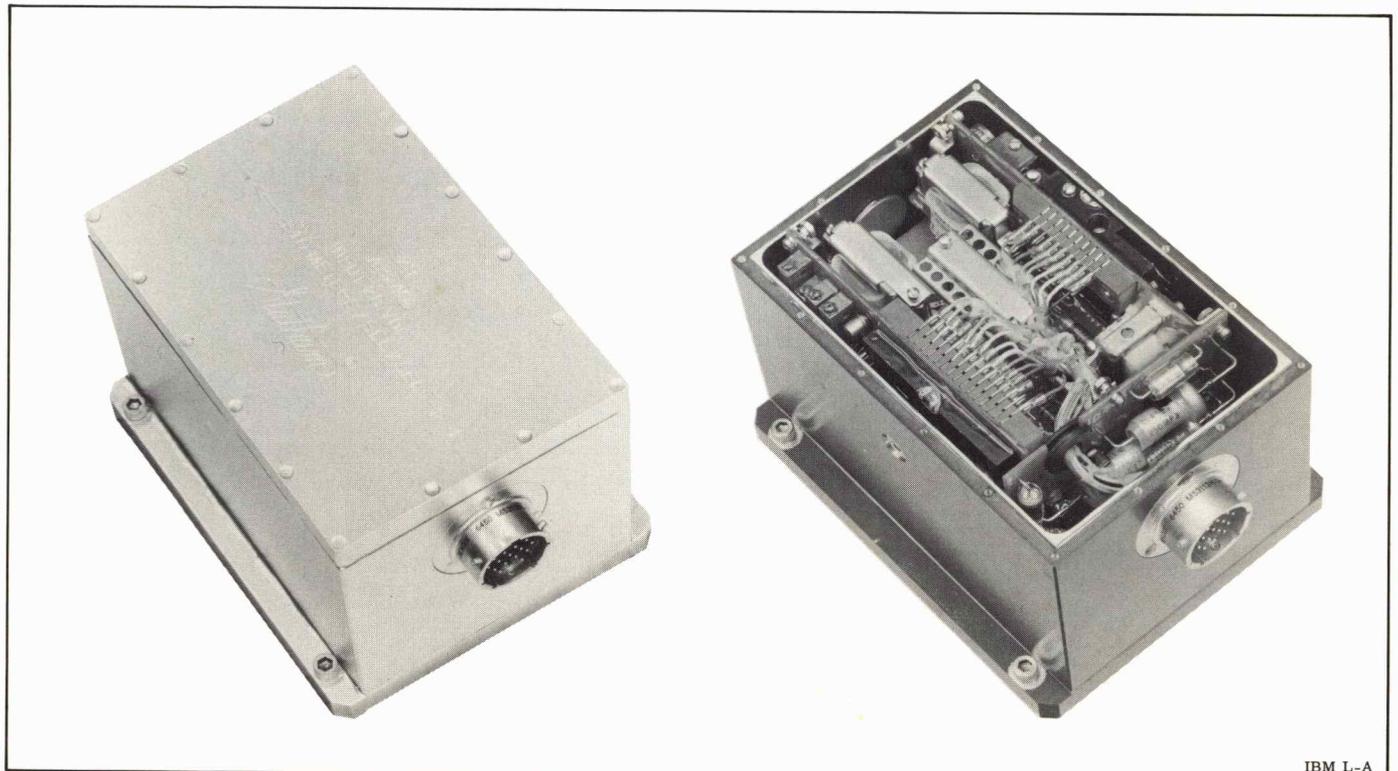


Figure 7-19. Control Accelerometer

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mately 200 millivolts rms/degree/second. The rate gyro has the capability of sensing angular rates to 20 degrees/second in either a clockwise or counter-clockwise direction. The rate gyros are fluid-damped devices which maintain a relatively constant damping factor over the range of temperatures in which the damping material retains its fluid characteristics.

The Rate Gyro Package, physically located on segment 602 of the Instrument Unit, is shown in Figure 7-22. For reliability purposes, nine rate gyros are divided into three groups with each group containing a pitch, roll, and yaw gyro. See Figure 7-23. All nine output signals (ϕP , ϕR , ϕY) are sent to the Control Signal Processor for comparison and selection purposes. For greater reliability, each group of gyros is electrically independent of the two other groups.

Characteristics of the Rate Gyro Package are given in Table 7-6.

In flight, the rate gyros are controlled by the angular motion of the vehicle. However, during test, vehicle dynamics must be simulated by a calibrated torquer coil which is built into each rate gyro. The torquer coil causes the rate gyro gimbal to be deflected a predetermined amount. This deflection is then measured in the normal manner. Testing of the Rate Gyro Package is controlled by an EDS/Control Rate Gyro panel which is part of the ESE equipment.

7-12 CONTROL SIGNAL PROCESSOR

The Control Signal Processor, herein referred to as the Signal Processor, demodulates the ac

Table 7-6. Characteristics of Control-EDS Rate Gyro Package

Reference Designation:	602A23
Size:	
Length	7.0 inches
Width	7.0 inches
Height	3.5 inches
Weight:	10.8 pounds (max)
Input Power:	
Voltage	26 \pm .3 Vac, 400 Hz
Wattage	45 watts (max)

signals from the Control-EDS Rate Gyros into dc analog signals required by the Control Computer. The Signal Processor compares the output signals from the triple redundant gyros and selects one each of the pitch, yaw, and roll signals for the Control Computer. The Signal Processor supplies the Control-EDS Rate Gyro Package with the necessary control and reference voltages. EDS and DDAS rate gyro monitoring signals also originate within the Signal Processor thus accounting for the EDS portion of the Control-EDS Rate Gyro name.

The Signal Processor, shown in Figure 7-24, is physically located on segment 602 of the Instrument Unit and is designated as 602A24. Electrically, it is located between the Control-EDS Rate Gyro Package on one side and the Flight Control Computer and the EDS and DDAS systems on the other. Signal Processor characteristics are given in Table 7-7.

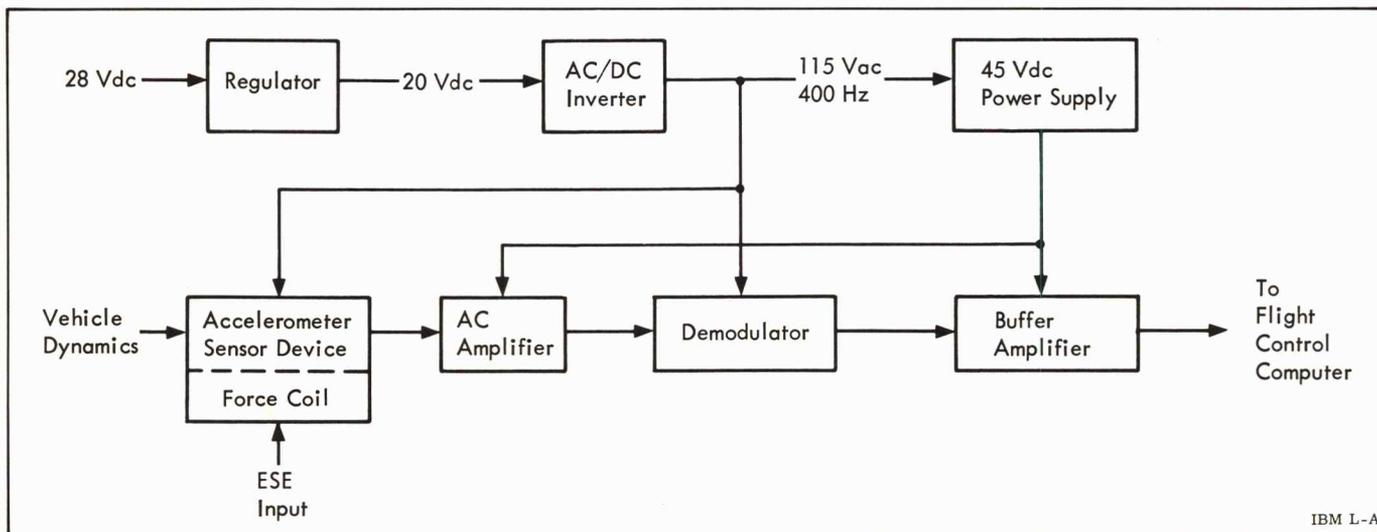


Figure 7-20. Control Accelerometer Block Diagram

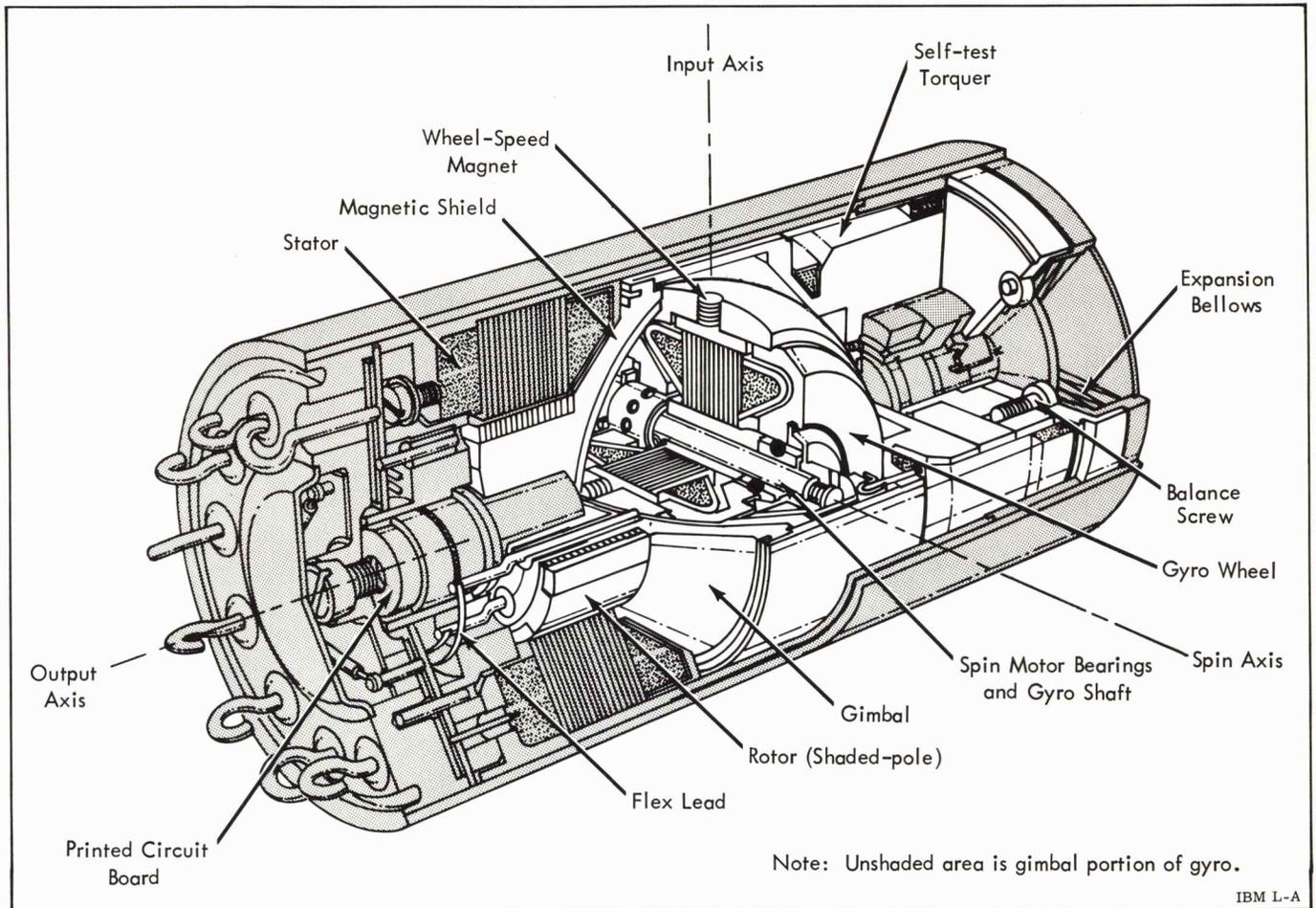


Figure 7-21. Rate Gyro (Cutaway View)

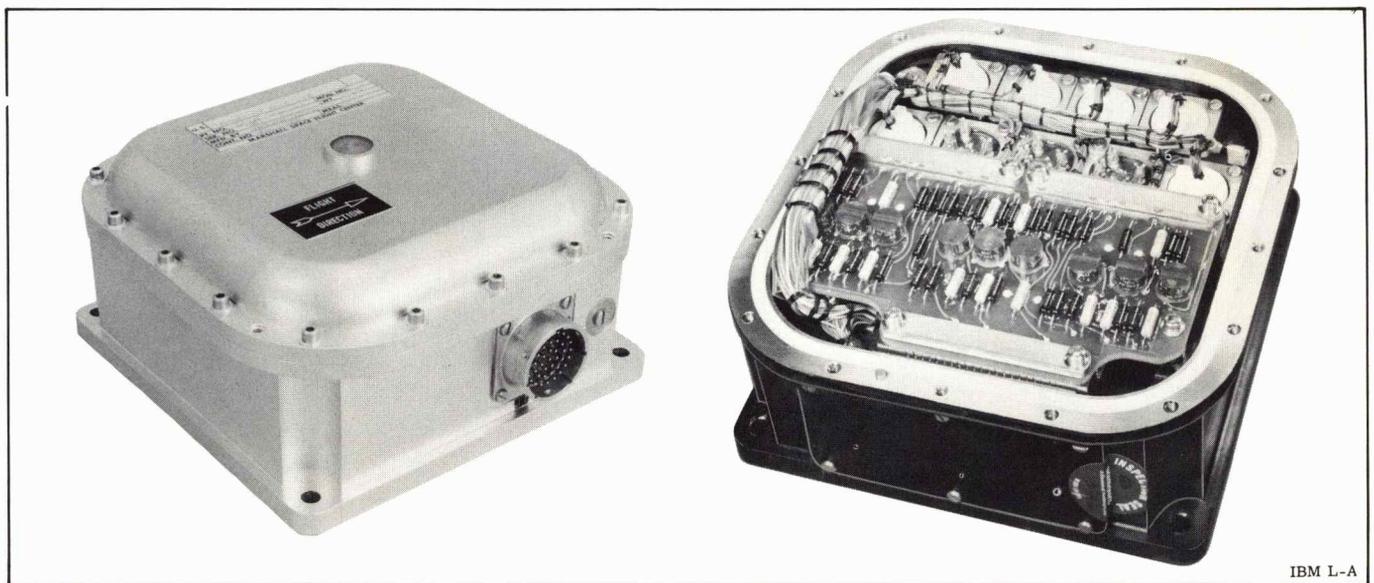


Figure 7-22. Control-EDS Rate Gyro Package

Figure 7-25 is a simplified block diagram of the Signal Processor. The rate gyro inputs (ac) are converted into dc analog signals by their associated demodulator circuits. Resolution for these signals is 4.5 volts/degree/second. The control rate output signals, represented by the phi-dot symbols ($\dot{\phi}_P$, $\dot{\phi}_Y$, $\dot{\phi}_R$) are the attitude rate inputs to the Control Computer.

The three rate gyro signals (three for each axis) are each labelled according to their function within the unit. The "command" signals* are compared with the "reference" signals within their respective comparator circuit blocks. Normally, the command signal is routed directly out of the Signal Processor. If there is a significant difference between the command and reference signal, a relay

*Sometimes referred to as the "normal" signals.

Table 7-7 Characteristics of Control Signal Processor

Reference Designation:	602A24
Size:	
Length	15.4 inches
Width	14.8 inches
Height	7 inches
Weight:	38 pounds
Input Power:	
Voltage	28 ± 4 Vdc
Wattage	135 watts

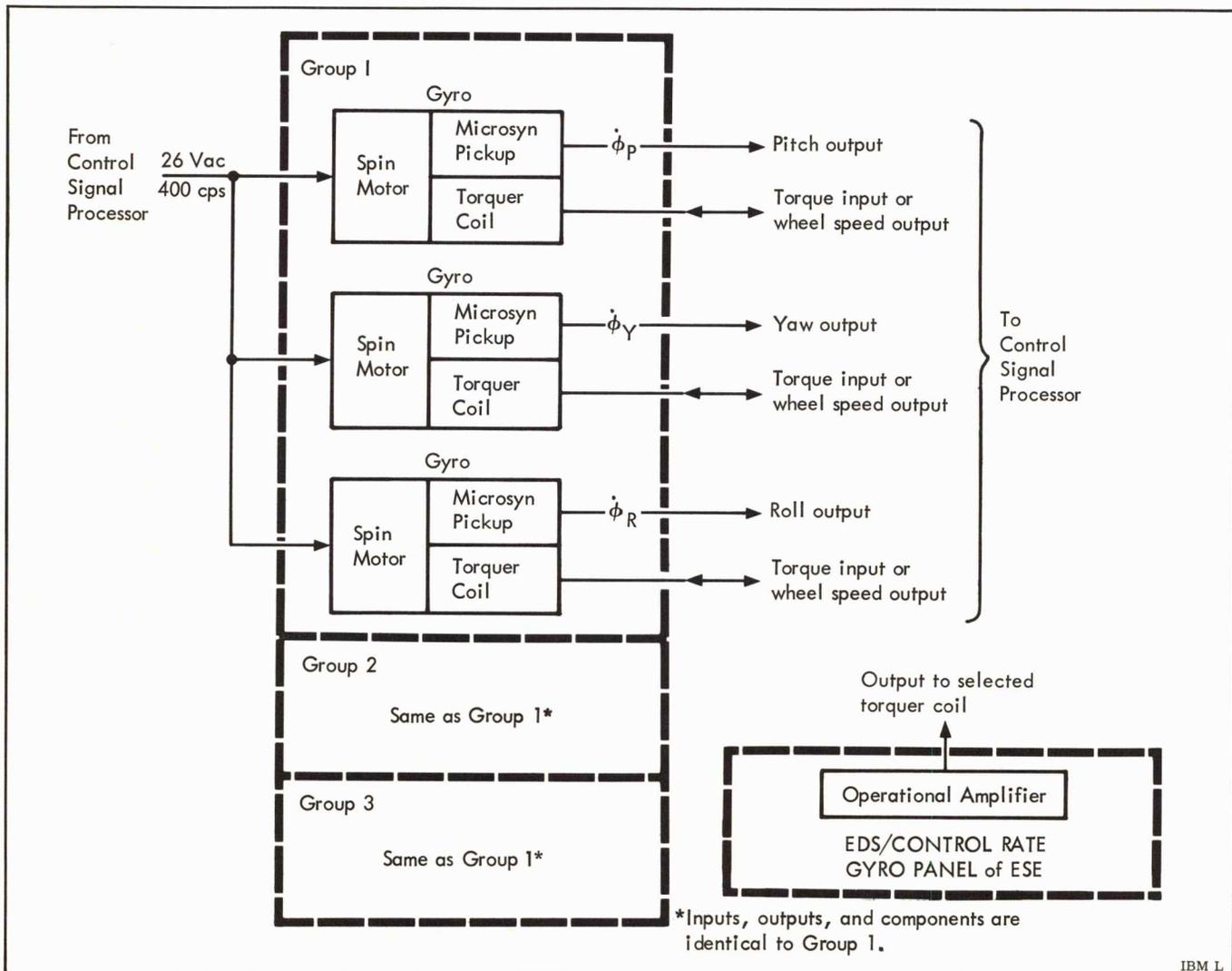


Figure 7-23. Control-EDS Rate Gyro Package (Block Diagram)

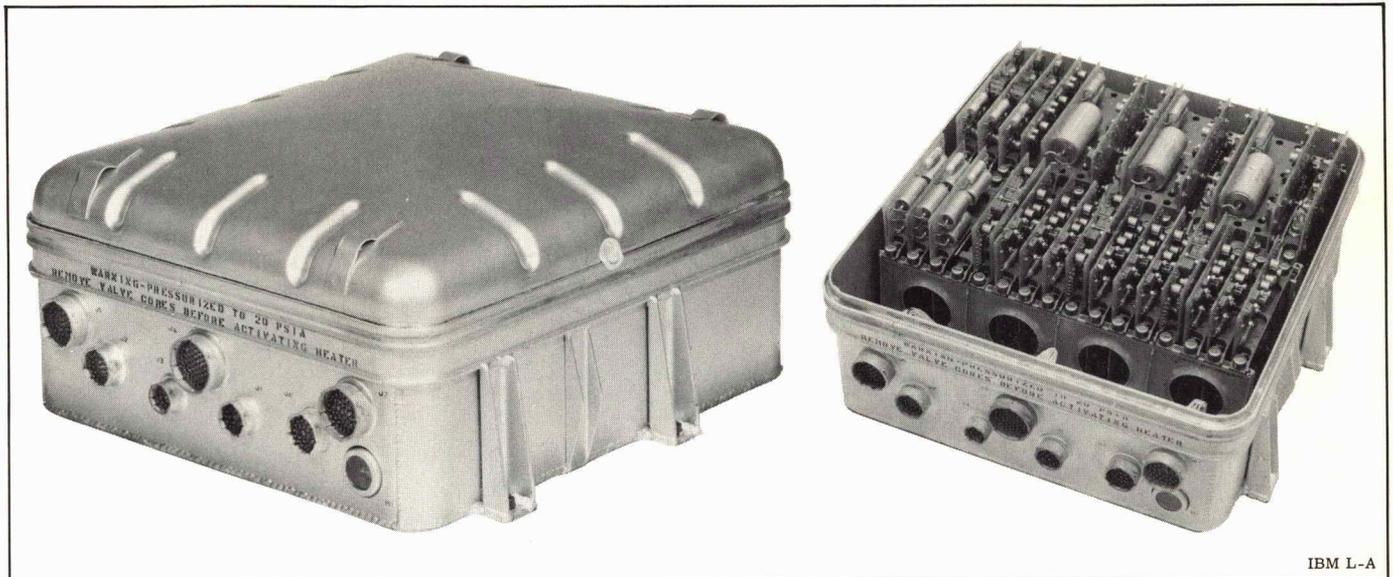


Figure 7-24. Control Signal Processor

switches the "spare" signal into the Control Computer. It is assumed that the spare signal is within tolerance and no further checks or switches are permitted. In ground testing, an optional reset is available.

Each rate switch receives a 400-cycle output from its associated gyro. The switch circuit will energize a relay if the output of the rate signal reaches a predetermined magnitude. This specific amplitude represents a high rate of vehicle movement about a particular axis and beyond which the vehicle is in danger of breaking up. The rate switch output signal is sent to the EDS and DDAS System for appropriate action and monitoring.

Input signals to the wheel speed sensor circuits are proportional to the speed of their respective rate gyros. Any deviation from a preset amount will generate a discrete signal for telemetry and ESE.

The power supply circuits furnish 26 volts, 400 cps to the Control-EDS Rate Gyro Package and to the demodulator circuits in the Signal Processor. These supplies also furnish 60 Vdc and 28 Vdc for internal Signal Processor use. The power supplies and inverters are triple redundant and are arranged in such a manner as to allow for the failure of one supply without any detrimental effects to the Signal Processor operation.

7-13 FLIGHT CONTROL COMPUTER

General Characteristics

The Flight Control Computer, hereinafter referred to as the Control Computer, is shown in

Figure 7-26. It is an analog computer which develops attitude correction commands (ψ), angular change rates ($\dot{\phi}$), and acceleration ($\ddot{\gamma}$) values into APS thruster nozzle and/or engine actuator positioning commands. Table 7-8 lists the physical characteristics of the Control Computer.

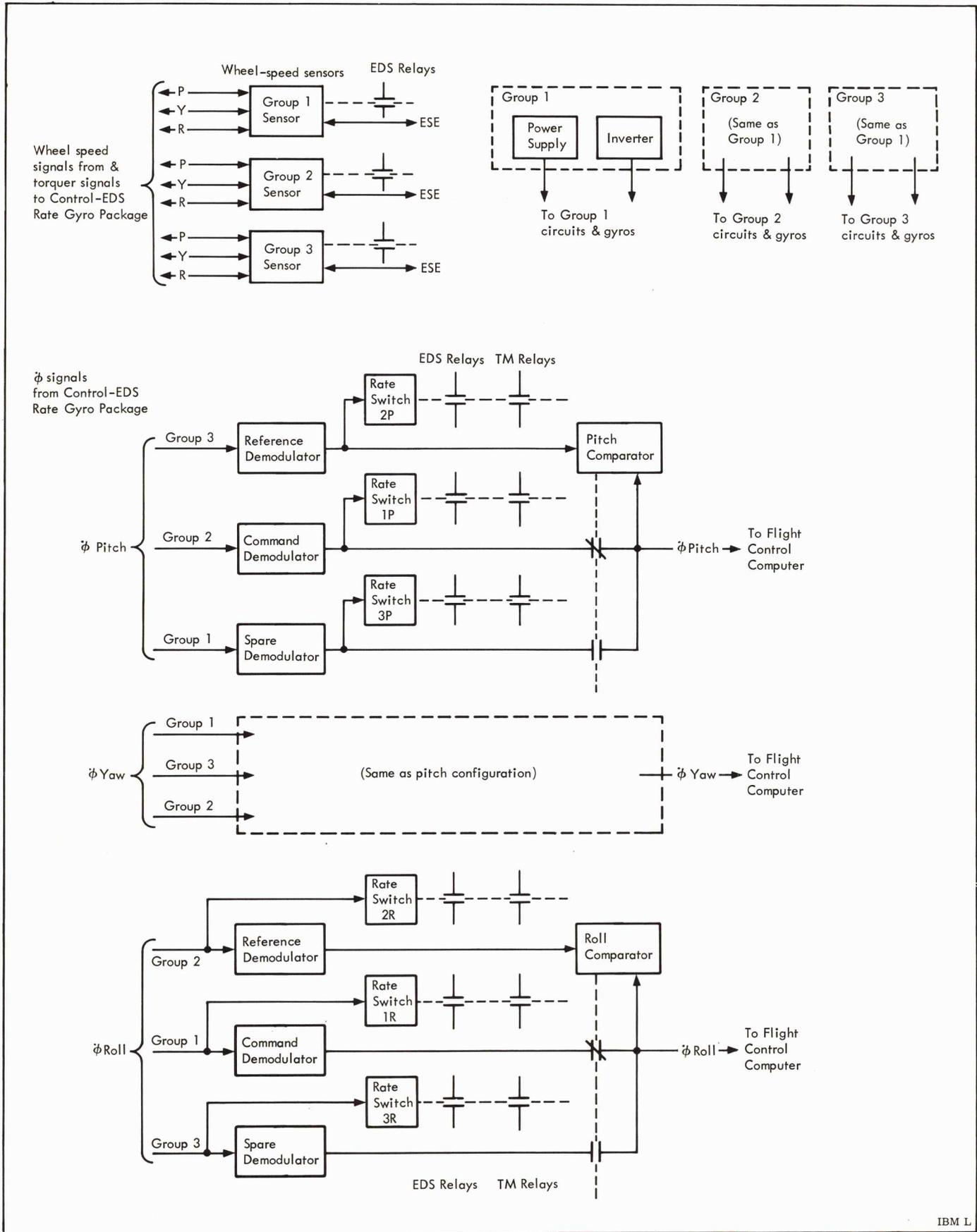
Input signals to the Control Computer include:

- Attitude correction commands (ψ) from the LVDC/LVDA or spacecraft
- Angular change rates ($\dot{\phi}$) from the Control-EDS Rate Gyro Package via the Control Signal Processor
- Lateral acceleration values ($\ddot{\gamma}$) from the Control Accelerometers (Uprated Saturn I only)
- Optional control sensor inputs from other stages of the vehicle
- An electrical feedback signal from the engine actuators (S-IB Stage of the Uprated Saturn I only)

Output signals from the Control Computer include:

- Command signals to the engine actuators (β_C)
- Command signals to the APS thruster nozzles
- Telemetry outputs which monitor internal operations and functions.

Although designed according to the same general scheme, the Uprated Saturn I and Saturn V



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Figure 7-25. Control Signal Processor Block Diagram

Flight Control Computers are somewhat different. The Uprated Saturn I Flight Control Computer contains an extra channel for Control Accelerometer inputs. One type of servo amplifier is used to control the engine actuators of the S1IB Stage, and another type (the same used in Saturn V) controls the S-IVB engine actuators. The engine actuator control loops for the S-IB Stage use electrical feedback.

The Saturn V Flight Control Computer has no channels for Control Accelerometer signals. The same servo amplifiers are used to control the engine actuators for each Stage (S-IC, S-II, and S-IVB).

Table 7-8 Characteristics of the Flight Control Computer

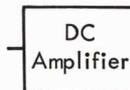
Reference Designation:	602A27
Size:	
Length	28 inches
Width	18.2 inches
Height	19 inches
Weight:	125 pounds
Input Power:	
Voltage	28 ± 4 Vdc
Wattage	150 watts

Flight Phases

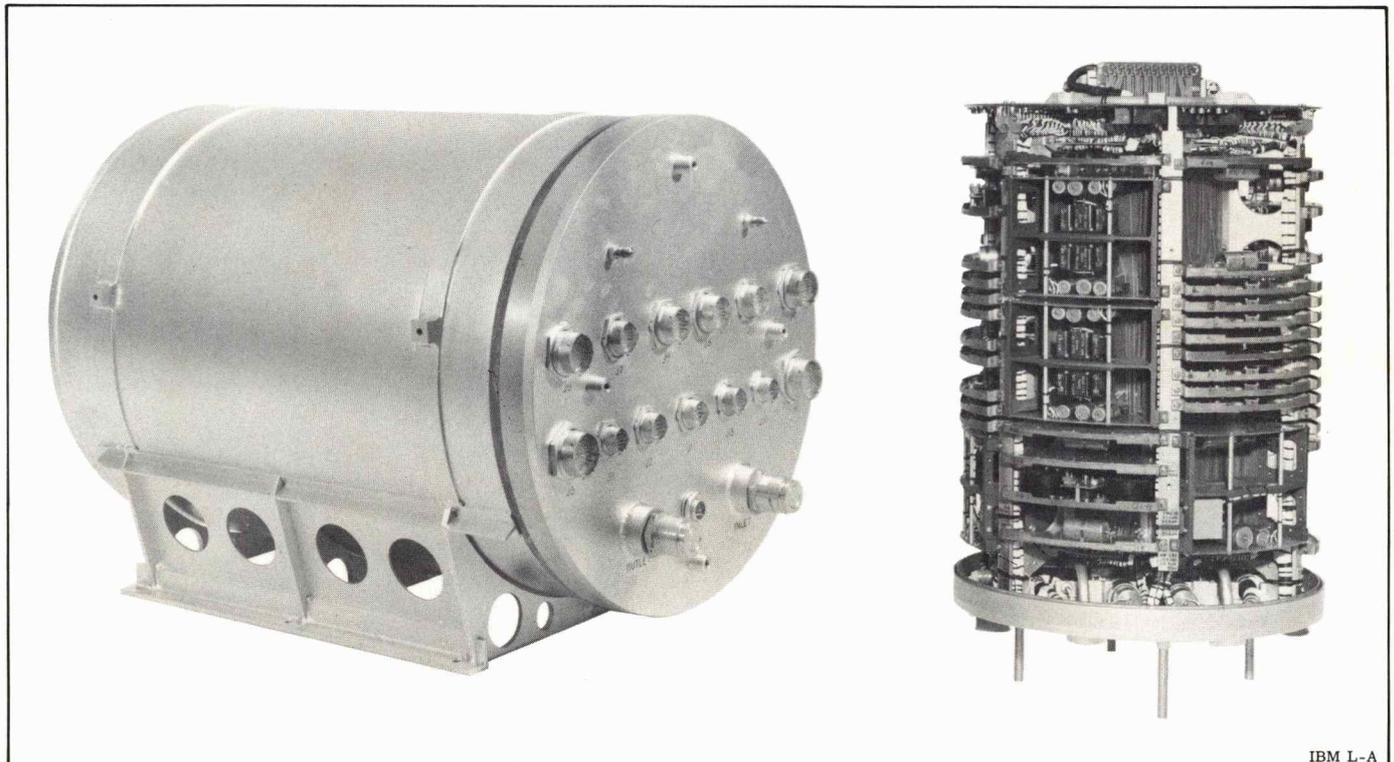
The flight phases (modes) for the Uprated Saturn I Flight Control Computer are referred to as: S-IB burn, S-IVB burn, and S-IVB coast. The Saturn V flight modes are: S-IC burn, S-II burn, S-IVB burn, and S-IVB coast. As mentioned earlier, the S-IVB modes and configuration are very similar for both vehicles.

Operation of the Control Computer is by sequential flight mode and will be presented in that manner. Figures 7-27 and 7-28 are detailed functional block diagrams of the overall Uprated Saturn I and Saturn V Flight Control Computers. Following these figures, are simplified block diagrams of the configuration for each mode (Figures 7-29 through 7-32). An explanation of each flight mode will be found with each figure. For simplicity, the switching logic, redundant lines, test lines, and optional inputs have not been included.

The following blocks are used to represent unique circuits and functions. A description of each is included.



DC amplifier - The Control Computer contains identical dc amplifiers which are used to amplify pitch, yaw, and roll signals (ψ and ϕ). These signals are carried on isolated, balanced lines. To maintain this



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Figure 7-26. Flight Control Computer

isolation and provide maximum amplification (with relatively little distortion), each side of the balanced lines is amplified. The signal passes through a scaling network, referred to as a scaling board, before being applied to the dc amplifier. The scaling board contains feedback and resistive attenuating networks which scale the gain of the inputs to predetermined levels. The scaling boards are not shown in the following figures, and for the purpose of simplicity, should be considered as part of each dc amplifier block.



Filter - The stage-associated filters are located in signal lines throughout the Control Computer. Each filter block represents a low pass filter and an attenuation network. These filters are sometimes referred to as "bending mode filters".

The low pass filter minimizes position error signals which result from physical flexing of the vehicle structure. This flexing occurs when the vehicle frame vibrates at its resonant frequency during high thrust loadings.

The low pass filter output is coupled through an attenuation network which controls the amplitude of the signal in relation to the phase and time of the flight. Initially, either maximum or minimum attenuation is provided by parallel resistors. As the flight progresses, "switch point" relay signals add or remove resistors from the network to change the amount of attenuation. The amount of attenuation and the time relationship is mission related and will vary accordingly. Refer to the flight sequence tables in Section VI for switch point times. It should be noted that some filters, depending upon their function, have fixed attenuation and are not subject to switch point sequencing.



Control Attenuation Timer - The CAT is a special attenuating device used only on the Uprated Saturn I Flight Control Computer. Basically, it consists of two motor-driven potentiometers which vary the two lateral acceleration signals (\dot{y}) as they enter the control computer. At T + 30 seconds the CAT provides maximum signal attenuation. From T + 30 to T + 60, the attenuation decreases to its minimum. At T + 80 the attenuation again increases until the maximum is reached at T + 110.



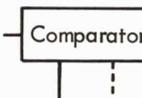
Servo Amplifiers - The Uprated Saturn I Flight Control Computer uses two types of servo amplifiers to develop drive signals for the various pitch and yaw actuators. Eight 12-milliampere servo amplifiers are used for the S-IB burn mode. During S-IVB burn and throughout the Saturn V powered flight, 50-milliampere servo amplifiers are used. The amplifiers, themselves, contain several stages of amplification, feedback circuits, and power supplies.



Spatial Amplifier - The Control Computers contain 3 groups of triple redundant spatial amplifiers. These amplifiers develop control signals (ON - OFF) for the APS thruster nozzles. The amplifier algebraically combines the attitude and angular rate signals and generates a proportionally balanced output signal when a predetermined threshold level of input has been reached. This level is established by an internal, time-delayed feedback circuit. The output signal, through relay drivers, is used to pick relays in two Control Relay Packages. These relays are used to open fuel and oxidizer valves for the APS thruster nozzles.



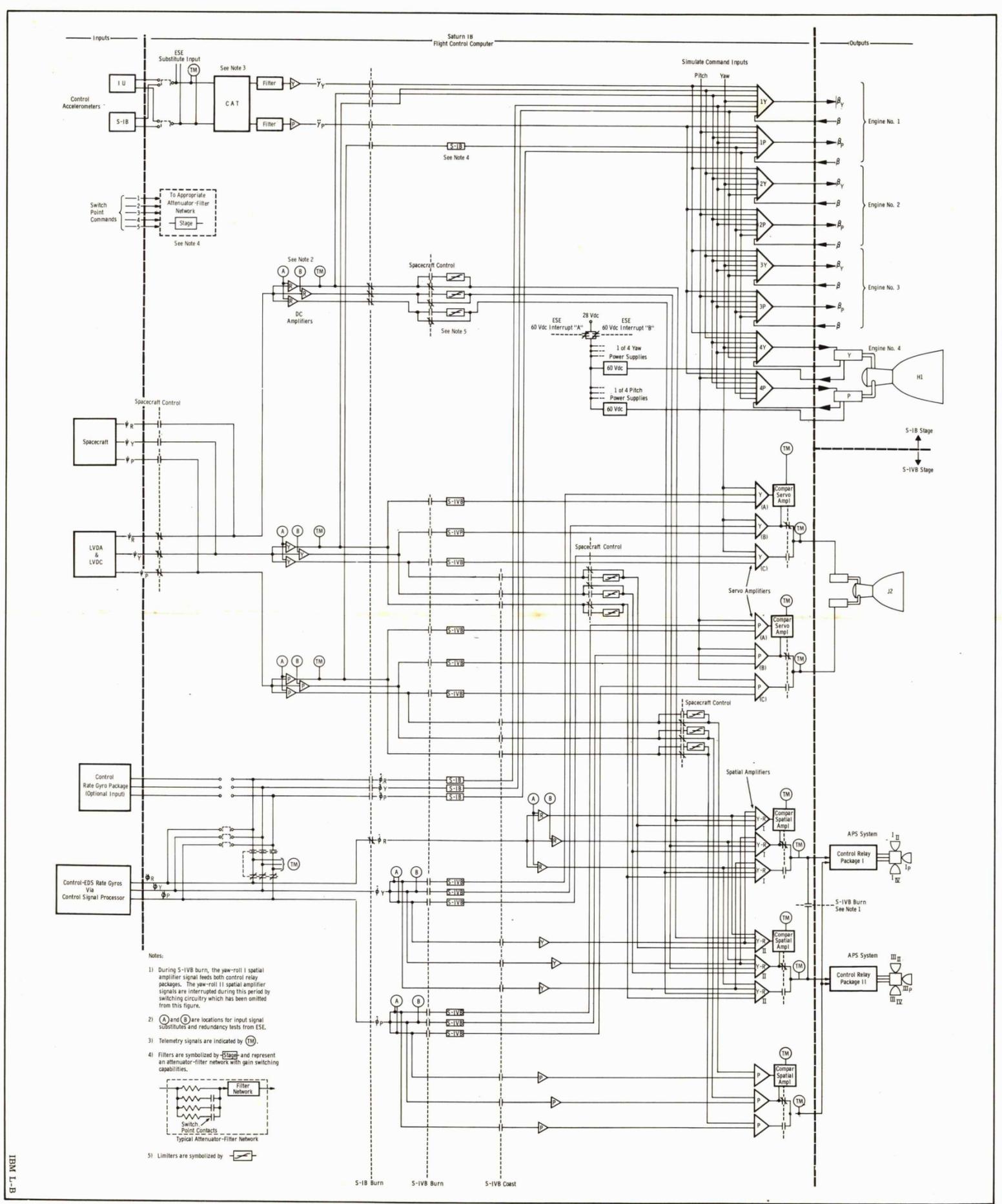
Limiter - These circuits are switched into the attitude command signal (ψ) lines when the vehicle is under spacecraft command (coast mode only). The purpose of the limiters is to prevent overcorrection of the S-IVB Stage attitude as a result of large spacecraft attitude error signals.



Comparator - These circuits monitor triple redundant signal and command lines. A reference signal is compared with a normally-used command line. If these two vary, a third (spare) signal is then used as the command output.

7-14 ENGINE SERVO ACTUATORS

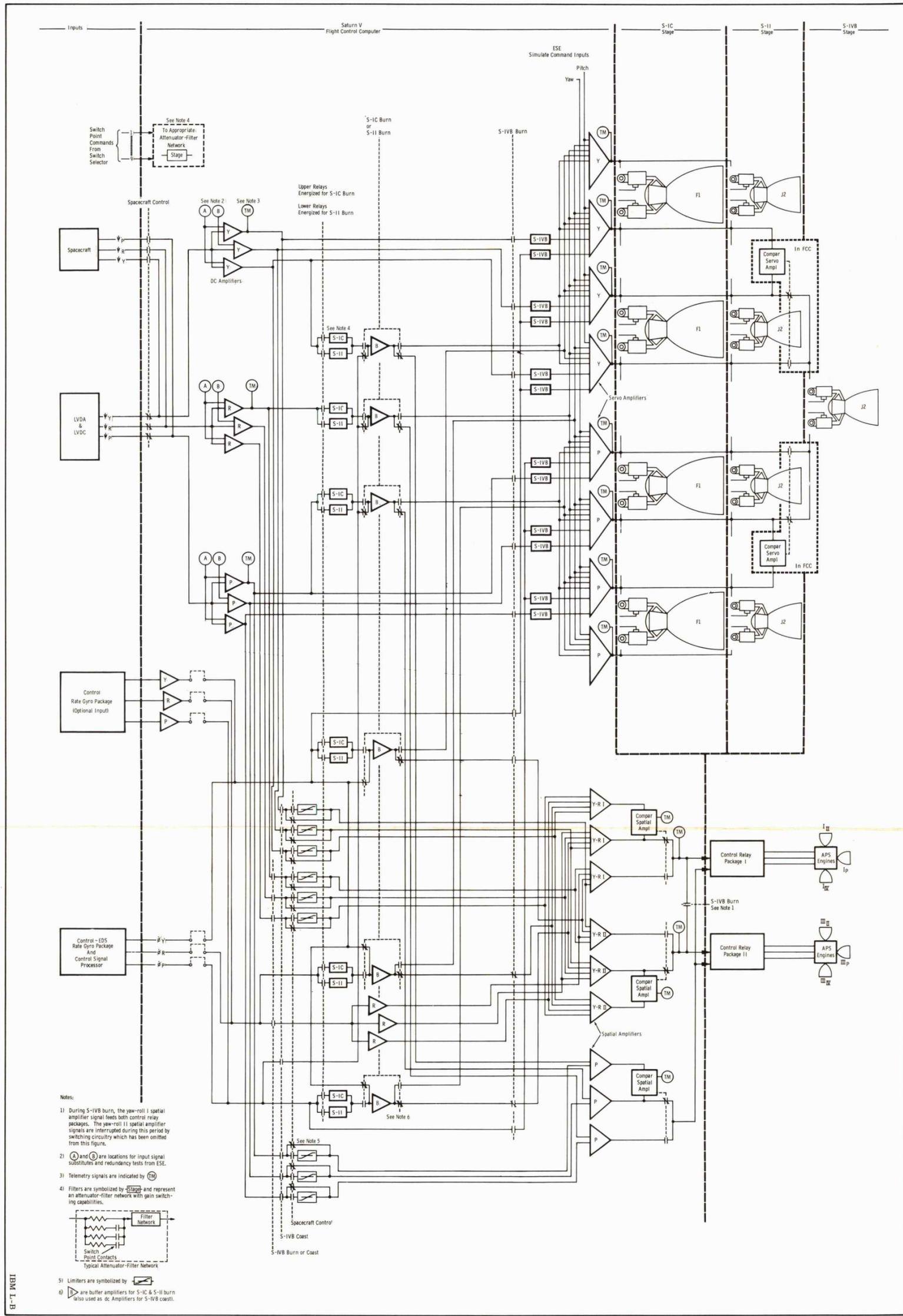
The angular direction of the thrust vector of the Uprated Saturn I and Saturn V engines is controlled by swivelling the gimbal-mounted propulsion engines. This control is obtained by linear hydraulic servo-actuators. Figure 7-33 shows a typical actuator system used in the Uprated Saturn I and Saturn V vehicles.



- Notes:
- 1) During S-1VB burn, the yaw-roll I spatial amplifier signal feeds both control relay packages. The yaw-roll II spatial amplifier signals are interrupted during this period by switching circuitry which has been omitted from this figure.
 - 2) (A) and (B) are locations for input signal substitutes and redundancy tests from ESE.
 - 3) Telemetry signals are indicated by (TM).
 - 4) Filters are symbolized by and represent an attenuator-filter network with gain switching capabilities.

Typical Attenuator-Filter Network
 - 5) Limiters are symbolized by

Updated Saturn I Flight Control Computer Functional Block Diagram
Figure 7-27



- Notes:
- 1) During S-1VB burn, the yaw-roll I spatial amplifier signal feeds both control relay packages. The yaw-roll II spatial amplifier signals are interrupted during this period by switching circuitry which has been omitted from this figure.
 - 2) A and B are locations for input signal substitutes and redundancy tests from ESE.
 - 3) Telemetry signals are indicated by TM.
 - 4) Filters are symbolized by and represent an attenuator-filter network with gain switching capabilities.
- Typical Attenuator-Filter Network
- 5) Limiters are symbolized by
 - 6) are buffer amplifiers for S-1C & S-1I burn (also used as dc. Amplifiers for S-1VB coast).

Figure 7-28
Saturn V Flight Control Computer Functional Block Diagram
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The actual arrangement of the actuators for the multi-engine stages and the single-engine S-IVB Stage of the Saturn Launch Vehicle is shown in Figures 4-1 and 4-2. Independent hydraulic systems for each gimballed engine are used to provide the following advantages:

- Flight system can be qualified by single-engine test.
- One system can be verified at a time.
- Malfunction and replacement can be isolated to 1 system.
- Post flight performance comparisons are easily accomplished
- Redundant capability.

For the multi-engine vehicle stages, the redundant capability is further increased by sizing the swivel range so that, despite the failure of one control engine, the remaining gimballed engines can maintain satisfactory control. The failure modes may be:

- Loss of thrust (engine out).
- Loss of hydraulic pressure (hydraulic system failure).
- Any actuation malfunction caused by servo-valve failure, failure in signal lines, or Flight Control Computer output stage.

The transformation of the electrical signal (β_c) from the Control Computer, which commands the angular deflection (β) of the engine into a linear displacement, is performed by servo actuator assemblies. The servo valves are four-way, flow-control devices with internal dynamic pressure feedback and mechanical feedback of the actuator piston position.

In the S-IB Stage servo actuators only, an electrical potentiometer is used as a feedback transducer. It applies a " β " feedback signal to the Control Computer servo amplifier. The mechanical feedback provides higher reliability, which results primarily from the elimination of the feedback potentiometer and its associated wiring, connections, and power supply, and reduction in corresponding failure modes. Further, the mechanical feedback has an important advantage in that the actuator goes to a null position ($\beta = 0$) if the " β_c " command signal from the Control Computer fails in the zero level.

7-15 AUXILIARY PROPULSION SYSTEM

The attitude control engines of the S-IVB Stage Auxiliary Propulsion System are used to control the

vehicle attitude in roll during the powered flight phases and in pitch, yaw, and roll during coast flight phases.

These engines are located in 2 modules, 180 degrees apart on the aft end of the S-IVB Stage. One module is located over position I and the other over position III as shown in Figure 7-34. Each module has three hypergolic attitude control engines (thruster nozzles).

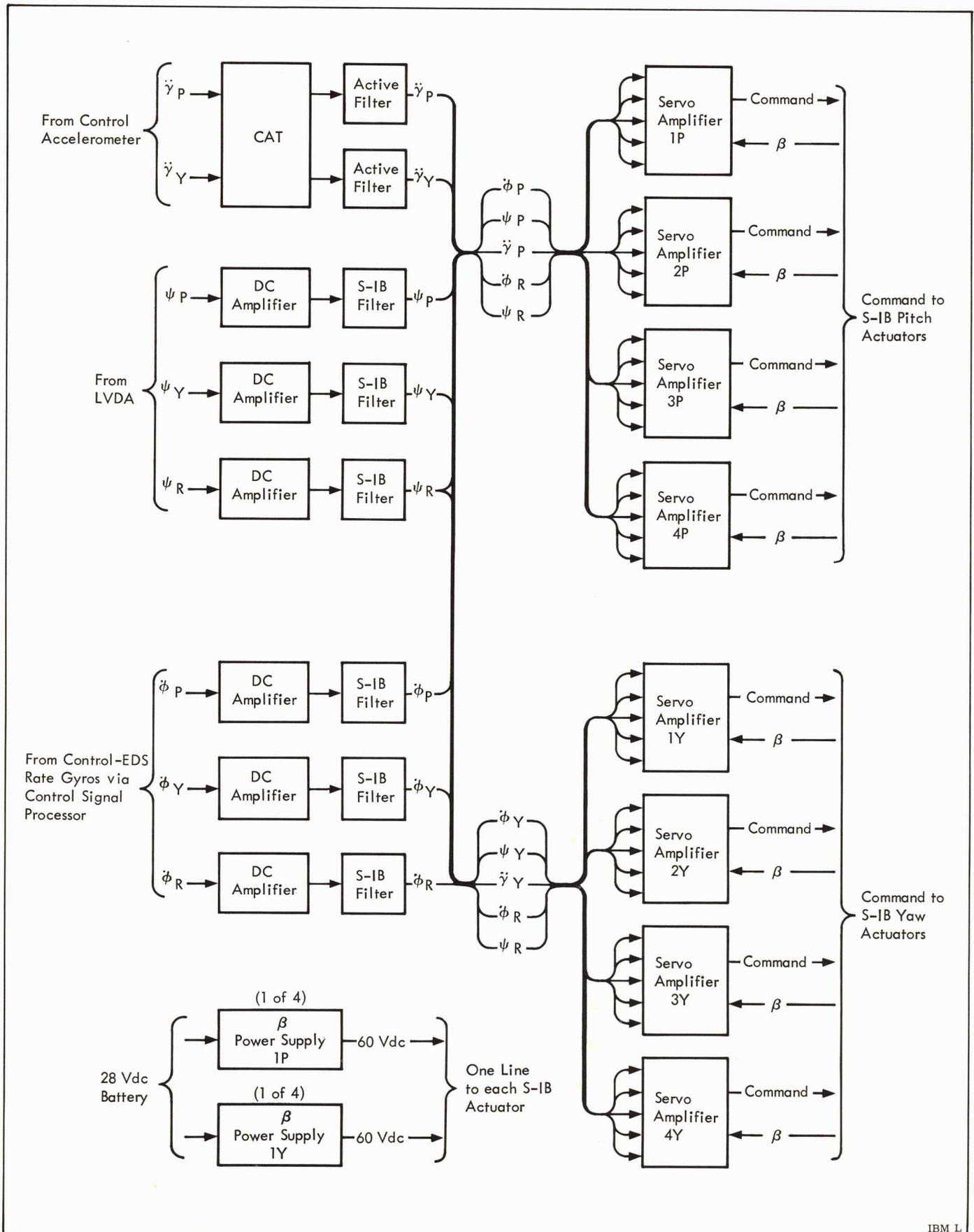
When fired, the nozzles produce torques about the center of gravity of the vehicle. They are controlled in a pulse-type manner - ON (full thrust) or OFF - by the spatial amplifiers in the Flight Control Computer. The attitude control engines are turned ON when the input signal to the spatial amplifier exceeds certain limits and turned OFF when the input signal falls below a set threshold.

When the Instrument Unit is controlling the vehicle attitude, the error information is supplied by the LVDC through the LVDA. When the Spacecraft is controlling the vehicle attitude error, information is obtained from the spacecraft over spacecraft/IU interface lines. It should be noted that attitude error limits of ± 2.5 degrees in pitch and yaw and ± 3.5 degrees in roll are imposed on the attitude error signals. These error signals are used only by the Auxiliary Propulsion System. The limits are imposed within the LVDC flight program for IU-generated attitude error signals and by the IU Control Computer limiter circuits for spacecraft-generated attitude error signals.

Spatial Amplifiers

Within the Control Computer, attenuator-filter networks adjust the gain coefficients (a_0 and a_1) to the proper value. The spatial amplifiers sum the input signals (ψ and ϕ) and compare the resulting signal level with a predetermined threshold feedback level. When the combined control signals exceed the limits set by the threshold, a switching circuit energizes the proper relays in the Control Relay Package, which, in turn, operate the valves of the corresponding thrust nozzles.

The control scheme generates thrust pulses of variable duration (at changing intervals) which are a function of the magnitude of the input signals. The pulse duration is controlled by delayed feedback circuits within the spatial amplifiers. Figure 7-34 shows the connection of the control signals via the spatial amplifiers to the Control Relay Packages.



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Figure 7-29. Flight Control Computer Configuration for S-IB Burn Mode (Uprated Saturn I)

◀ S-IB BURN MODE

Input signals from the LVDA (ψ) and Control Signal Processor (ϕ) pass through dc amplifiers and stage-associated filters before being summed in the servo amplifiers. Control Accelerometer signals ($\dot{\gamma}$), which are used only during this flight phase, are varied by the Control Attenuation Timer (CAT). These acceleration signals are then routed to their respective servo amplifiers. The power supplies, shown in the figure, furnish a 60-volt dc reference voltage to potentiometers on the S-IB actuators. Each potentiometer produces a signal feedback voltage which is proportional to its associated engine actuator position. This feedback from each actuator, called a Beta (β) signal, is the fifth input to each of the S-IB servo amplifiers.

The CAT block contains two motor-driven potentiometers which adjust the analog $\dot{\gamma}$ signals in a time-related, non-linear manner. The CAT program is activated 30 seconds into the flight and is completed approximately 80 seconds later (since this is the time period of maximum lateral acceleration and turbulence). The adjusted signals are then filtered and amplified before being routed to their respective servo amplifiers where they are algebraically summed with the ψ and ϕ signals.

After being amplified by the dc amplifiers, the analog ψ and ϕ pitch, roll, and yaw signals are filtered and attenuated before being applied as servo amplifier inputs. The filter blocks adjust the signal amplitude by relay-switched attenuation networks called switch points. Three switch point commands are issued during this burn mode with a maximum of five commands for the complete Uprated Saturn I flight.

Eight servo amplifiers are used for this flight mode – four for pitch and four for the yaw maneuvers. Since roll maneuvers are a function of pitch and yaw, the roll commands are applied to all 8 servo amplifiers. The S-IB servo amplifiers are often referred to as 12-milliampere servos and are only associated with the S-IB Stage configuration. The S-IB servo amplifier/actuator combinations use an electrical feedback signal scheme, whereas all other Saturn Stages rely on mechanical feedback within the actuator itself.

S-IC AND S-II BURN MODES ▶

The S-IC and S-II configurations are very similar to that of the S-IB burn mode in the Uprated Saturn I Flight Control Computer. The most significant change between the two control schemes is that lateral acceleration measurements and actuator feedback signals are not used in computing the engine actuator commands in Saturn V Vehicles.

The attitude control signals (ψ) pass through dc amplifiers before being conditioned by filters. Switching circuits, determined by the particular mode of flight (S-IC or S-II), route the ψ and ϕ signals to their respective filters. From the filter networks, the signals pass through another stage of dc amplification (buffer) before being processed by their respective servo amplifiers. As in the S-IB mode, the roll signals (ψ_R and ϕ_R) are routed to all eight servo amplifiers.

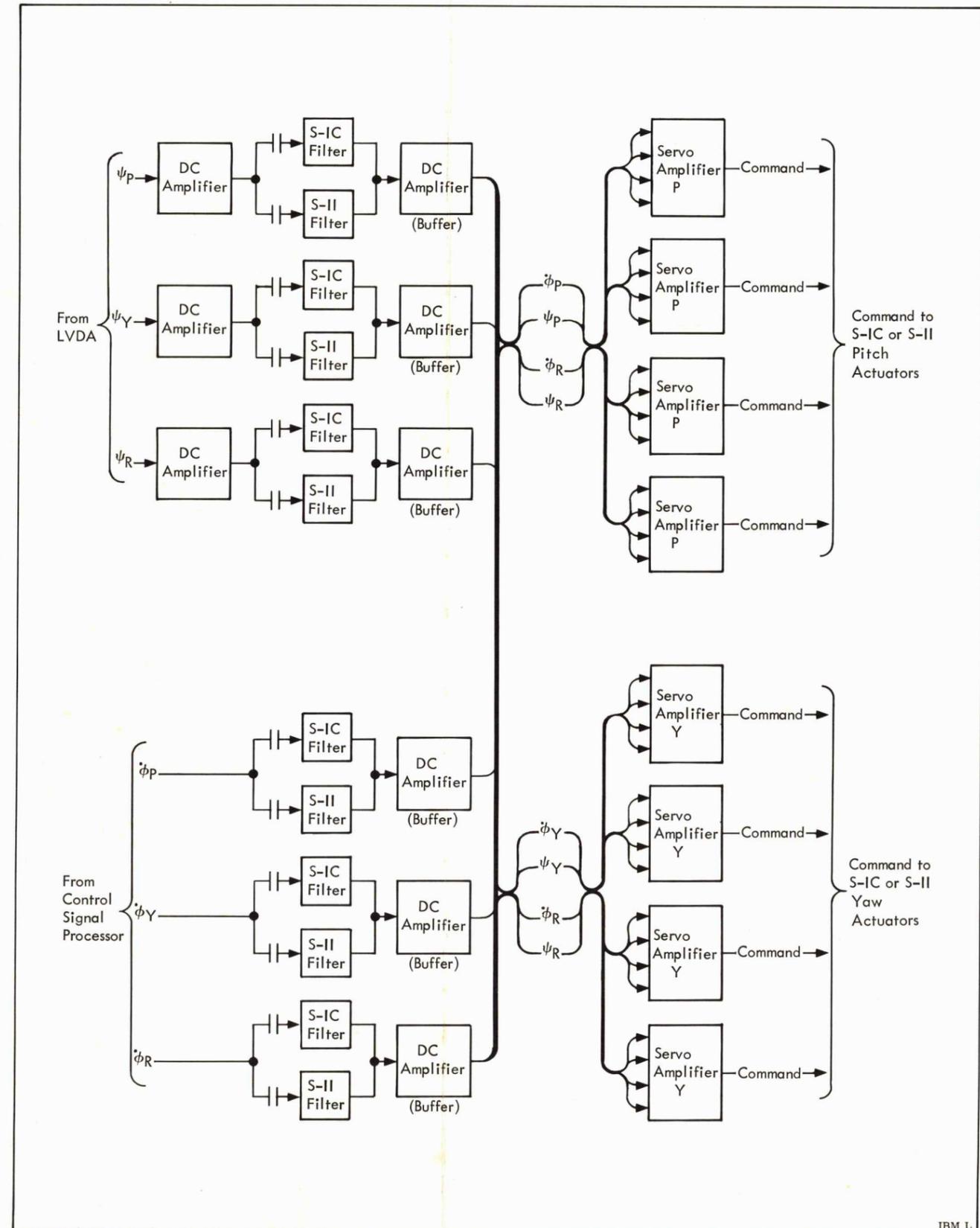
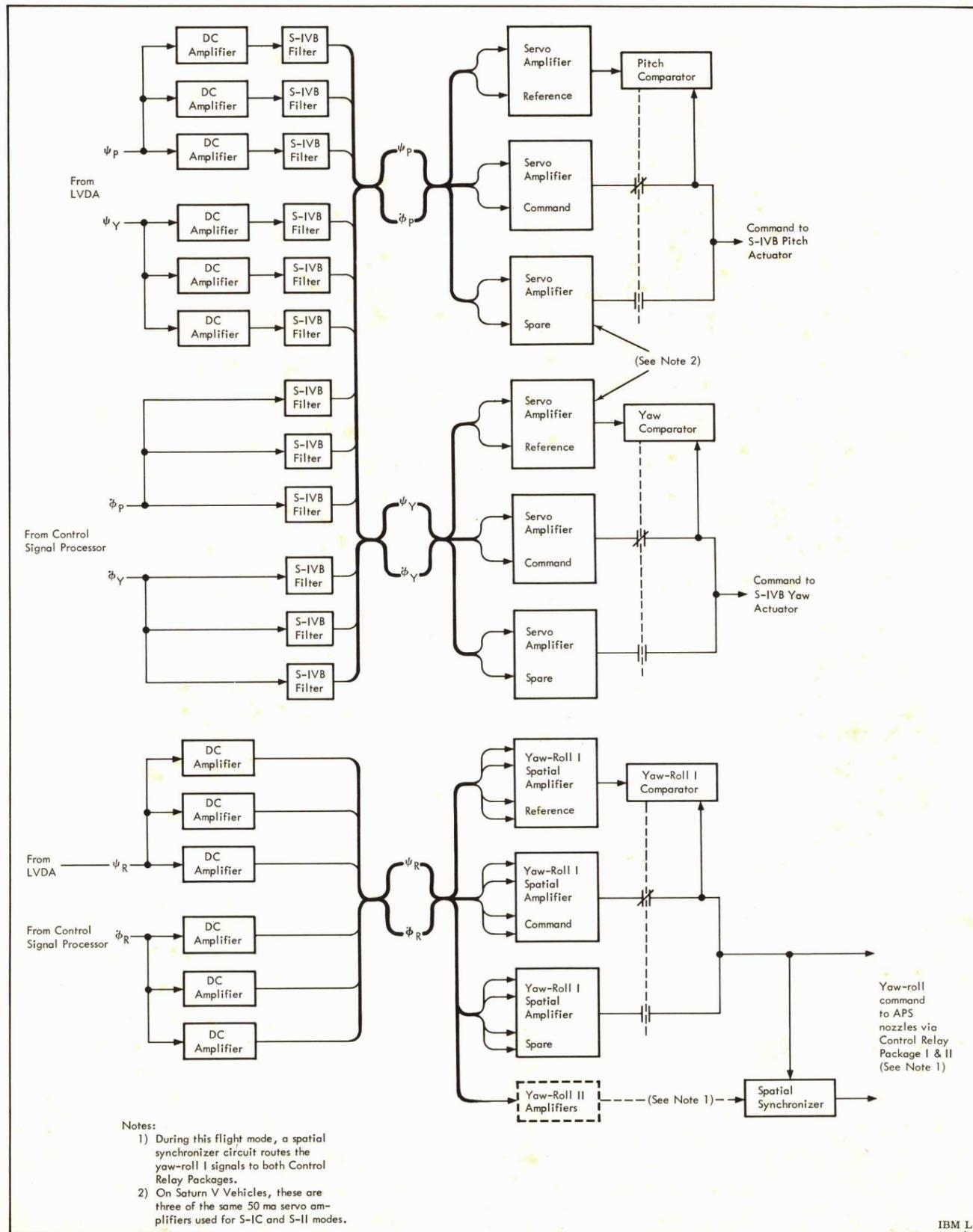


Figure 7-30
Flight Control Computer Configuration for S-IC and S-II Burn Modes (Saturn V)



S-IVB BURN MODE

The attitude error (ψ) and attitude rate ($\dot{\phi}$) signals are amplified and/or filtered before being routed to their respective servo or spatial amplifiers.

Since the single J-2 engine in the S-IVB Stage cannot perform roll maneuvers, the roll signals (ψ_R and $\dot{\phi}_R$) are routed to yaw-roll spatial amplifiers. A special circuit, the spatial synchronizer, switches the yaw-roll I output command to both Control Relay Packages and interrupts the output from the yaw-roll II spatial amplifiers.

All output signal paths are triple redundant and utilize comparator circuits to maintain reliable output commands. The command and reference signals are continually compared, and if a predetermined difference occurs, the spare signal is switched into the command output path.

In this flight mode, one significant difference should be noted between the Uprated Saturn I and Saturn V Flight Control Computer configurations. As shown in Figure 7-27, the Uprated Saturn I Flight Control Computer uses 8 servo amplifiers for the S-IB burn mode and 6 different servo amplifiers for the S-IVB burn mode. In the Saturn V control computer (see Figure 7-28), 6 of the 8 servo amplifiers used for the S-IB burn mode configuration. The S-IB servo amplifiers are rated at 12 milliamperes and use electrical feedback, whereas the S-IVB servo amplifiers are rated at 50 milliamperes and have no feedback. All servo amplifiers are rated at 50 milliamperes in the Saturn V Flight Control Computer.

S-IVB COAST MODE

During this flight mode, vehicle attitude is maintained solely by the Auxiliary Propulsion System. The roll function utilizes the same Control Computer circuits and APS hardware as used during the S-IVB burn mode. Yaw functions also become an input to the yaw-roll spatial amplifiers for this flight phase. However, pitch maneuvers require another triple set of spatial amplifiers. The pitch outputs are compared in exactly the same manner as the yaw-roll outputs. It should be noted that no filters are utilized in this mode.

Commencing with vehicles AS-206 and AS-501, limiter circuits will be included in the coast mode circuitry. The limiters are automatically switched into the attitude command signal (ψ) lines whenever the vehicle is under spacecraft control. The purpose of the limiters is to prevent overcorrection of the S-IVB Stage attitude as a result of any large spacecraft attitude error signals.

While not shown in this figure, the Saturn V pitch and yaw $\dot{\phi}$ signals use the same dc amplifier blocks identified in the S-IC/S-II configuration as buffer amplifiers. They are dual purpose amplifiers with relay-switched inputs. See Figure 7-28 for their functional layout within the Control Computer.

Figure 7-31

Flight Control Computer Configuration for S-IVB Burn Mode (Uprated Saturn I and Saturn V)

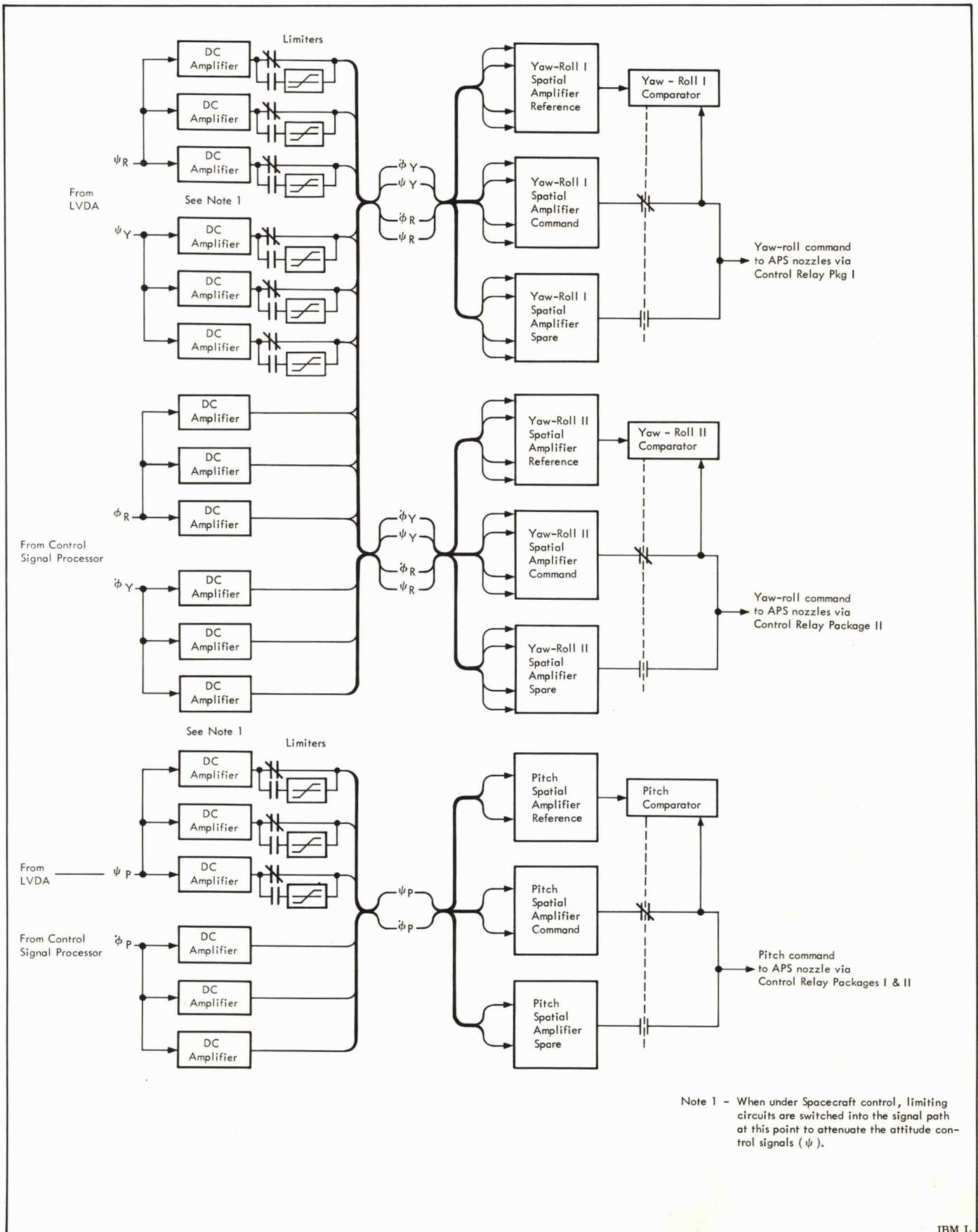


Figure 7-32. Flight Control Computer Configuration for S-IVB Coast Flight
(Upgraded Saturn I and Saturn V)

The spatial synchronizer, shown in the figure, allows the yaw-roll I spatial amplifier to signal both Control Relay Packages during S-IVB burn mode.

Control Relay Package

Each Control Relay Package consists of 12 miniature double-pole, double-throw relays. Two such packages are used to control the S-IVB attitude control engine valve coils. These valve coils are an integral part of the engine and control the fuel and oxidizer valves. The relays are driven in groups of

eight from the three S-IVB attitude control spatial amplifiers in the Control Computer. Figure 7-35 shows the arrangement of the relays, valve coils, and quad-redundant fuel and oxidizer valves associated with one Control Relay Package.

As an example, if the attitude control command requires that nozzle I_{II} be turned ON, the spatial amplifier energizes coils K1 through K4, which closes the associated contacts (1, 1', etc.). Valve coils 1, 1', etc., are energized and open fuel valves 1, 2, 3,

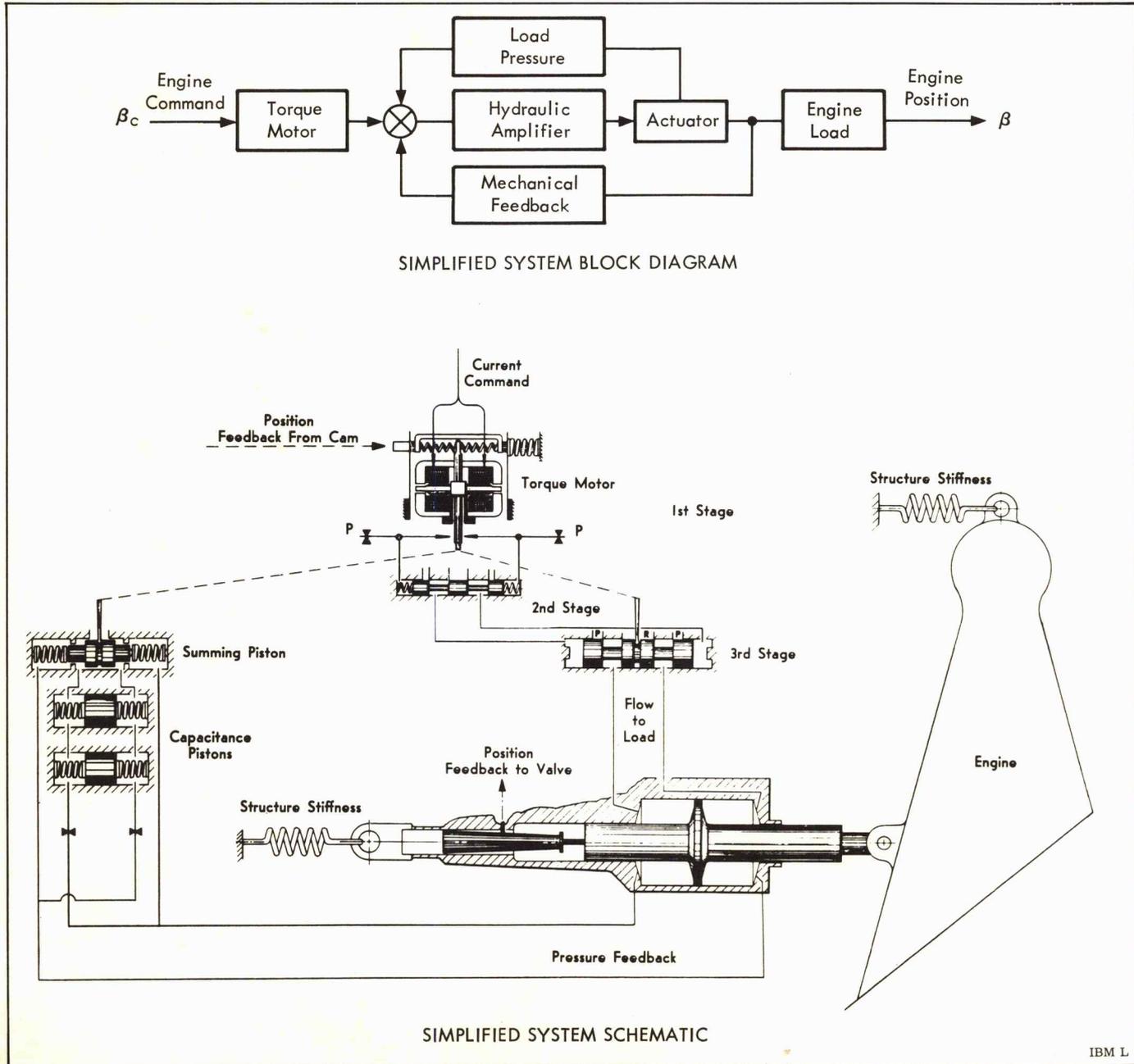


Figure 7-33. Typical Hydraulic Actuator System

and 4 and oxidizer valves 1' and 2', 3' and 4' in the quad-valve network.

The control relay package was designed to take advantage of the redundant-valve configuration by providing failure isolation from the predominant modes of relay failure (open-circuited coils, failure-to-make contacts, and welded contacts).

This relay redundancy can be shown by considering relay 1 as an example. When relay coil K1 is energized, it closes contacts 1 and 1' which causes fuel valve 1 and oxidizer valve 1' to be open. An open in coil K1 or a failure of contacts 1 and 1' to close results in no operation of fuel valve 1 and oxidizer valve 1'. However, this does not cause a failure of the attitude control system, since the quad-redundant valves provide an operative flow path through valves 2, 4 and 2', and 4'. If, on the other hand, either or both sets of contacts of relay 1 should weld, or otherwise become permanently closed, fuel valve 1 and oxidizer valve 1' would be open. However, control of fuel and oxidizer would be maintained by valves 3 and 3', respectively.

The Control Relay Package was introduced into the design of the S-IVB attitude control system to improve the interstage cabling design between the IU Control Computer and the S-IVB valve coils by reducing the current requirements from 12 amperes to 200 milliamperes. Therefore, the Control Relay Packages save about 100 pounds of cabling and reduce the Control

Computer spatial amplifier's power requirements by switching the power to the valve coils in the S-IVB Stage.

7-16 SWITCH SELECTOR, MODEL II

The Switch Selector, Model II, shown in Figure 7-31, is the connecting link between the LVDC/LVDA (which generates flight sequence commands) and the circuitry in a vehicle stage where the command is to be executed.

Table 7-9 lists the characteristics of the IU Switch Selector. Function and circuit description has been previously described in Section VI of this manual.

Table 7-9 Switch Selector (Model II)
Characteristics

Reference Designation:	603A17
Size:	
Length	12.5 inches
Width	8.5 inches
Height	5.5 inches
Weight:	20 pounds
Input Power:	1.9 to 17 watts

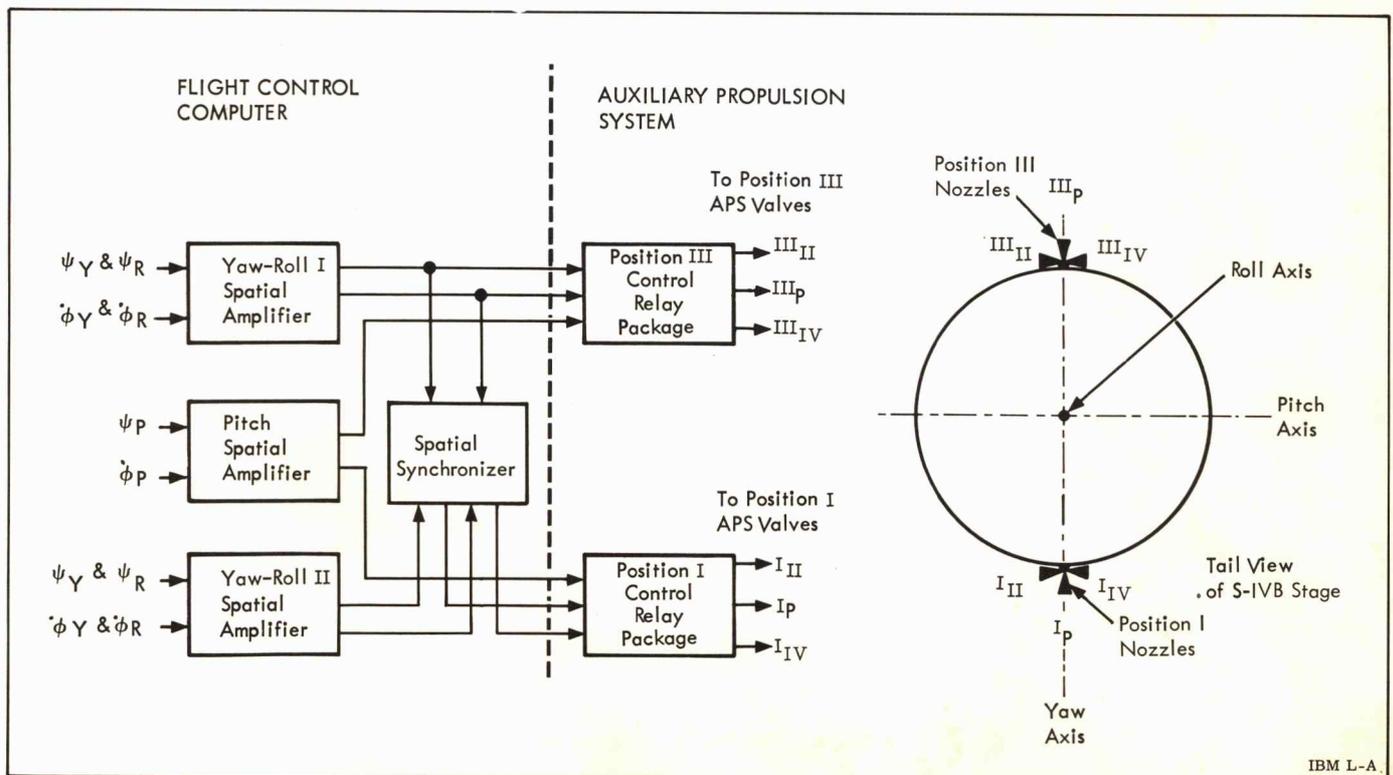


Figure 7-34. Auxiliary Propulsion System Block Diagram

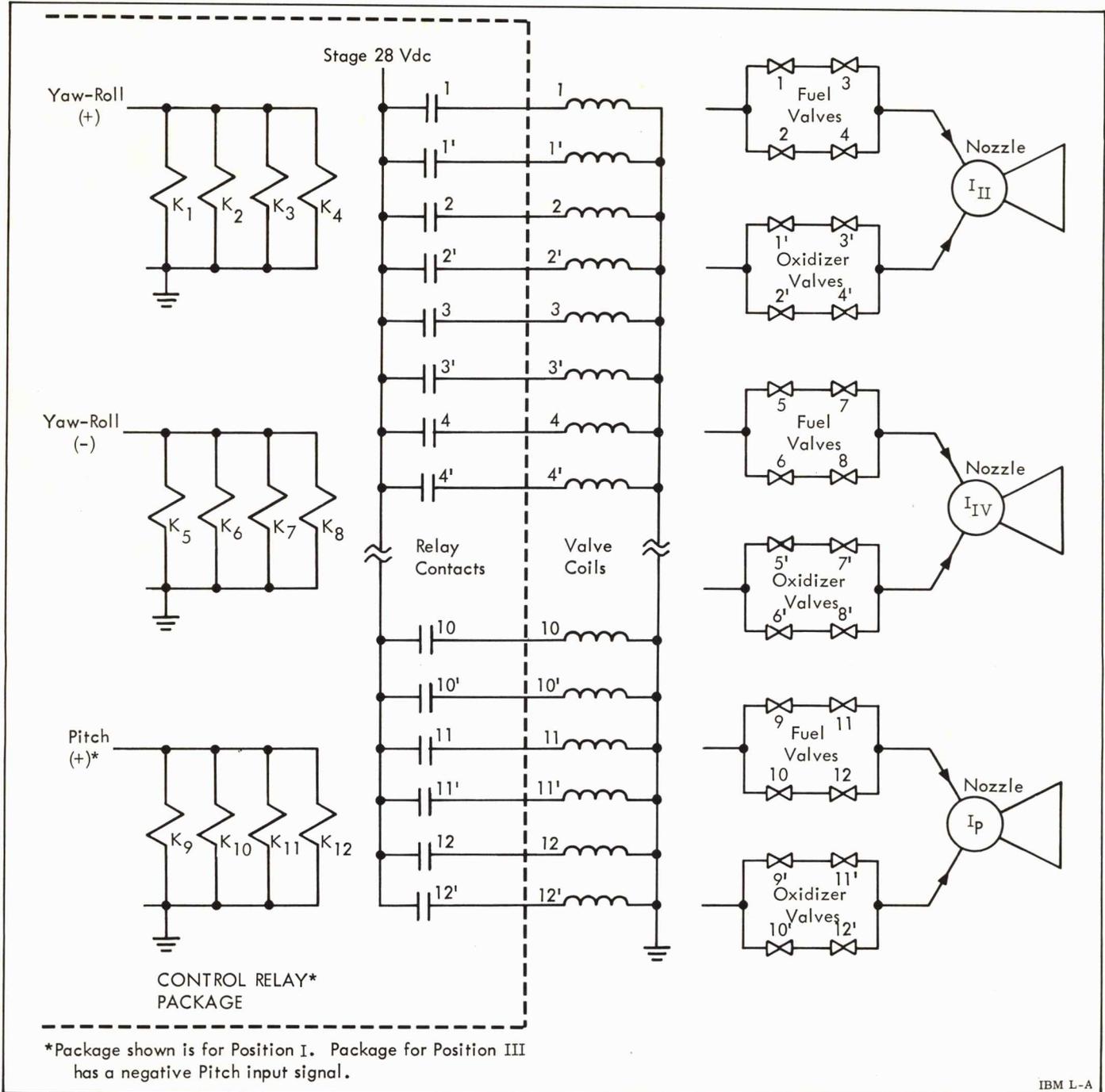


Figure 7-35. Control Relay Package and Quad-Redundant Valves

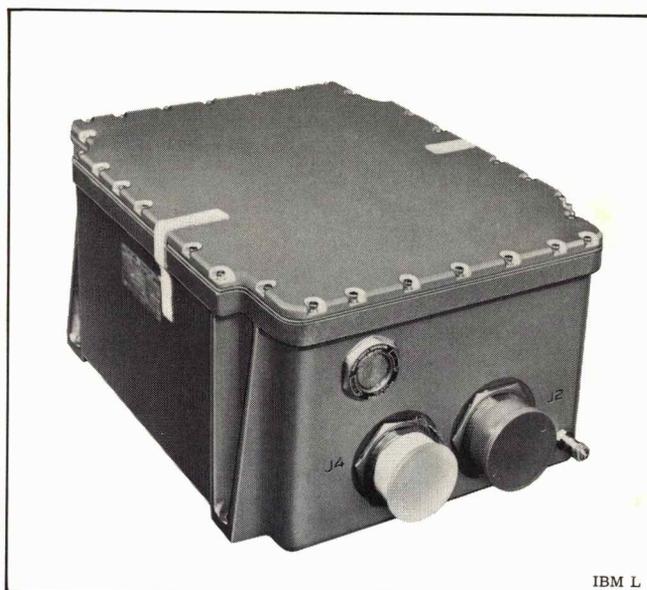


Figure 7-36. Switch Selector, Model II

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Space Systems Center
Huntsville, Alabama

Printed in USA

