Report No. ATR-74(7341)-1

DESCRIPTION OF THE ATTITUDE CONTROL, GUIDANCE AND NAVIGATION SPACE REPLACEABLE UNITS FOR AUTOMATED SPACE SERVICING OF SELECTED NASA MISSIONS

Prepared by V. A. Chobotov

Mission Analysis Department
Guidance & Flight Dynamics Subdivision
Guidance & Control Division
Engineering Science Operations

5 APR 1974

Prepared for

OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Systems Engineering Operations
THE AEROSPACE CORPORATION
El Segundo, California

Contract No. NASW-2575

(NASA-CR-139589) DESCRIPTION OF THE ATTITUDE CONTROL, GUIDANCE AND NAVIGATION SPACE REPLACEABLE UNITS FOR AUTOMATED SPACE SERVICING OF (Aerospace Corp., El Segundo, Calif.) 42 p HC $5.25 CSCL 17G G3/21

N74-32098

Unclas
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Prepared by

V.A. Chobotov
Mission Analysis Department

Approved by

H.K. Karrenberg, Head
Mission Analysis Department
Guidance & Flight Dynamics Subdivision
Guidance & Control Division
Engineering Science Operations

R.R. Wolfe
NASA Study 2.1 Director
Advanced Mission Analysis Directorate
Advanced Orbital Systems Division
Systems Engineering Operations

FOREWORD

Study 2.1, Operations Analysis, has been performed under the direction of Mr. V. N. Huff, NASA Headquarters, Washington, D. C., Code MTE, Contract No. NASW-2575.

ABSTRACT

Attitude control, guidance and navigation performance requirements are examined for selected NASA space serviceable mission spacecraft. Control elements (sensors, momentum exchange devices and thrusters) are described which can be used to define space replaceable units (SRU's). A number of SRU's are developed and their reliability block diagrams presented. An assignment of the SRU's is made to define a set of feasible space serviceable spacecraft for the missions of interest.

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I. INTRODUCTION

This report summarizes the results of a study intended to define a set of space replaceable units (SRU's) which can be used for attitude control, guidance and navigation of selected automated NASA missions. The intent of the study was to develop feasible space replaceable units of standard design. Also, sufficient detail was desired so that a preliminary cost and reliability analysis could be performed and integrated into an overall computer simultation currently being developed.

The space replaceable SRU's were defined in terms of the various sensors, thrusters and momentum exchange devices required for attitude control, station-keeping and guidance and navigation functions. Minimum interfacing between the SRU's and the physical dimensions essentially determined their composition. Sun and earth sensors were grouped together while different reaction wheel sizes, control moment gyros, magnetic torquers and propulsion units were defined in other SRU's.

The report provides a brief description of the separate components of all SRU's. The attitude control, navigation and guidance requirements for the missions of interest were obtained from various sources or assumed based on the mission objectives. A definition of the various SRU's was presented and an assignment to different spacecraft made. The results of the study may be regarded as a first approximation to a feasible system of automated space serviceable satellites which can be placed into mission orbits and serviced periodically by an upper stage of the Space Transportation System (i.e., Tug).

II. BASIC ATTITUDE AND VELOCITY CONTROL SYSTEM ELEMENTS

A. Computer and the Auxiliary Electronics Assembly

This section of the report examines various control elements which can be used in the space replaceable units for the attitude and the on-orbit control (stationkeeping, guidance and navigation) functions. A general functional control concept is shown in Fig. 1. The central element is seen to be the guidance and control processor assembly (GCPA) or computer to which an auxiliary electronics assembly may be appended.

The main function of the GCPA (computer) is to:

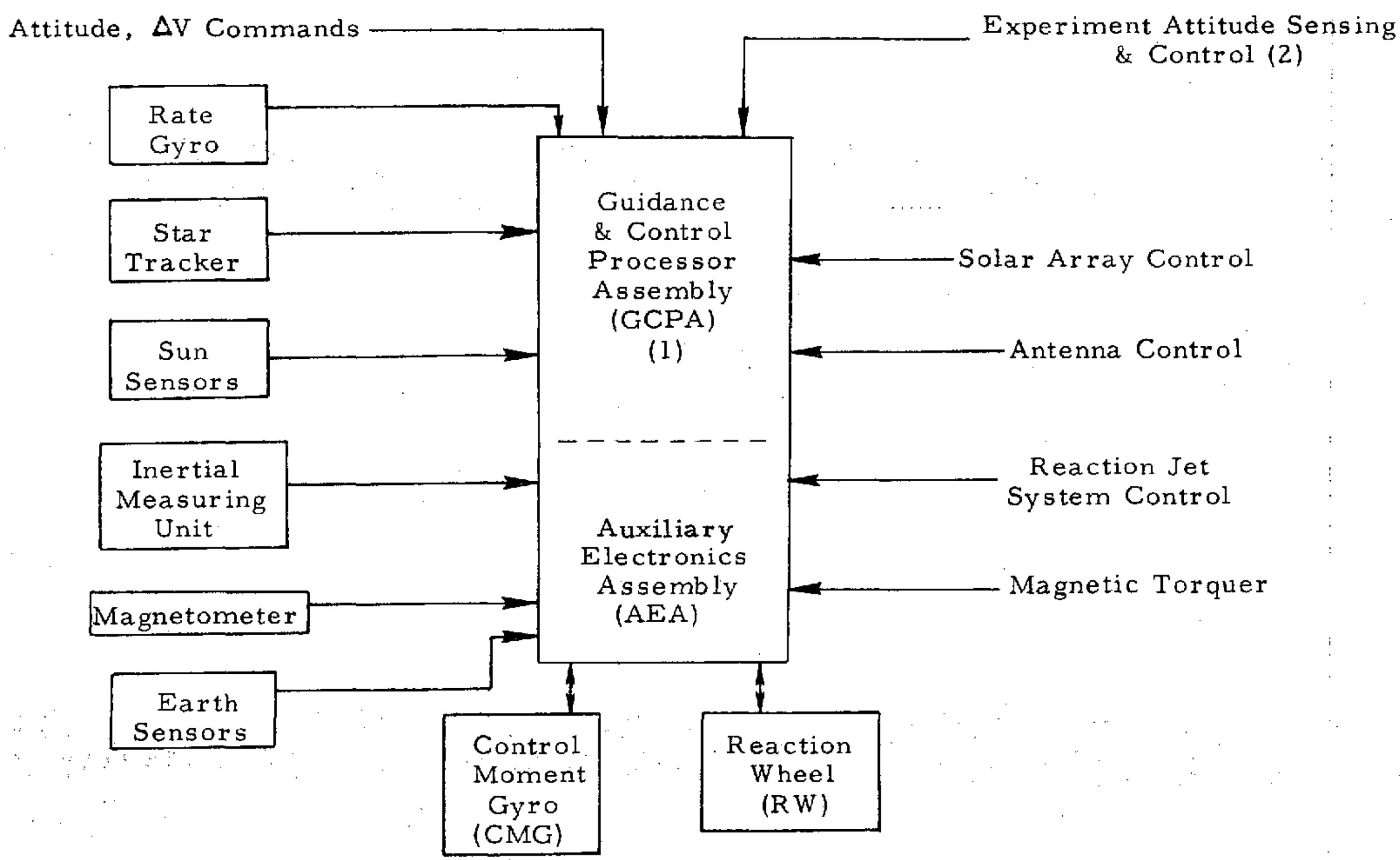
1. Store gains, time constants, saturation limits for all control modes.
2. Perform arithmetic operations using attitude and orbit maintenance control laws.
3. Provide fault detection and diagnostics.
4. Provide time, synchronization, restart and initialization of programs.

The functional parts of the GCPA can be identified as shown in Fig. 2. The size can be on the order of 7 × 8 × 13 inches and the weight 20 lb.

The auxiliary electronics assembly (AEA) collects in one package all attitude and velocity control electronics that are not a part of the guidance and control processor assembly. The AEA can thus be used to perform attitude control functions if GCPA is not required or if the power level and processing speed cannot be provided conveniently with the GCPA.

The AEA can be generally divided into the following functional areas:

1. Selection and configuration control of attitude and velocity control system (AVCS) hardware.
2. Timing and Detection (frequency clock, countdown logic, power transient detector).



(1) On-Board Data Processing & Control

(2) Payload Supplied Error Signals

Fig. 1. General Control Concept

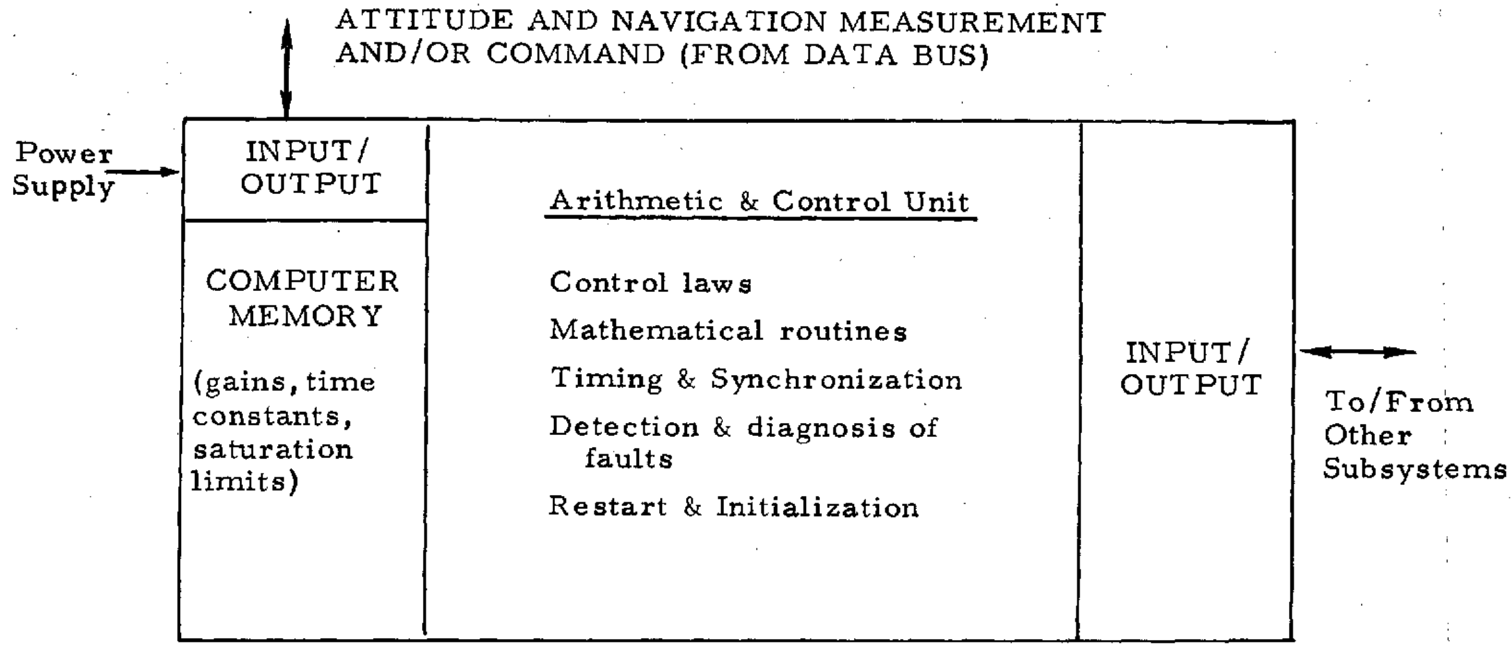


Fig. 2. Guidance & Control Processor Assembly (GCPA)

3. Power amplification and drive to the reaction wheel or control moment gyro spin motor. Also tachometer transmission to GCPA.
4. Gimbal Drive Electronics for RW or CMG (stepper, motor drive, resolver drive and position processing).
5. Solar array drive (stepper motor with position feedback loop).
6. Valve Timing and Drive (redundant drive amplifiers).

The AEA assembly is typically 7 × 8 × 9 inches and weights 10 lb.

B. Sensing Elements

The basic sensors which can be used are indicated in Fig. 1.

(1) Earth Sensors

Earth Sensor Assembly (ESA) is typically a scanning sensor utilizing the 14 to 16 micrometer spectral range. Four separate heads can be used with separate electronic channels for each head. Any two channels can provide roll and pitch error angles for earth-following vehicles. The ESA telescope field of view is dependent on the orbital altitude. The infrared discontinuity at the horizon edges is detected by a thermistor bolometer the output of which is digital words. Typical accuracy is 0.041° (3σ) for a scanning sensor at synchronous altitude.

Typical power required is 10 watts, weight is 24 lb and the size 10 × 10 × 5 inches, which includes the electronics circuits as well. A functional block diagram is shown in Fig. 3.

(2) Sun Sensors

A coarse Sun Sensor Assembly (SSA) can be used for spacecraft or solar array control. The solar aspect signals can be generated by the SSA. Each SSA consists typically of six silicon solar cells with the output from opposing pairs subtracted from each other in the auxiliary electronics assembly (AEA). Two SSA's are generally required for a 4π steradian coverage. Typical accuracy (3σ) is 0.32° (null), weight 0.9 lb per head and the size 2.4 × 3.0 × 3.6 inches. Minimum or no power is required.

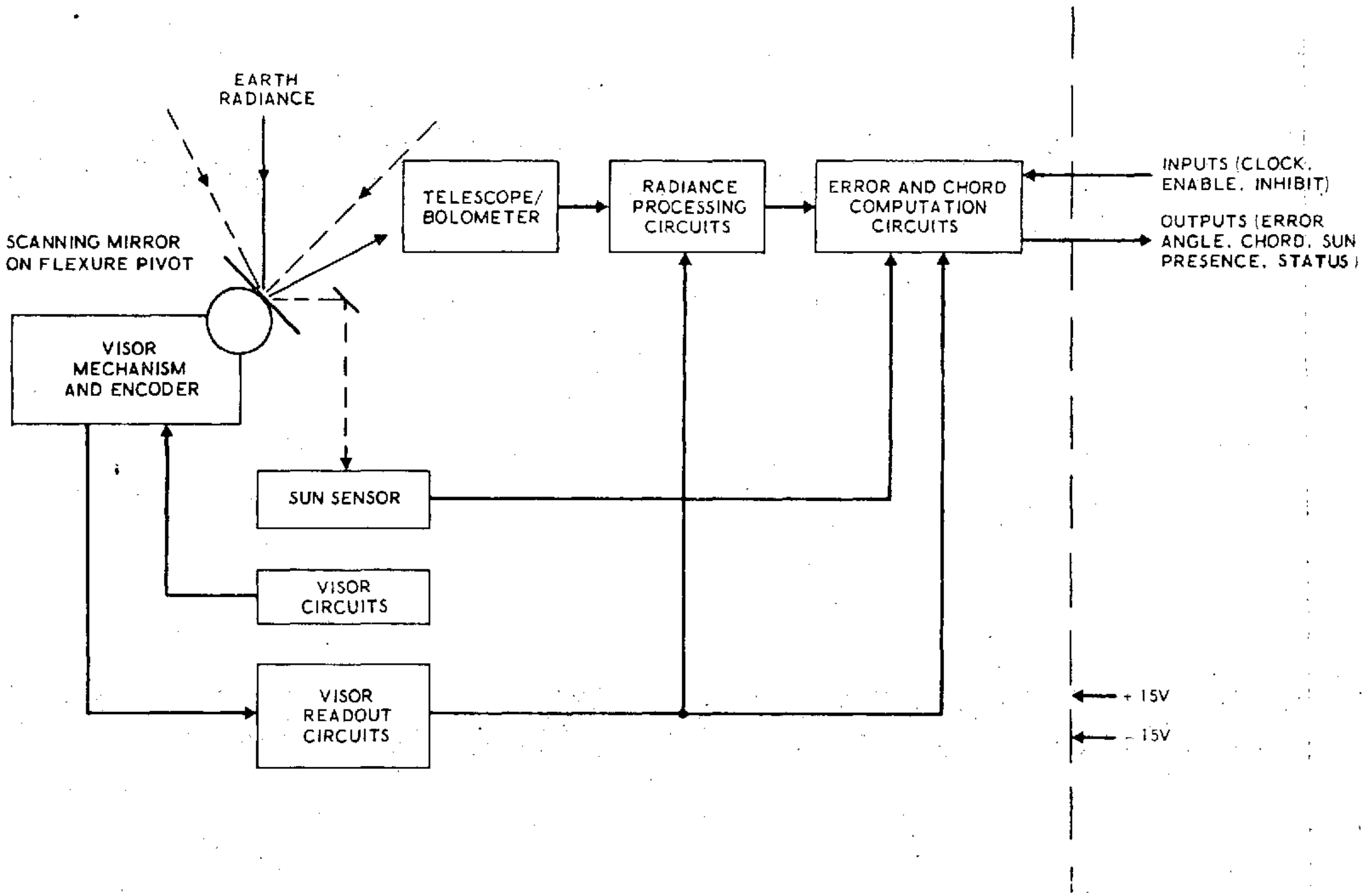


Fig. 3. Earth Sensor Block Diagram (Ref. 1)

A Fine Sun Sensor Assembly (FSSA) is required for pointing accuracies on the order of ± 2 arc minutes. The field of view is ± 15°. The FSSA also uses silicon cells.

An ADCOLE Aspect Digital Sun Sensor can be used where intermediate accuracies (± 0.25°) are required. Three axis attitude determination is possible with 5 sensors each weighing under a pound. A block diagram is shown in Fig. 4. A high resolution Adcole sun sensor can also be used for 14 arc second resolution and 1 arc minute accuracy.

(3) Gimbaled Star Trackers

A two degree of freedom gimbal star tracker of the Orbiting Astronomical Observatory type can be used for detection, acquisition and tracking of 2.0 magnitude stars in space. The general characteristics are as follows:

Tracking Accuracy (Two Axes)	30 arc sec (1σ)
Field of view	± 0.5°
Resolution of Encoder	5 arc sec
Command Resolution	10 arc sec
System Weight (Gimbal Electronics, Resolver)	52 lb
High voltage	1000 VDC
System Power	20 watts

The command and track modes enable the tracker telescope to be pointed by external command signals and track in a closed loop servosystem. A simplified functional block diagram for these modes is shown in Fig. 5.

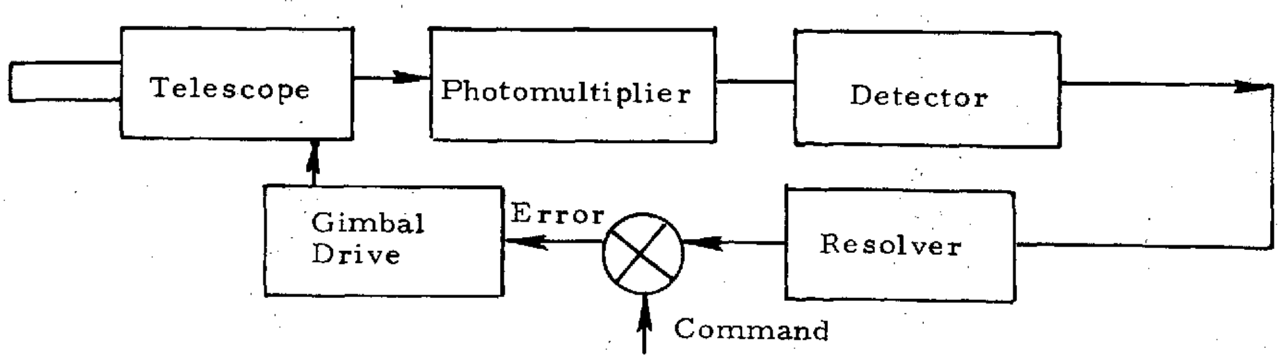


Fig. 5. Gimbaled Star Tracker Electronics

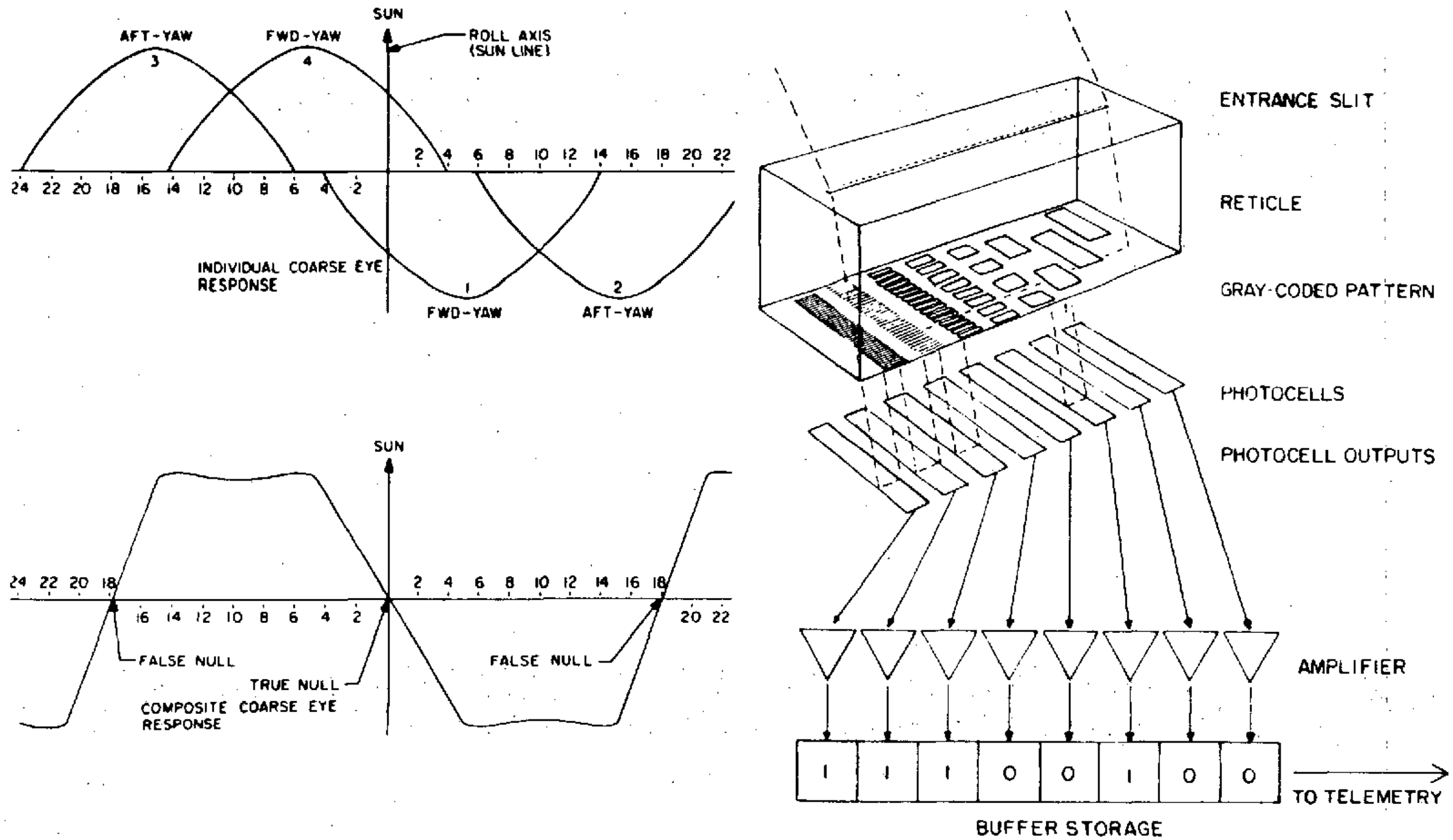


Fig. 4. Block Diagram of ADCOLE Aspect Sensor Operations
(Ref. 2)

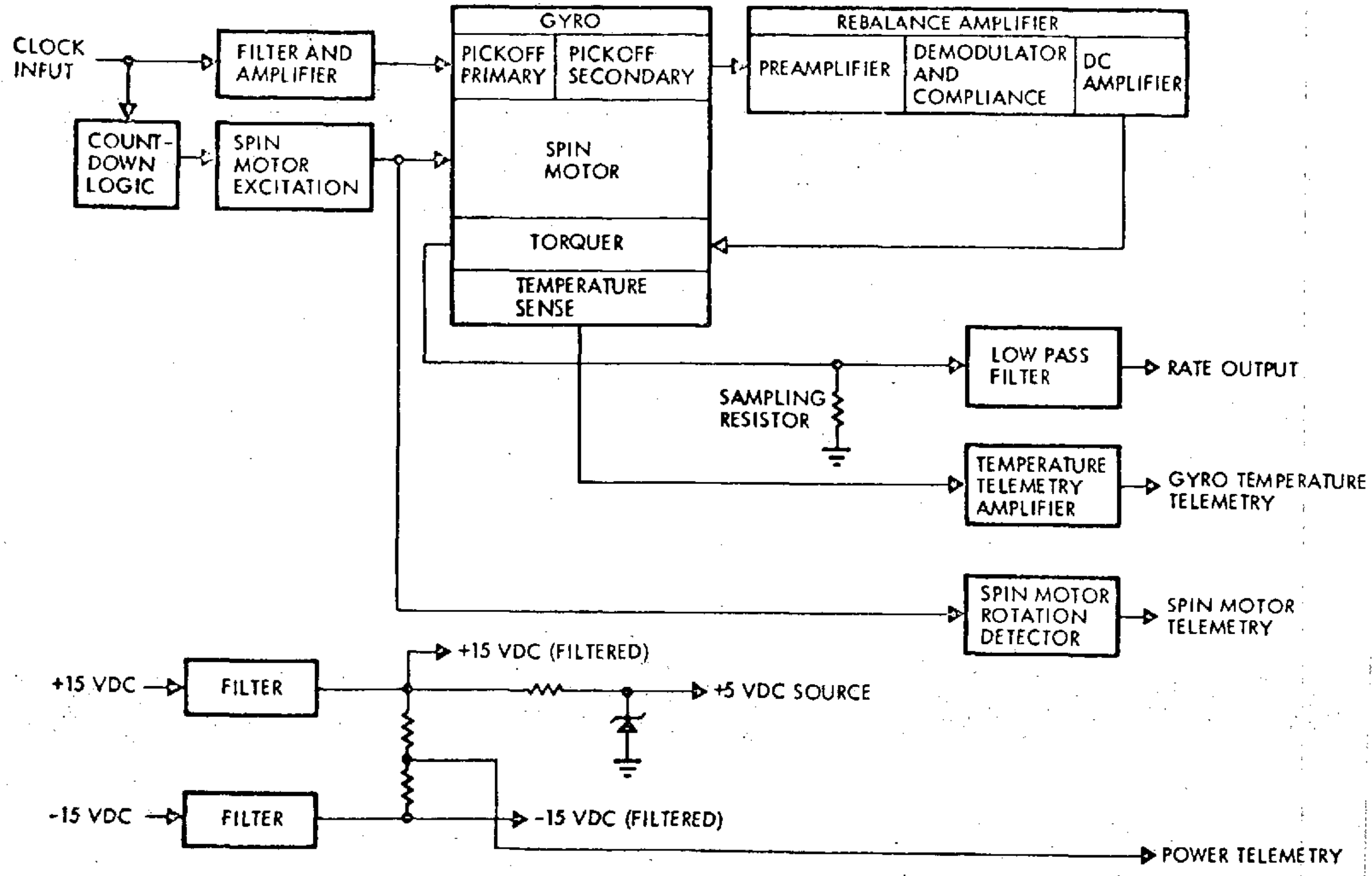


Fig. 6. RGA Block Diagram

(4) Rate Gyro Assembly

The rate gyro assembly (RGA) consists of a single degree of freedom rate integrating gyro with a torque-rebalance servo loop. External power at ± 15 vdc and a clock signal are required. A block diagram is shown in Fig. 6. The size is 2 x 6 x 8 inches, weight 2.9 lb.

A group of three rate gyros with orthogonal sensing axes may be employed for three-axis measurement of angular velocities if an inertial measuring unit is not included. The latter can also provide angular position and translational acceleration information (optional) and would generally obviate the need for a three-axis rate gyro package.

(5) Inertial Measuring Unit (IMU)

The IMU is an ultra-precision gyro inertial system. The inertial package is a temperature controlled cube 9 inches on a side. It contains three precision rate integrating gyros, three accelerometers, the gyro control and readout electronics and a frequency source required for the electronics. The gyros are operated with binary pulse restrained torque loop. Torque data from the gyros is processed as rate and rate integrals (i.e., angles) in the electronics and converted to analog signals for use in the spacecraft attitude and velocity control system (AVCS). A functional block diagram for the "strapdown" configuration where the gyros are hard mounted to the spacecraft is shown in Fig. 7.

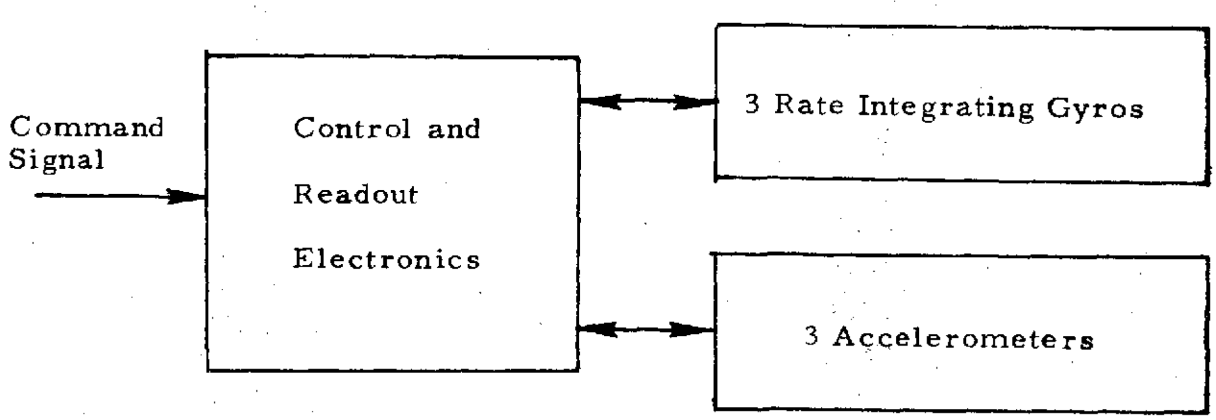


Fig. 7. IMU Block Diagram

A single integrating rate gyro restraint loop is shown in Fig. 8.

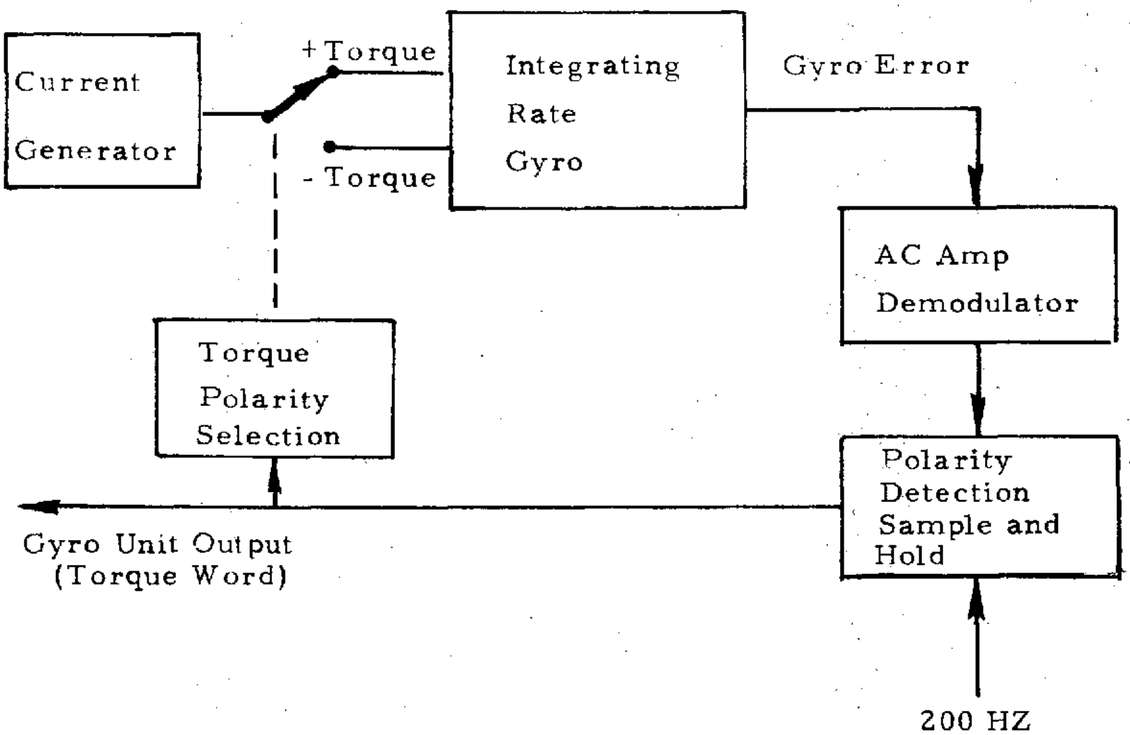


Fig. 8. IMU Gyro Restraint Loop
(Ref. 2)

The IMU characteristics depend on the mode of operation selected. Thus for SLEW and HOLD modes, the rate measuring capabilities are 2 and .004 deg/sec respectively. The power required is 75 watts (28 v unregulated). The weight is on the order of 100 lb (inertial package and electronics). The IMU receives and transmits signals to the Guidance and Control Computer for execution of precise attitude and orbit velocity control commands.

C. Force & Torque Generating Systems

The control authority (force and torque generation) for attitude and on-orbit position maintenance can be obtained from mass expulsion systems. Most common applications involve cold gas (gaseous nitrogen GN_2), hot gas (hydrazine N_2H_4) or ion thrusters. Torque generation can be obtained from momentum exchange devices (reaction wheel or control moment gyro) or a magnetic torquer. The basic characteristics of these elements are described in what follows:

(1) Reaction Wheel (RW)

Three reaction wheels may be employed to stabilize a spacecraft about each of three axes or a single wheel (gimbaled, constant speed or modulated) may be utilized to provide gyroscopic stability about two axes and closed loop control about the third axis. A momentum unloading (dumping) mechanism is usually required to maintain the wheel speed below a critical value. This can be a mass expulsion or magnetic type.

A typical block diagram for closed loop reaction wheel control about an axis is shown in Fig. 9. In this Figure the lead compensation introduces a phase lead into the control loop to insure good transient response and sufficient damping. Integral compensation drives the pointing error to zero. The Limiter allows the tachometer loop to assume control of the wheel when attitude errors are too large. This prevents wheel speed from exceeding design limits. In normal operation, the tachometer deadzone limits the signal. However, during wheel turn-on and when attitude errors are large, the tachometer loop brings the wheel up to proper speed.

A typical 5 ft-lb-sec wheel requires 1 - 24 watts (peak) power for operation, weighs 15 lb and is 12 x 5 inches in size. Approximate weight of a reaction wheel can be found from $W = 7H^{0.4}$ where H is the angular momentum.

(2) Control Moment Gyro (CMG)

A two degree of freedom control moment gyro (CMG) is a constant high speed rotor device with two orthogonal gimbals. The CMG is useful primarily when high control torques and pointing accuracy are required. Velocity response of the spacecraft is obtained with low and constant power, high torque gains and minimum reset times. Because of interaxis dynamic coupling and relatively complex control laws, an onboard computer is required.

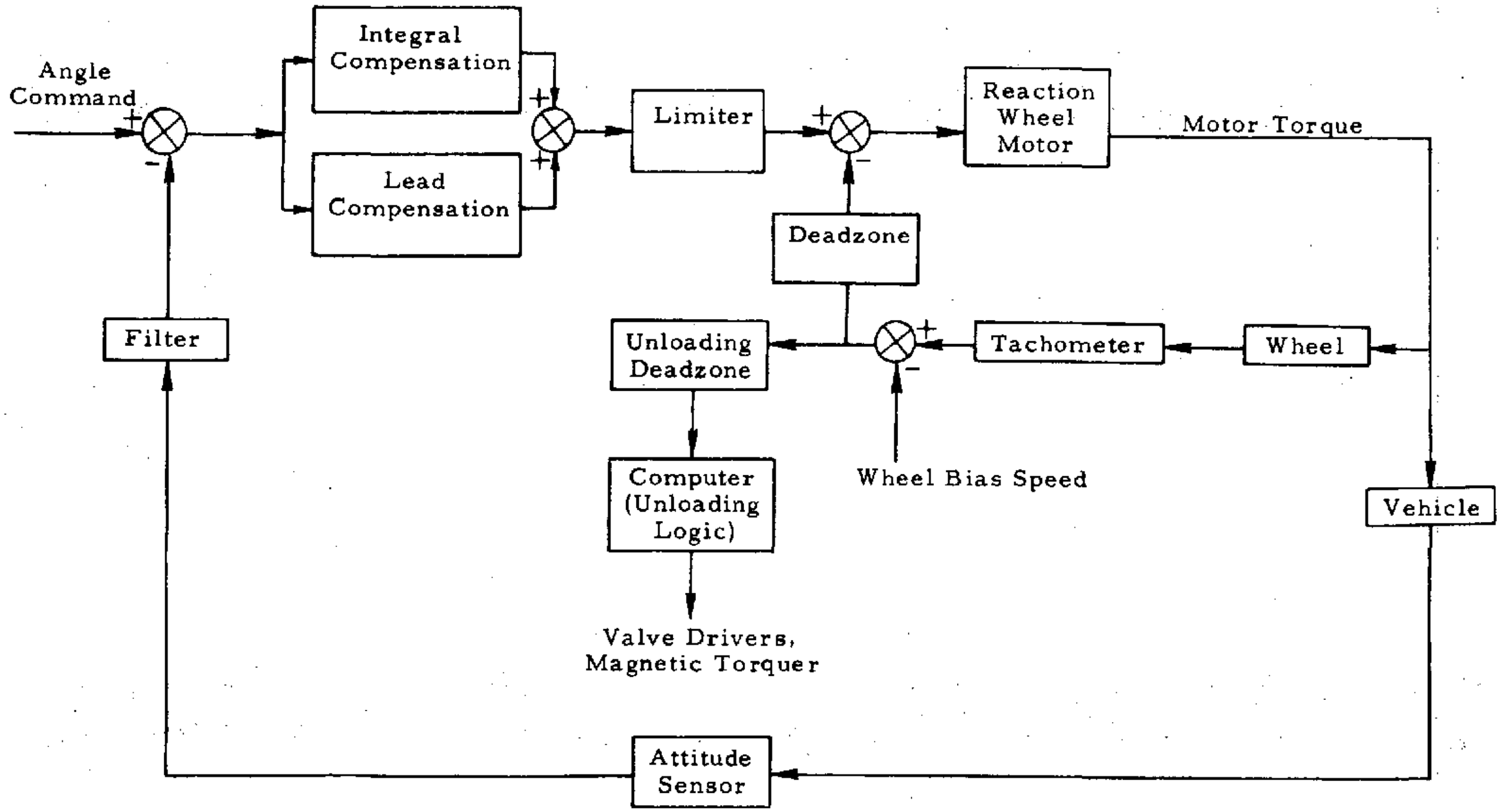


Fig. 9. Reaction Wheel Attitude Control Subsystem

The CMG's can be used in clusters of three units for maximum efficiency and reliability. The steering law uses the attitude and attitude rate errors to generate a three axis torque command vector which is transformed into the CMG command gimbal rates. A matrix relating the six gimbal rates (3 CMG's) to the resultant torque output enables calculation of the desired gimbal rates.

A typical block diagram is shown in Fig. 10 which is similar to the Apollo Telescope Mount Control System. The 3CMG cluster can provide high accuracies and stability (over a specified time interval) such as ± 0.5 arc sec in conjunction with a star sensing system and a magnetic momentum unloading torquer. For a 500 ft-lb-sec CMG the weight is 200 lb, size 4 ft^3 and the average power required, 25 watts.

(3) Mass Expulsion Systems

Simplest mass expulsion (reaction control) systems utilize gaseous nitrogen (GN_2) or hydrazine N_2H_4. A cold gas propulsion subsystem which can be used is shown in Fig. 11 and a hydrazine RCS in Fig. 12. The nitrogen gas provides an $I_{sp} \approx 70$ sec, while that for the hydrazine is on the order of 200 sec for the higher level thrusters.

(4) Momentum Removal by a Magnetic Torquer

The earth's ambient magnetic field can be used effectively for a satellite's angular momentum removal in low earth orbits. This can be achieved by generating a controlled magnetic moment in a vehicle which interacts with the earth's magnetic field producing an external torque. The basic advantage of this approach is that no propellant is expended for removing the angular momentum from reaction wheels or control moment gyros. The primary requirements are electrical power and a set of magnetometers (three axis) shown in Fig. 13 which determine the components of the magnetic field in the spacecraft body coordinates. A set of three orthogonal coils for current loops and an appropriate logic (computer) are also required in such a scheme. A block diagram is shown in Fig. 14.

The size and weight of the magnetic torquer would normally depend on the size and orbit altitude of the vehicle. Such considerations as whether the torquing is continuous, intermittent or optimal also affect the physical

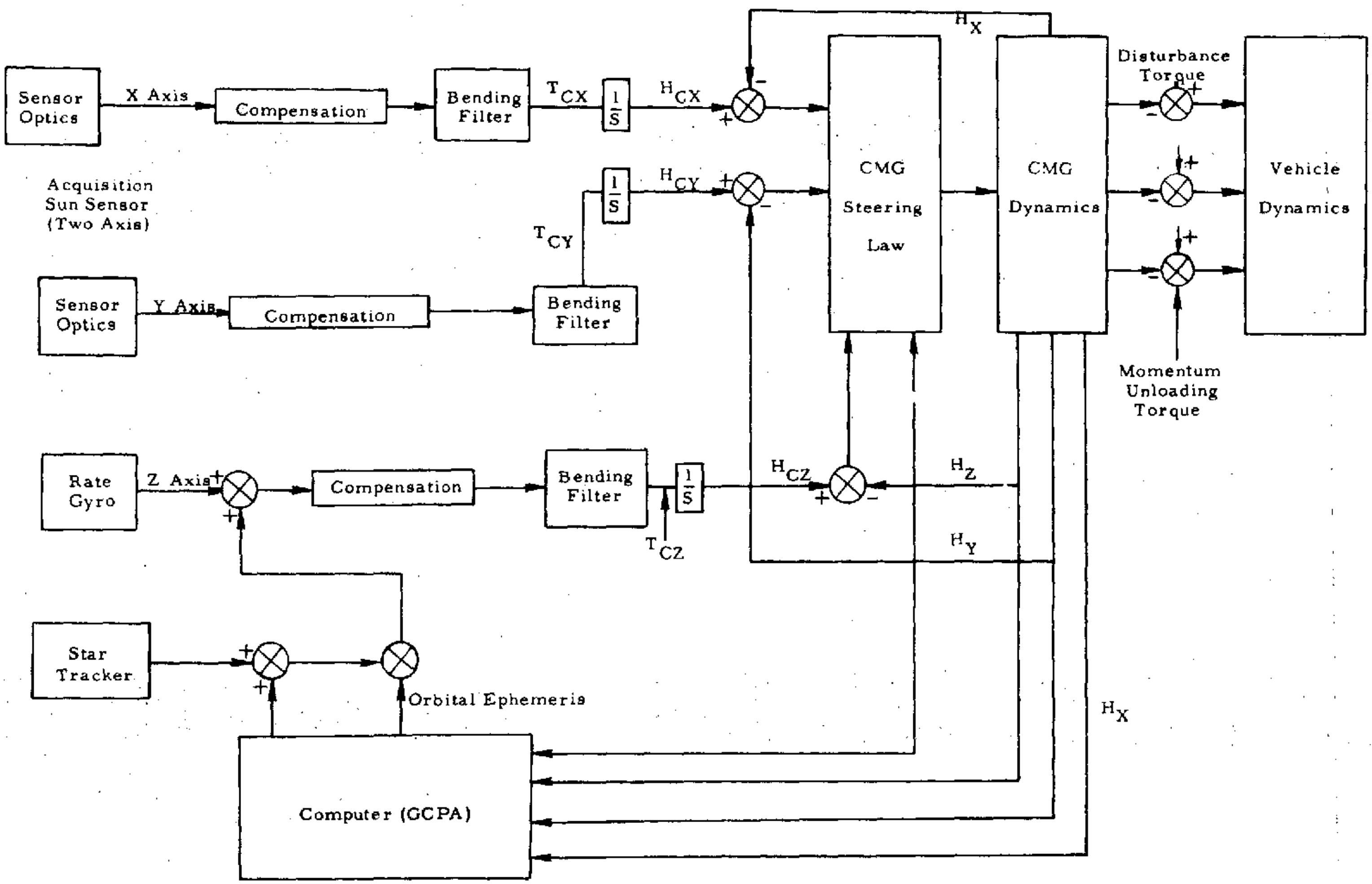


Fig. 10. Simplified CMG Control Subsystem

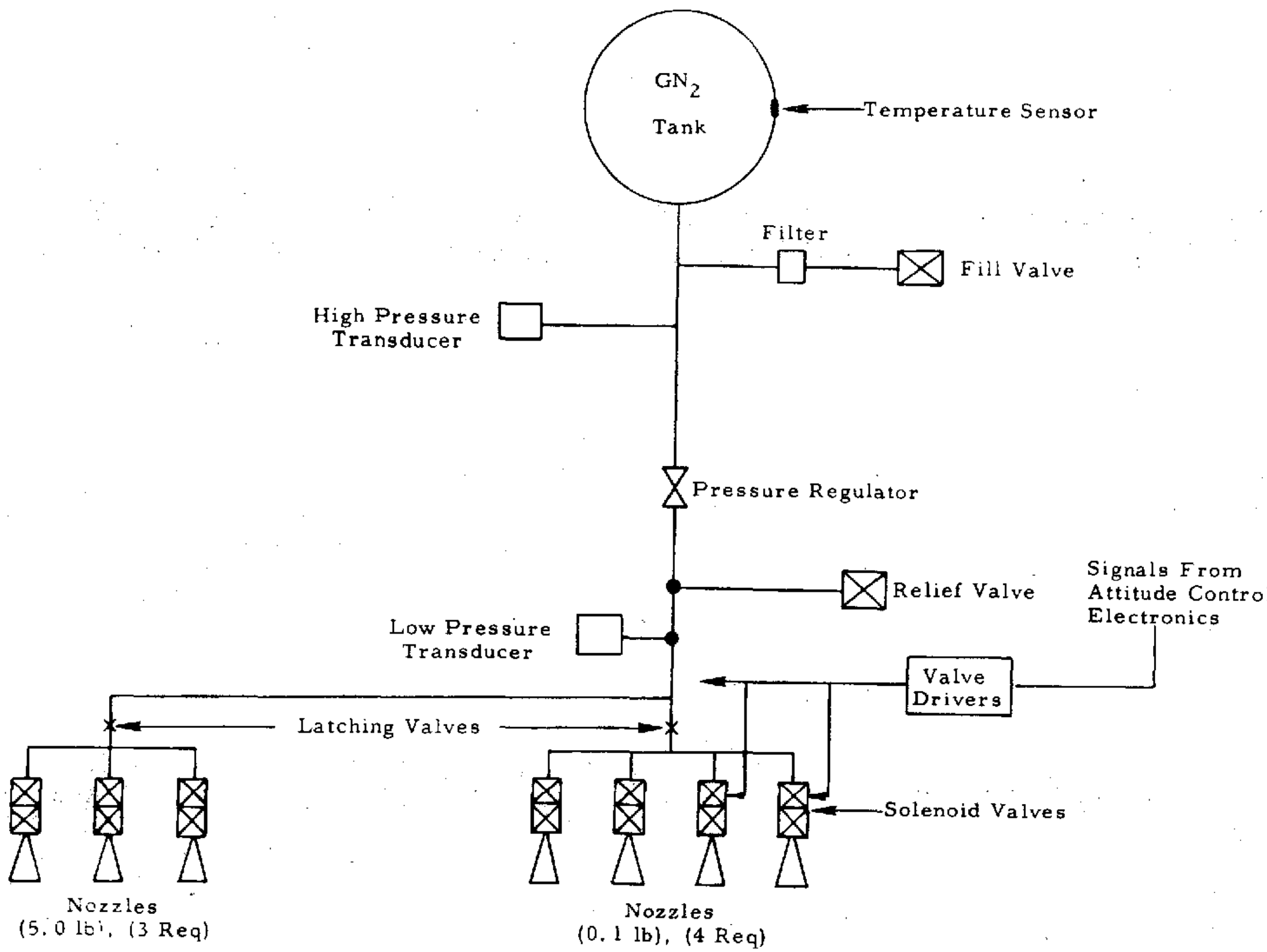


Fig. 11. Cold Gas (GN_2) Propulsion Subsystem

(Ref. 2)

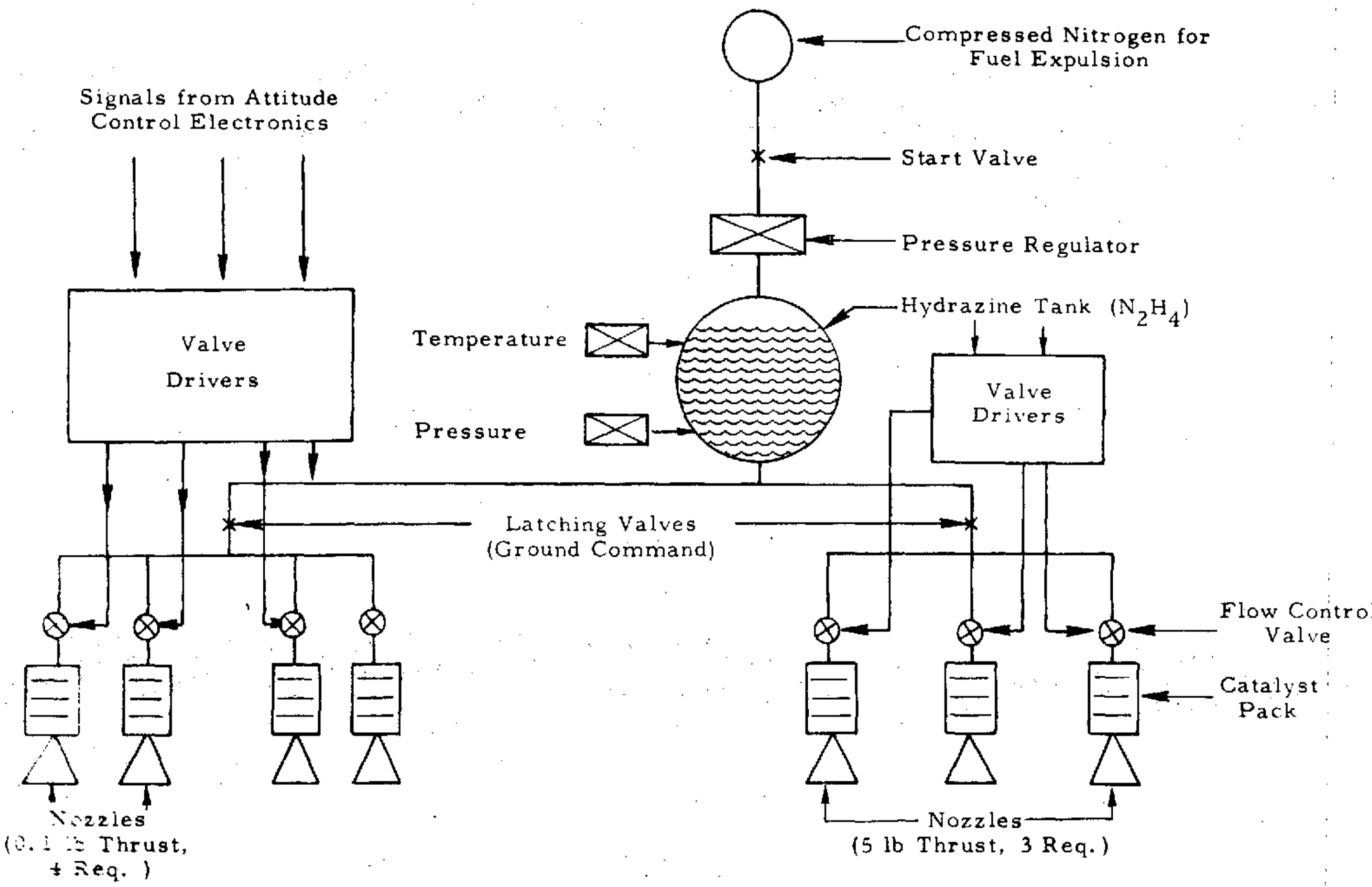


Fig. 12. Hydrazine Propulsion Subsystem

(Ref. 2)

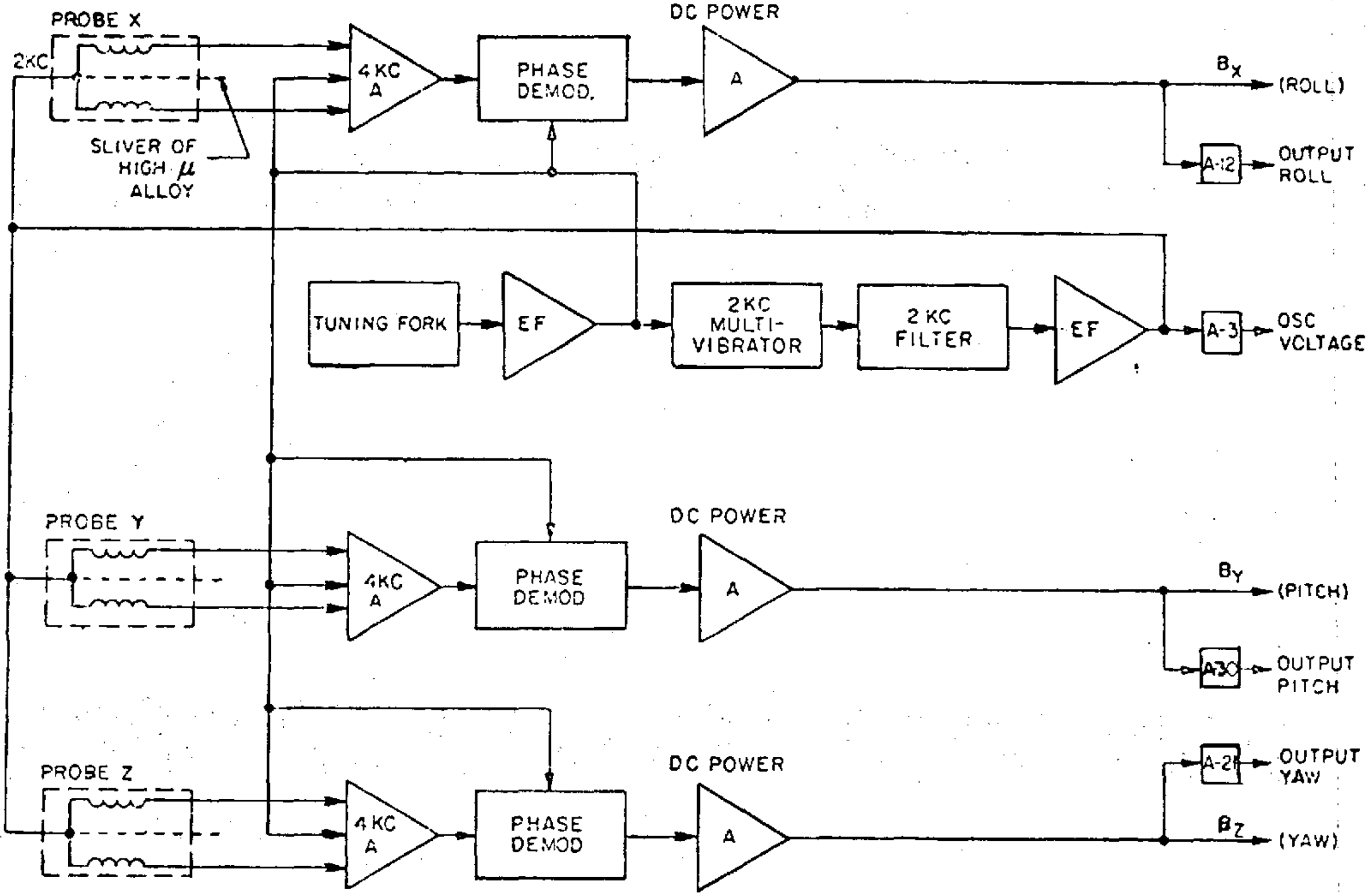


Fig. 13. Magnetometer Subsystem

(Ref. 2)

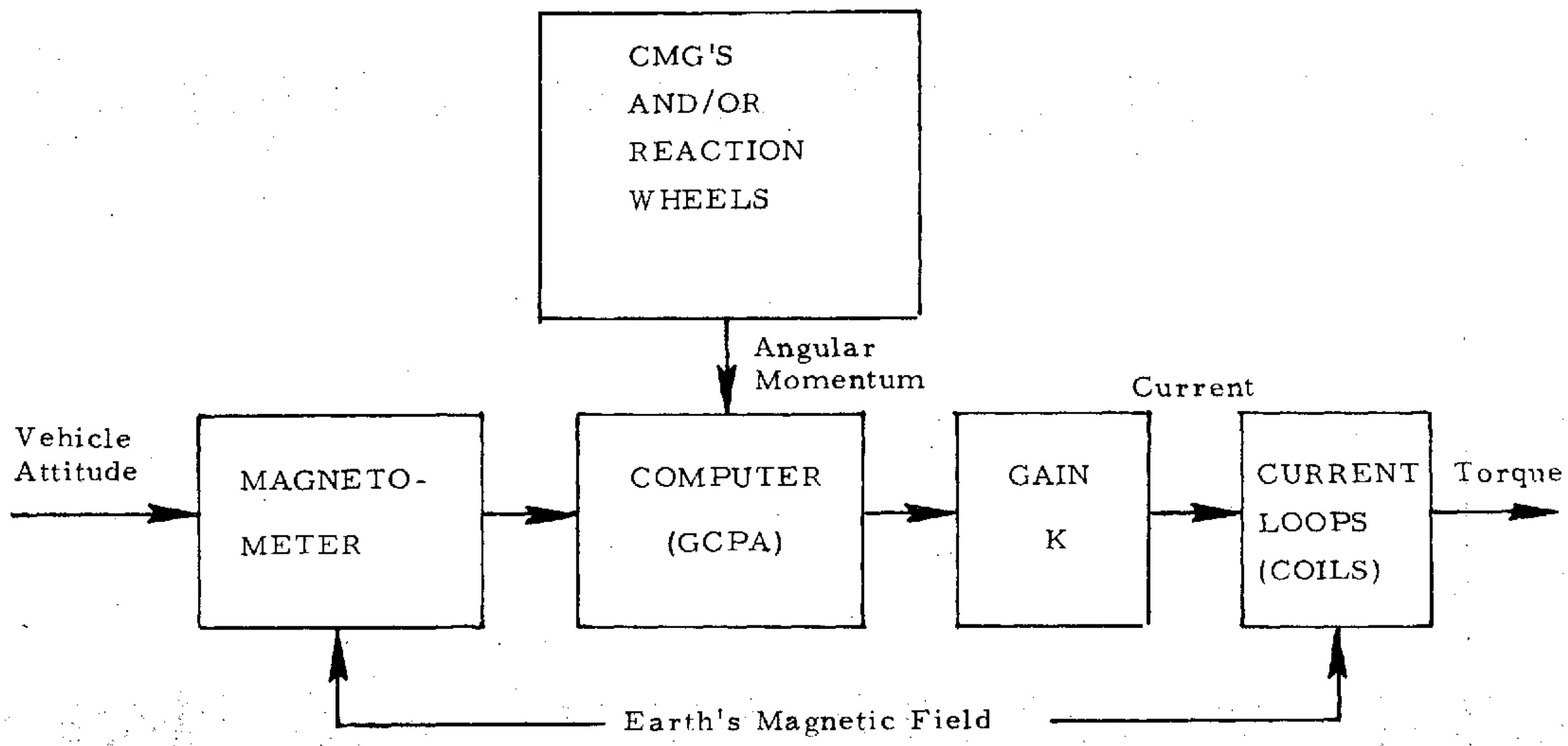


Fig. 14. A Momentum Removal Scheme by a Magnetic Torquer

characteristics of the torquer and the computer logic required. As an example, a representative coil might consist of a thousand turns of an aluminum or copper wire, have a one foot radius and require a current of 6 milliamperes. Power required would be on the order of 100 milliwatts and the weight 10 lb. Three such coils could be required for a typical vehicle application.

III. SPACE SERVICEABLE ATTITUDE, VELOCITY, AND GUIDANCE REQUIREMENTS

The pointing accuracies, attitude and slew rate requirements for the satellites of interest were obtained or estimated from NASA and other sources. The guidance and navigation requirements were estimated assuming earth tracking and data processing capabilities. The control elements (reaction wheels, CMG's, gas jets, etc.) and their characteristics were similarly determined on the basis of past experience or previous studies. These requirements are summarized in Tables I and II.

The estimates of the satellite's momentum storage requirements were made using approximately 0.5 to 1% or less of the satellite weight. This approach shows that a number of different reaction wheel SRU's are required. The actual reaction wheel requirements depend on the pointing accuracy, attitude rates, and the environmental torques which will be seen by the satellites. Since only the pointing accuracies and attitude rates are known at present (the environmental torques are a strong function of the vehicle geometry), three different reaction wheel SRU's can be used. Single 5- and 10 ft-lb-sec wheel modules and a 3-wheel (orthogonal axes) SRU thus appear to be adequate for the satellites of interest.

The thruster characteristics indicate that a 0.1 lb low-level thruster and a 5-lb high-level thruster appear most frequently in the requirements. The low level thruster can be used for attitude control while the 5-lb thruster is suitable for orbit maintenance (stationkeeping) and repositioning. The total velocity impulse requirements are specified either in ft/sec, propellant weight or impulse units as available. These quantities are useful only for the propellant loading estimates and are also subject to significant revisions in future studies. The guidance and navigation requirements represent the current state-of-the-art capabilities.

Table I Attitude and Velocity Control System Design Parameters

Payload Code		Payload Name	Pointing Accuracy ±(deg)	Attitude Rates Less Than (deg/sec)	Slew Rates (deg/sec)
Mission Model	SSPDA				
AST-1B	AS-03	Cosmic Background	1 min	.001	0.1 - 1.0
AST-1C	AS-05	Adv Radio Astronomy	1 sec	10^{-4}	0.1 - 1.0
AST-3	SO-03	Solar Physics Mission	1.2 sec, 0.25°	1.2 sec/sec	0.1 - 1.0
AST-9A	HE-11	Focusing X-ray Telescope - 1.2 M	30 sec, 1 sec	10^{-4}	0.01 - 1.0
AST-9B	HE-01	Focusing X-ray Telescope - 3.0 M	30 sec, 1 sec	10^{-4}	0.01 - 1.0
PHY-1A	HE-07	Small High Energy Observatory	1 min	.001	0.1
PHY-1B	AP-01	Upper Atmosphere Explorer	2	.001	0.1
PHY-1C	AP-02	Medium Altitude Explorer	2	.001	0.1
PHY-2A	AP-04	Gravity & Rel - Earth Orbit	(1 → 0.05) sec	10^{-4}	0.1
EO-3A	EO-08	Earth Observatory Satellite	1 → 0.01	2×10^{-6}	0.0
EO-4A	EO-09	Sync Earth Observatory Sat	.0172 (1)	10^{-4}	1.0
EO-6	EO-12	TIROS	.01	2×10^{-6}	0.1
EO-7	EO-7	Sync Meteorological Sat	0.07 (2)	10^{-4}	0.3
EOP-3	OP-07	SEASAT - B	2 (3)	.001	None
EOP-4	OP-01	Geopause	3 (4)	.001	0.1
EOP-07	OP-04	GRAVSAT	3 (5)	.001	0.1
NN/D-1	CN-51	International Comm	0.16	0.001	0.1
NN/D-2A	CN-52	U.S. Domestic - A	0.2 (6)	0.001	0.1
NN/D-2B	CN-53	U.S. Domestic - B (Adv)	0.16	0.001	0.1
NN/D-2C	CN-58	U.S. Domestic - C (TDRS)	0.58 (7)	0.001	0.1
NN/D-3	CN-54	Disaster Warning	0.11	10^{-4}	0.01
NN/D-4	CN-55	Traffic Management	0.3	0.001	0.1
NN/D-5	CN-56	Foreign Communications	0.2	0.001	0.1
NND-6	CN-59	Communications R&D/Proto	0.2	0.001	0.1
NN/D-8	EO-56	Environmental Monitoring Satellite	.01	2×10^{-6}	0.1
NN/D-11	EO-61	Earth Resource - LEO	0.7	.001	0.01
NN/D-12	EO-59	Earth Resource - Geosync	10 sec	.001	0.1
NN/D-13	EO-62	Earth Resource - Foreign	6 min	.001	0.1
NN/D-14	OP-08	Global Earth & Ocean Monitoring	0.5	.001	0.1

(1) Knowledge of pointing ± 0.00172 deg
(2) Knowledge of pointing ± 0.00143 deg
(3) Measure attitude ±0.1° relative to an earth centered coordinate system
(4) Measure attitude ±0.5° relative to an earth centered coordinate system
(5) More accurate pointing (to ±1°) will be required during orbit maintenance
(6) Attitude determination to ±0.05° (knowledge to ±0.0025°)
(7) Attitude determination to ±0.25°

Table I.

Attitude and Velocity Control System Design Parameters

(continued)

Payload Code		Momentum Storage ft-lb-sec	Attitude and Stationkeeping Thrusters		
Mission Model	SSPDA		Thrust (lb)	Total Velocity/Impulse	Orientation Reference
AST-1B	AS-03	15 R.W.	0.1 and 5	330 ft/sec	Inertial
AST-1C	AS-05	13 R.W.	0.1 and 5	330 ft/sec	Inertial
AST-3	SO-03	30 R.W.	0.1 and 5	100 lb GN_2	Sun/Star
AST-9A	HE-11	500 CMG (3 Req.)	0.5 and 10	220 lb GN_2 + Magnet. Torq.	Star (computer)
AST-9B	HE-01	500 CMG (3 Req.)	0.5 and 10	400 lb GN_2 + Magnet. Torq.	Star (computer)
PHY-1A	HE-07	14	0.1 and 5	50 lb GN_2	Inertial
PHY-1B	AP-01	None	0.1 and 5	200 lb GN_2	Inertial
PHY-1C	AP-02	None	0.1 and 5	200 lb-sec	Inertial
PHY-2A	AP-04	20 R.W.	Low	300 lb He	Star
EO-3A	EO-08	18 R.W.	0.1 and 5	200 lb GN_2	Earth
EO-4A	EO-09	6 R.W.	0.1 and 5	151 ft/sec	Earth
EO-6	EO-12	30 R.W.	0.1 and 5	200 lb GN_2	Earth
EO-7	EO-7	5 R.W. (3 Req.)	0.5	100 lb N_2H_4	Earth
EOP-3	OP-07	30 R.W.	0.1 and 5	200 lb GN_2	Earth
EOP-4	OP-01	30 R.W.	0.1 and 5	250 lb GN_2	Earth
EOP-07	OP-04	100 R.W.	0.1 and 5	1120 lb GN_2	Earth
NN/D-1	CN-51	20 R.W.	0.0015 Ce Ion 0.5 N_2H_4	120 lb N_2H_4	Earth
NN/D-2A	CN-52	5 R.W.	0.1, 0.5 N_2H_4	50 lb N_2H_4	Earth
NN/D-2B	CN-53	20 R.W.	0.0015 Ion 0.5 N_2H_4	120 lb N_2H_4	Earth
NN/D-2C	CN-58	5 R.W.	0.1, 0.5 N_2H_4	60 lb N_2H_4	Earth
NN/D-3	CN-54	5 R.W.	3×10^{-4} Ion	25 lb Ce	Earth
NN/D-4	CN-55	5 R.W.	.1, 5	40 lb GN_2 + N_2H_4	Earth
NN/D-5	CN-56	5 R.W.	.1, 0.5	27,577 lb-sec (128 lb)	Earth
NND-6	CN-59	5 R.W.	0.0015 Ion 0.5 N_2H_4	170 lb N_2H_4	Earth
NN/D-8	EO-56	30 R.W.	0.1, 5	200 lb GN_2 + N_2H_4	Earth
NN/D-11	EO-61	5 R.W.	.1 N_2H_4 + Magnetic	30 lb N_2H_4	Earth
NN/D-12	EO-59	30 R.W.	.1, 5	180 lb N_2H_4	Earth
NN/D-13	EO-62	30 R.W.	.1, 5	180 lb N_2H_4	Earth
NN/D-14	OP-08	25 R.W.	.1, 5	180 lb N_2H_4	Earth

Table II Guidance and Navigation System Design Parameters

Payload Code			Navigation Accuracy (1σ)[1]			
Mission Model	SSPDA	Payload Code	Position (ft)	Velocity (ft/sec)	Inertial Measuring Unit[2]	Guidance Computer[3]
AST-1B	AS-03	Cosmic Background	100	0.05	S. D.[4]	A. C.[5]
AST-1C	AS-05	Adv Radio Astronomy	200	0.10	S. D.	A. C.
AST-3	SO-03	Solar Physics Mission	100	0.05	S. D.	A. C.
AST-9A	HE-11	Focusing X-ray Telescope - 1.2 M	100	0.05	S. D.	A. C.
AST-9B	HE-01	Focusing X-ray Telescope - 3.0 M	100	0.05	S. D.	A. C.
PHY-1A	HE-07	Small High Energy Observatory	100	0.05	S. D.	A. C.
PHY-1B	AP-01	Upper Atmosphere Explorer	100	0.05	N/A[6]	N/A
PHY-1C	AP-02	Medium Altitude Explorer	200	0.10	N/A	N/A
PHY-2A	AP-04	Gravity and Rel - Earth Orbit	100	0.05	S. D.	A. C.
EO-3A	EO-8	Earth Observatory Satellite	100-150	0.05	S. D. (High Perf.)	A. C.
EO-4A	EO-9	Sync Earth Observatory Sat	200	0.10	S. D. + Star Sens.	A. C.
EO-6	EO-12	TIROS	100-150	0.05	S. D. + Star Sens.	A. C.
EO-7	EO-7	Sync Meteorological Sat	200	0.10	4 Gyros + 2 Star Sens.	A. C.
EOP-3	OP-07	SEASAT-B	100	0.05	N/A	N/A
EOP-4	OP-01	Geopause	200	0.10	N/A	N/A
EOP-07	OP-04	GRAVSAT	100	0.05	N/A	N/A
NN/D-1	CN-51	International Comm	200	0.10	3 Axis Rate Gyro	N/A
NN/D-2A	CN-52	U.S. Domestic - A	200	0.10	3 Axis Rate Gyro	N/A
NN/D-2B	CN-53	U.S. Domestic - B (Adv)	200	0.10	3 Axis Rate Gyro	N/A
NN/D-2C	CN-58	U.S. Domestic - C (TDRS)	200	0.10	3 Axis Rate Gyro	N/A
NN/D-3	CN-54	Disaster Warning	200	0.10	Single Axis Gyro	N/A
NN/D-4	CN-55	Traffic Management	200	0.10	N/A	N/A
NN/D-5	CN-56	Foreign Communication	200	0.10	N/A	N/A
NN/D-6	CN-59	Communication R&D/Proto	200	0.10	Single Axis Gyro	A. C.
NN/D-8	EO-56	Environmental Monitoring Satellite	100	0.05	S. D. + Star Sens.	A. C.
NN/D-11	EO-61	Earth Resource - LEO	100	0.05	N/A	N/A
NN/D-12	EO-59	Earth Resource - Geosync	200	0.10	S. D. + Star Sens.	A. C.
NN/D-13	EO-62	Earth Resource - Foreign	200	0.10	S. D. + Star Sens.	A. C.
NN/D-14	OP-08	Global Earth and Ocean Monitoring	100	0.05	N/A	N/A

(1) Ground Tracking Assumed
(2) 3 Rate and Integrating Gyros + Accelerometers
(3) On Board Data Processing and Control
(4) Strapped Down Type
(5) Attitude Control (15 Bit Data Word Capability Max
(6) Not Applicable

IV. STANDARDIZED SUBSYSTEM MODULES

Several modules for sensing, torquing, propulsion and other functions were defined in terms of the basic control elements shown in Fig. 1. The primary purpose of the subsystem modules is to provide standardized space replaceable units on an as-needed basis. Such SRU's are required to provide 3-axis active attitude control and orbital velocity adjustment for the satellites of interest. The SRU's would normally be placed on a ring type spacecraft structure and are therefore limited in size, weight, and volume.

A total of 7 SRU's and six variants were defined initially to provide the sensing, torquing, and computational functions. Three sizes and types of reaction wheel SRU's were found desirable and two types of propulsion units (cold gas and hydrazine) were also considered.

In the interest of saving weight and reducing the variety of the total number of SRU's, only the hot gas (hydrazine) propulsion system was finally adopted. Two different tank sizes are considered necessary, however, in order to satisfy the propellant requirements for all missions. Thus the AVCS-7 is a hydrazine SRU with a 15-inch diameter tank while the AVCS-8 is a similar SRU with a 24-inch diameter tank. The use of a single type of propulsion SRU for all missions appears feasible at this time although a more detailed study of the performance requirements and capabilities can invalidate this conclusion.

Two sensing SRU's containing sun and star sensors, respectively, were defined along with their variants utilizing the low and high altitude earth sensors. A high performance inertial measuring unit (OAO-type) and a computer SRU were specified for the applications involving high pointing accuracies or stringent measurement requirements. The magnetic torquer module is included for angular momentum control in low earth orbits. Description of the SRU's and the corresponding information flow block diagrams are shown in Table III.

TABLE III. STANDARDIZED SUBSYSTEM MODULES -- ATTITUDE AND VELOCITY CONTROL SYSTEM

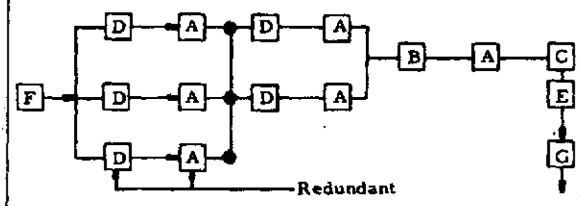
MODULE CODE	MODULE NAME	ITEM	COMPONENT	QTY	WT (lb) ITEM	BLOCK DIAGRAM
AVCS-1	Reaction Wheel (5 ft-lb-sec)	A	Reaction Wheel	1	10	
		B	Wheel Electronics	1	3	
		C	Cables and Connectors	1	3	
		D	Power Conditioning	1	5	
		E	Remote Terminal	1	5	
AVCS-2	Reaction Wheel (10 ft-lb-sec)	A	Reaction Wheel	1	18	
		B	Wheel Electronics	1	3	
		C	Cables and Connectors	1	3	
		D	Power Conditioning	1	5	
		E	Remote Terminal	1	5	
AVCS-3	Reaction Wheel (10 ft-lb-sec/wheel)	A	Reaction Wheel	3	54	
		B	Wheel Electronics	1	6	
		C	Cables and Connectors	1	5	
		D	Power Conditioning	1	5	
		E	Remote Terminal	1	5	
AVCS-4	Control Moment Gyro (Double Gimbal) (500 ft-lb-sec)	A	CMG Wheel	1	150	
		B	Wheel Electronics	1	10	
		C	Torquer, Damper and Resolver	2	10	
		D	Cables and Connectors	1	5	
		E	Power Conditioning	1	5	
		F	Remote Terminal	1	5	
AVCS-5	Sensing	A	Auxiliary Electronics Assembly AEA)	1	10	
		B	Rate Gyro Package	1	3	
		C	High Altitude Horizon Sensor	1	12	
		D	Sun Aspect Sensor	5	5	
		E	Cables and Connectors	1	3	
		F	Power Conditioning	1	5	
		G	Remote Terminal	1	5	

TABLE III. STANDARDIZED SUBSYSTEM MODULES -- ATTITUDE AND VELOCITY CONTROL SYSTEM (CONTINUED)

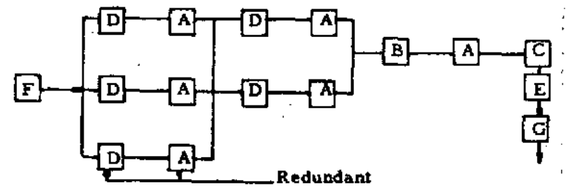
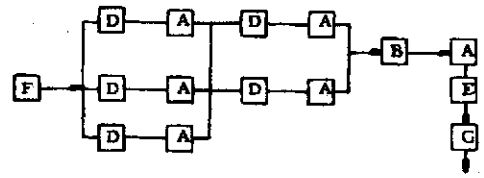
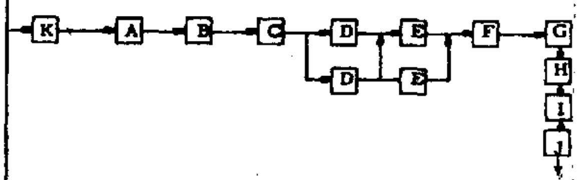
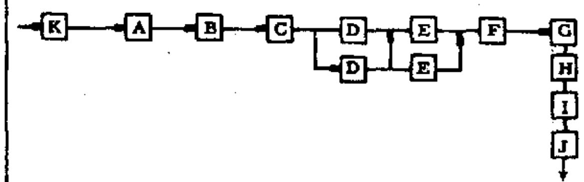
MODULE CODE	MODULE NAME	ITEM	COMPONENT	QTY	(lb) WT ITEM	BLOCK DIAGRAM
AVCS-5A	Sensing	A	Auxiliary Electronics Assembly (AEA)	1	10	
		B	Rate Gyro Package	1	3	
		C	Low Altitude Horizon Sensor	1	12	
		D	Sun Aspect Sensor	5	5	
		E	Cables and Connectors	1	3	
		F	Power Conditioning	1	5	
		G	Remote Terminal	1	5	
AVCS-6	Sensing	A	Auxiliary Electronics Assembly (AEA)	1	10	
		B	Gimballed Star Tracker	1	40	
		C	High Altitude Horizon Sensor	1	12	
		D	Sun Sensor	5	5	
		E	Cables and Connectors	1	3	
		F	Power Conditioning	1	5	
		G	Remote Terminal	1	5	
AVCS-6A	Sensing	A	Auxiliary Electronics Assembly (AEA	1	10	
		B	Gimballed Star Tracker	1	40	
		C	Low Altitude Horizon Sensor	1	12	Same as AVCS-6-1
		D	Sun Sensor	5	5	
		E	Cables and Connectors	1	3	
		F	Power Conditioning	1	5	
		G	Remote Terminal	1	5	
AVCS-7	Hot Gas Propulsion (N_2H_4) Small Tank	A	Nitrogen Tank (7.5-in OD)	1	5	
		B	Start Valve	1	1	
		C	Regulator Valve	1	4	
		D	Temperature Transducer	2	0.1	
		E	Pressure Transducer	2	0.1	
		F	Hydrazine Tank (15-in OD)	1	15	
		G	Latching Valves	2	1	
		H	Thruster (0.1 lb)	4	2	
		I	Thruster (5.0 lb)	3	3	
		J	Remote Terminal	1	5	
		K	Power Conditioning	1	5	
			Cabling	AR		
			Connectors	AR		
			Environmental Protection	AR		
			Structure	AR		

TABLE III. STANDARDIZED SUBSYSTEM MODULES -- ATTITUDE AND VELOCITY CONTROL SYSTEM (CONTINUED) 3

MODULE CODE	MODULE NAME	ITEM	COMPONENT	QTY	(lb) WT ITEM	BLOCK DIAGRAM
AVCS-8	Hot Gas Propulsion (N_2H_4) Large Tank	A	Nitrogen Tank (7.5-in OD)	1	5	
		B	Start Valve	1	1	
		C	Regulator Valve	1	4	
		D	Temperature Transducer	2	0.1	
		E	Pressure Transducer	2	0.1	
		F	Hydrazine Tank (24-in OD)	1	25	
		G	Latching Valves	2	1	
		H	Thruster (0.1 lb)	4	2	
		I	Thruster (5.0 lb)	3	3	
		J	Remote Terminal	1	5	
		K	Power Conditioning	1	5	
			Cabling	AR		
			Connectors	AR		
			Environmental Protection	AR		
			Structure	AR		
AVCS-9	Magnetic Torquer	A	Magnetometer (3 Axis)	1	7	
		B	Amplifier	1	3	
		C	Coil	3	10	
		D	Power Conditioning	1	5	
		E	Remote Terminal	1	5	

STANDARD SUBSYSTEM MODULES --GUIDANCE & NAVIGATION

MODULE CODE	MODULE NAME	ITEM	COMPONENT	QTY	(lb) WT ITEM	BLOCK DIAGRAM
GN-1	Inertial Measuring Unit	A	Control and Readout Electronics	1	40	
		B	Three Rate and Rate Integration Gyro Assy	1	40	
		C	Three Accelerometer Assy	1	20	
		D	Power Conditioning	1	5	
		E	Remote Terminal	1	5	
GN-2	Guidance & Control Processor Assembly	A	Input/Output Unit	1	7	
		B	Memory Unit	1	7	
		C	Arithmetic & Control Unit	1	7	
		D	Power Conditioning	1	5	
		E	Remote Terminal	1	5	

V. SATELLITE MODULE ASSIGNMENT

The primary factors for the satellite module assignment of SRU's are the performance requirements. Where high pointing accuracy ($\leq 0.1^{\circ}$) or low attitude rate ($\leq 10^{-4}$ deg/sec) is required, the reaction wheel can operate within the jet deadband. This implies a set of three orthogonal wheels (AVCS-3) and four reaction jet SRU's (AVCS-7 or -8 depending on whether a small or a large tank is used) placed symmetrically about the satellite. Some overcapacity (overkill) will result with this approach but the attitude control requirements can be met. The results are shown in Table IV.

In cases where the attitude pointing accuracy is less restrictive, a biased momentum system can be implemented. This implies a single reaction wheel (AVCS-2, for example) SRU which can be operated at a constant speed to provide gyroscopic stability about two orthogonal axes. Precessional control and the control about the wheel spin axis can be effected by two reaction jet SRU's. This approach tends to minimize the total number of SRU's per satellite and should provide a sufficiently satisfactory performance. The assignment of the sensing SRU's depends on whether a low or high altitude orbit is involved and if a star tracker is required. All sensing SRU's contain five sun sensors for a 4π steradian coverage of the sun. The magnetic torquer SRU can be used in low earth orbits for momentum desaturation. The IMU and the computer SRU's are required for highly accurate and complex applications.

It should be noted, however, that the assignment approach presented would result in a feasible rather than an optimum system. Further optimizations with respect to the SRU configurations, weight, and number per satellite are necessary. The feasibility of using a single type of reaction jet SRU (hot gas, resistojet or catalytic thruster) for all missions should also be reexamined in the future when the performance requirements and the satellite characteristics become still better defined.

Table IV

Satellite Module Assignment

Satellite			Space Replaceable Units			
Payload Code			Attitude and Velocity Control		Guidance & Navigation	
Mission Model	SSPDA	Payload Code	Item	Qty	Item	Qty
AST-1B	AS-03	Cosmic Background	AVCS-3	1	GN-1	1
			AVCS-6A	1	GN-2	1
			AVCS-7	4		
			AVCS-9	1		
AST-1C	AS-05	Advanced Radio Astronomy	AVCS-3	1	GN-1	1
			AVCS-5	1	GN-2	1
			AVCS-7	4		
AST-3	SO-03	Solar Physics Mission	AVCS-3	1	GN-1	1
			AVCS-6A	1	GN-2	1
			AVCS-7	4		
			AVCS-9			
AST-9A	HE-11	Focusing X-Ray Telescope - 1.2 M	AVCS-4	3	GN-1	1
			AVCS-6A	1	GN-2	1
			AVCS-7	4		
			AVCS-9	1		
AST-9B	HE-01	Focusing X-Ray Telescope - 3.0 M	AVCS-4	3	GN-1	1
			AVCS-6A	1	GN-2	1
			AVCS-7	4		
			AVCS-9	1		
PHY-1A	HE-07	Small High Energy Observatory	AVCS-3	1	GN-1	1
			AVCS-5A	1	GN-2	1
			AVCS-7	4		
			AVCS-9	1		

Table IV

Satellite Module Assignment (continued)

Satellite			Space Replaceable Units			
Payload Code			Attitude and Velocity Control		Guidance and Navigation	
Mission Model	SSPDA	Payload Code	Item	Qty	Item	Qty
PHY-1B	AP-01	Upper Atmospheric Explorer	AVCS-2	1		
			AVCS-5A	1		
			AVCS-8	2		
			AVCS-9	1		
PHY-1C	AP-02	Medium Altitude Explorer	AVCS-2	1		
			AVCS-7	2		
			AVCS-5A	1		
			AVCS-9	1		
PHY-2A	AP-04	Gravity and Relativity Satellite - LEO	AVCS-3	1	GN-1	1
			AVCS-5A	1	GN-2	1
			AVCS-8	4		
			AVCS-9	1		
EO-3A	EO-08	Earth Observatory Satellite	AVCS-3	1	GN-1	1
			AVCS-6A	1	GN-2	1
			AVCS-8	4		
			AVCS-9	1		
EO-4A	EO-09	Sync. Earth Observatory Satellite	AVCS-1	1	GN-2	1
			AVCS-6	1		
			AVCS-8	4		
EO-6	EO-12	Tiros	AVCS-3	1	GN-2	1
			AVCS-6A	1		
			AVCS-7	4		
			AVCS-9	1		
EO-7	EO-07	Synchronous Meteorological Satellite	AVCS-3	1	GN-1	1
			AVCS-6	1	GN-2	1
			AVCS-7	4		

Table IV
Satellite Module Assignment (continued)

Satellite			Space Replaceable Units			
Payload Code			Attitude and Velocity Control		Guidance and Navigation	
Mission Model	SSPDA	Payload Code	Item	Qty	Item	Qty
EOP-3	OP-07	Seasat B	AVCS-2 AVCS-5A AVCS-7 AVCS-9	1 1 2 1	N/A	
EOP-4	OP-01	Geopause	AVCS-2 AVCS-5 AVCS-7	1 1 2	N/A	
EOP-7	OP-04	Gravsat	AVCS-3 AVCS-5A AVCS-8 AVCS-9	1 1 4 1	N/A	
NND-1	CN-51	International Communication Satellite	AVCS-3 AVCS-5 AVCS-7	1 1 4	GN-2	1
NND-2A	CN-52	U.S. Domestic Satellite - A	AVCS-1 AVCS-5 AVCS-7	1 1 4	N/A	
NND-2B	CN-53	U.S. Domestic Satellite - B	AVCS-2 AVCS-5 AVCS-7	1 1 4	GN-2	1
NND-2D	CN-58	U.S. Domestic Satellite - C	AVCS-1 AVCS-5 AVCS-7	1 1 4	N/A	

Table IV
Satellite Module Assignment (continued)

Satellite			Space Replaceable Units			
Payload Code			Attitude and Velocity Control		Guidance and Navigation	
Mission Model	SSPDA	Payload Code	Item	Qty	Item	Qty
NND-3	CN-54	Disaster Warning Satellite	AVCS-3 AVCS-5 AVCS-7	1 1 4	N/A	
NND-4	CN-55	Traffic Management Satellite	AVCS-3 AVCS-5 AVCS-7	1 1 4	N/A	
NND-5	CN-56	Foreign Communication Satellite	AVCS-1 AVCS-5 AVCS-8	1 1 2	N/A	
NND-6	CN-59	Communication R&D Prototype	AVCS-1 AVCS-5 AVCS-8	1 1 2	GN-2	1
NND-8	EO-56	Environment Monitoring Satellite	AVCS-3 AVCS-6A AVCS-8 AVCS-9	1 1 4 1	GN-2	1
NND-11	EO-61	Earth Resources Satellite - LEO	AVCS-3 AVCS-5 AVCS-7 AVCS-9	1 1 4 1	GN-2	1
NND-12	EO-59	Earth Resources Satellite - GEO	AVCS-3 AVCS-6 AVCS-8	1 1 4	GN-1 GN-2	1 1

Table IV
Satellite Module Assignment (continued)

Satellite			Space Replaceable Units			
Payload Code			Attitude and Velocity Control		Guidance and Navigation	
Mission Model	SSPDA	Payload Code	Item	Qty	Item	Qty
NND-13	EO-62	Earth Resources Satellite - Foreign	AVCS-3 AVCS-6 AVCS-8	1 1 4	GN-1 GN-2	1 1
NND-14	OP-08	Global Earth and Ocean Monitoring Satellite	AVCS-3 AVCS-5A AVCS-8 AVCS-9	1 1 4 1	N/A	

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REPORT TITLE
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REPORT NO.	PUBLICATION DATE	SECURITY CLASSIFICATION
ATR-74(7341)-1	5 April 1974	UNCLASSIFIED

(NOTE: FOR OFF-SITE PERSONNEL, SHOW LOCATION SYMBOL, e.g. JOHN Q. PUBLIC/VAFB)

J. R. Allder
T. A. Bergstralh
V. A. Chobotov (3)
H. Hecht
J. P. Johnson
H. K. Karrenberg
L. J. Kulakowski
J. L. LeMay
L. R. Sitney
L. T. Stircker
M. G. Wolfe
R. R. Wolfe

APPROVED BY Robert R Wolfe DATE 6/4/74

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NASA Scientific & Technical
Information Facility (3)
P. O. Box 33
College Park, Maryland 20740

NASA-Headquarters
Washington, D. C. 20546

V. Huff, Code MTE (29)

R. R. Carley, Code MTE (2)

Dr. J. W. Wild, Code MTE (1)

NASA
Mr. Duncan Collins
P. O. Box 92960
Worldway Postal Center
Los Angeles, CA 90009
Building 120, Rm. 1406B (1)

New Technology Representative
Code KT (1)

APPROVED BY Robert R Wolfe DATE 6/4/74

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