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APOLLO TRAINING

STABILIZATION & CONTROL
SYSTEM
STUDY GUIDE

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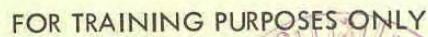
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LIST OF SCS ABBREVIATIONS

ACS	ATTITUDE CONTROL SUBSYSTEM (OF SCS)	IMU	INERTIAL MEASURING UNIT
AGAP	ATTITUDE GYRO ACCELEROMETER PACKAGE	LCL VERT. . . .	LOCAL VERTICAL
AGC	APOLLO GUIDANCE COMPUTER	MIN-IMP	MINIMUM IMPULSE
AGCU	ATTITUDE GYRO COUPLING UNIT	MTVC.	MANUAL THRUST VECTOR CONTROL
ARCS	AUTOMATIC REACTION CONTROL SYSTEM	P	ROLL BODY RATE
ARS	ATTITUDE REFERENCE SUBSYSTEM	PHI ϕ	ROLL
AS/GPD	ATTITUDE SET/GIMBAL POSITION DISPLAY	PSI ψ	YAW
BMAG	BODY MOUNTED ATTITUDE GYRO	$\dot{\phi}$	PITCH BODY RATE
CDU	COUPLING DISPLAY UNIT	$\dot{\psi}$	YAW BODY RATE
CSS	CONTROL STICK STEERING (MANEUVER)	RC	CONTROL RESOLVER
DAGAPECA	DISPLAY-AGAP-ELECTRONIC CONTROL ASSEMBLY	RCS	REACTION CONTROL SYSTEM
DECA	DISPLAY ELECTRONIC CONTROL ASSEMBLY	RGP	RATE GYRO PACKAGE
DRCS	DIRECT REACTION CONTROL SYSTEM	SMRD.	SPIN MOTOR ROTATION DETECTOR
ECA	ELECTRONIC CONTROL ASSEMBLY	SPS	SERVICE PROPULSION SYSTEM
ECA-P	PITCH ELECTRONIC CONTROL ASSEMBLY	THETA θ	PITCH
ECA-R	ROLL ELECTRONIC CONTROL ASSEMBLY	TVC	THRUST VECTOR CONTROL
ECA-Y	YAW ELECTRONIC CONTROL ASSEMBLY	V_C	CIRCULAR ORBIT VELOCITY
ECA-X	AUXILIARY ELECTRONIC CONTROL ASSEMBLY	V_0	INITIAL VELOCITY
ETI	ELAPSE TIME INDICATOR		
FDAI	FLIGHT DIRECTOR ATTITUDE INDICATOR		
G&N	GUIDANCE & NAVIGATION		
GOSS	GROUND OPERATION SUPPORT SYSTEM		

SECTION I
INTRODUCTION

1.1 GENERAL

THE STABILIZATION AND CONTROL SYSTEM (SCS) IS THE FIRST OF FOUR INTEGRATED SYSTEMS FOR SPACECRAFT CONTROL. THE SCS RECEIVES MANUAL INPUTS FROM THE CREW AND ELECTRICAL INPUTS FROM THE INERTIAL SENSORS TO GENERATE COMMANDS THAT RESULT IN ROTATION AND TRANSLATION MANEUVERS. SECOND, THE PROPULSION SYSTEMS PROVIDE ALL THE EXTERNAL FORCES AND MECHANICAL COUPLES WHICH CAUSE THE SPACECRAFT TO MANEUVER UNDER DIRECT CONTROL OF THE SCS. THIRD, MAN IS INCLUDED BECAUSE OF THE FLEXIBILITY AND RELIABILITY THAT HE CONTRIBUTES. THE CREW WILL OBTAIN INFORMATION FROM THE ON-BOARD APOLLO GUIDANCE COMPUTER (AGC), MANNED SPACE FLIGHT NETWORK (MSFN), OR DISPLAYS THAT WILL INDICATE THE NECESSITY TO INITIATE ONE OR MORE OF THE SIX BASIC MOTIONS. FOURTH, A COMBINATION OF THE GUIDANCE AND NAVIGATION SYSTEM (G&N) AND SCS HAVE THE CAPABILITY OF COMPLETE CONTROL OVER C/M ATTITUDE AFTER THE REQUIRED ELECTRONICS HAVE BEEN PROPERLY CONFIGURED BY THE ASTRONAUTS.

1.2 PHYSICAL DESCRIPTION

THE SCS CONSISTS OF CONTROLS AND DISPLAYS, LOCATED ON THE MAIN DISPLAY PANEL, THE INERTIAL SENSORS, AND THE ELECTRONIC CONTROL ASSEMBLIES, LOCATED IN THE LOWER EQUIPMENT BAY. THE SCS COMPONENT LOCATION IN THE LOWER EQUIPMENT BAY IS SHOWN IN FIGURES 1-1 AND 1-2.

THE RATE GYRO PACKAGE (RGP) CONTAINING THE THREE RATE GYROS.

THE ATTITUDE GYRO AND ACCELEROMETER PACKAGE (AGAP) CONTAINING THE PENDULOUS ACCELEROMETER AND THREE BODY MOUNTED ATTITUDE GYROS (BMAG).

THE ELECTRONIC CONTROL ASSEMBLY (ECA) FOR PITCH (ECA-P), AND YAW ECA (ECA-Y), AND ROLL ECA (ECA-R).

THE AUXILIARY ECA (ECA-X) CONTAINING THE ATTITUDE GYRO COUPLING UNIT (AGCU) AND THE SPS THRUST ON/OFF LOGIC.

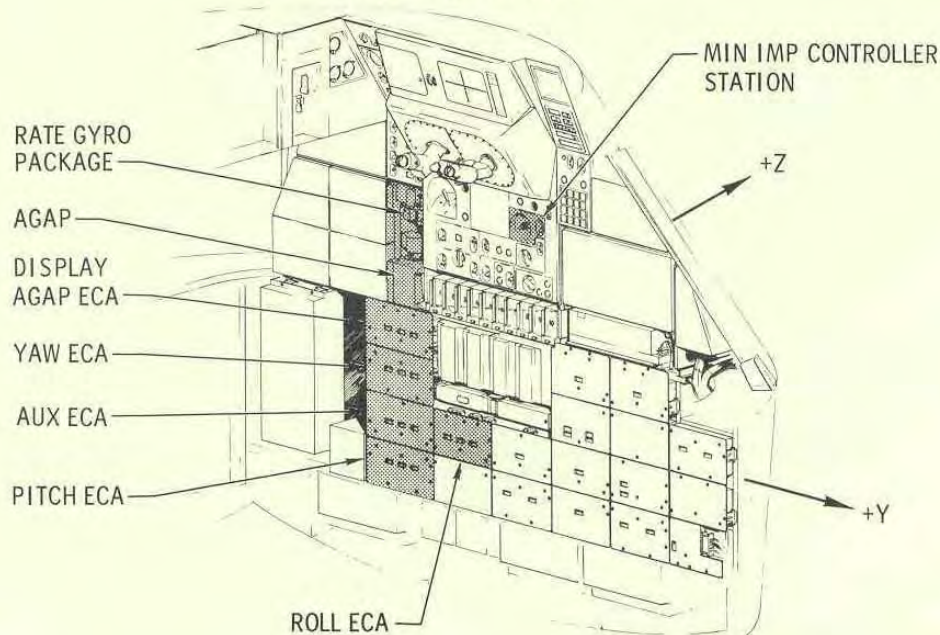
THE DISPLAY AND AGAP ECA (DAGAPECA) CONTAINING THE DISPLAY AND AGAP ELECTRONICS.

FOR DISCUSSION PURPOSES THE SCS MAY BE DIVIDED INTO THE FOLLOWING FIVE CATEGORIES:

INERTIAL SENSORS (3 TYPES)
ELECTRONIC CONTROL ASSEMBLIES (5)
SCS CONTROL PANEL
MANUAL CONTROLS (2 TYPES)
SCS DISPLAYS (3)

1-1

LOWER EQUIPMENT BAY SCS FUNCTIONS



F204B

FIGURE 1-1

1-2

SCS EQUIPMENT

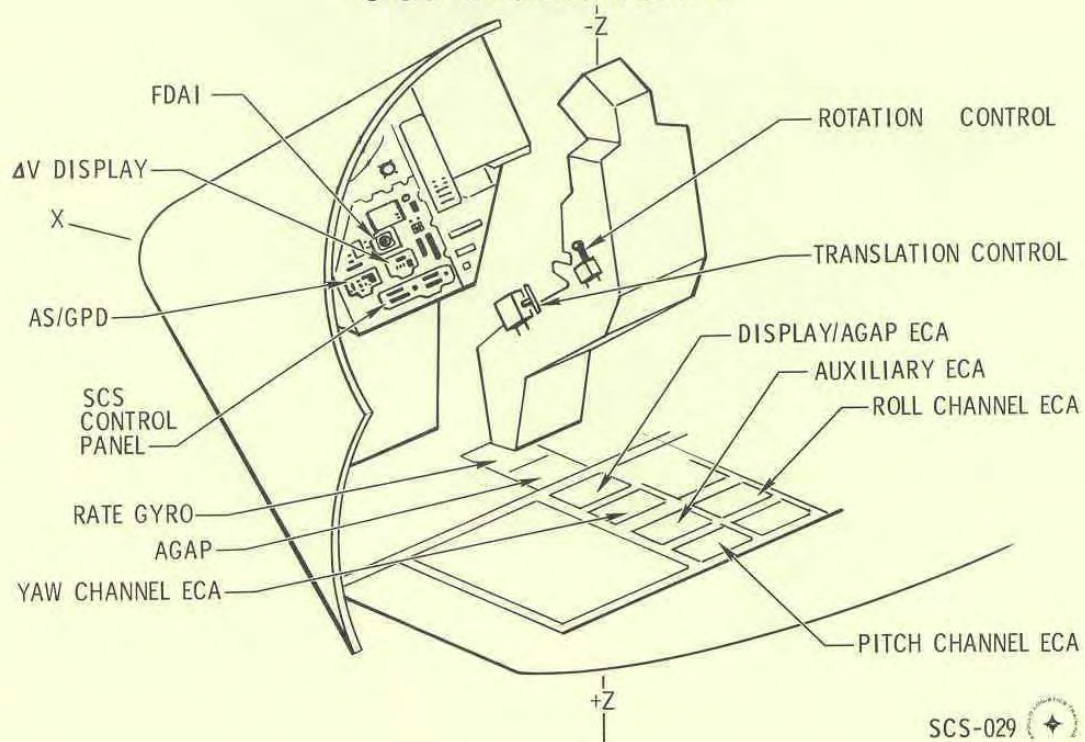


FIGURE 1-2

1-3

SCS AND APOLLO SUBSYSTEM INTERFACES

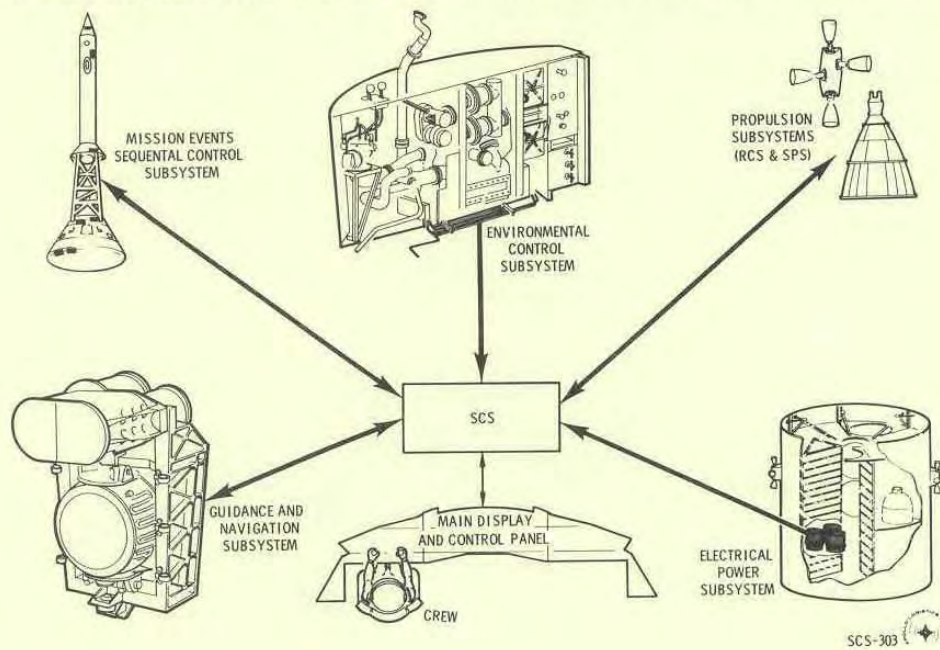


FIGURE 1-2A

1-3A

CONTAINED WITHIN THESE PACKAGES OR CATEGORIES ARE THE FOLLOWING UNITS COMPRISING THE STABILIZATION AND CONTROL SYSTEM (FIGURE 1-3).

- A. RATE GYRO PACKAGE
- B. ATTITUDE GYRO ACCELEROMETER PACKAGE
- C. PITCH ELECTRONIC CONTROL ASSEMBLY
- D. YAW ELECTRONIC CONTROL ASSEMBLY
- E. ROLL ELECTRONIC CONTROL ASSEMBLY
- F. AUXILIARY ELECTRONIC CONTROL ASSEMBLY
- G. DISPLAY AND AGAP ELECTRONIC CONTROL ASSEMBLY
- H. THREE AXES ROTATION CONTROLS (TWO)
- I. TRANSLATION CONTROLS (TWO)
- J. FLIGHT DIRECTOR ATTITUDE INDICATOR (FDAI)
- K. ATTITUDE SET/ GIMBAL POSITION DISPLAY (AS/GPD)
- L. DELTA V DISPLAY
- M. SCS CONTROL PANEL

1.3 FUNCTIONAL DESCRIPTION

THE SCS IS THE MEDIUM BY WHICH THE ASTRONAUTS, THE SERVICE PROPULSION SYSTEM, THE REACTION CONTROL SYSTEM, AND THE G&N SYSTEM ARE INTEGRATED INTO A CLOSED LOOP SPACECRAFT CONTROL SYSTEM.

THE TWO CLOSED LOOPS OF THE SCS ARE DEPICTED IN FIGURE 1-4. THE INNER LOOP INDICATES THE CAPABILITIES OF THE SCS TO PROVIDE S/C AUTOMATIC ATTITUDE HOLD, RATE STABILIZATION, AND THRUST VECTOR CONTROL WITH THE CAPABILITY OF CREW ACTION. THE OUTER LOOP REPRESENTS THE CAPABILITY OF THE G&N SYSTEM TO PROVIDE S/C ATTITUDE

CONTROL OR THRUST VECTOR CONTROL THROUGH THE SCS INTERFACE. RATE STABILIZATION, ORIGINATING IN THE RATE GYROS OF THE SCS FOR ALL OPERATING MODES, AIDS IN CONTROL OF S/C ATTITUDE. A THIRD LOOP, IMPLIED IN THE DIAGRAM, IS CREW OPERATION OF THE MANUAL DIRECT CONTROL TO PERFORM S/C MANEUVERS. THE SCS DISPLAYS PROVIDE THE CREW WITH INDICATION OF S/C RATES, ATTITUDE, AND ATTITUDE ERROR.

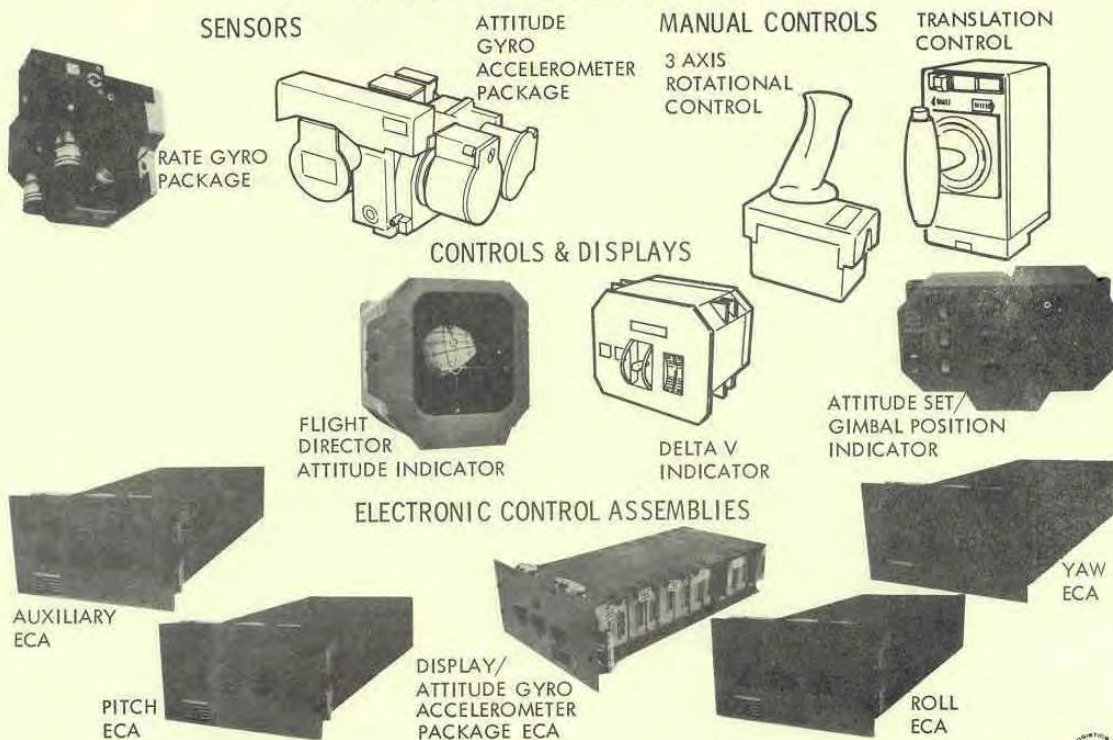
THE SCS PROVIDES THE FOLLOWING CAPABILITIES:

- A. RATE STABILIZATION DURING HIGH ALTITUDE ABORT AFTER S/C SEPARATION FROM THE BOOSTER, STABILIZATION OF THE C/M AFTER TOWER JETTISON, AND RATE DAMPING DURING ENTRY.
- B. ATTITUDE CONTROL AND RATE STABILIZATION ABOUT THREE AXES IN RESPONSE TO EITHER MANUAL OR AUTOMATIC ROTATION COMMANDS.
- C. TRANSLATION CONTROL ALONG THREE AXES IN RESPONSE TO MANUAL COMMANDS FOR ULLAGE MANEUVERS, TRANSPOSITION DOCKING, AND AS A BACKUP MODE TO THE LUNAR EXCURSION MODULE CONTROLLED RENDEZVOUS AND DOCKING.
- D. SERVICE PROPULSION SYSTEM THRUST VECTOR CONTROL.
- E. MANUAL SPS ENGINE THRUST ON-OFF FUNCTIONS WITH AN AUTOMATIC THRUST OFF FROM WITHIN THE DELTA V DISPLAY.
- F. DISPLAYS FOR VISUAL INDICATION OF S/C RATE, ATTITUDE, AND ATTITUDE ERROR.

THE SYSTEM HAS BEEN DIVIDED INTO THE FIVE CATEGORIES LISTED UNDER THE PHYSICAL DESCRIPTION. THE FUNCTION OF EACH OF THE CATEGORIES WILL BE DISCUSSED

1-4

SCS HARDWARE



SCS-019C

FIGURE 1-3

1-5

G&C FUNCTIONAL CONTROL LOOPS

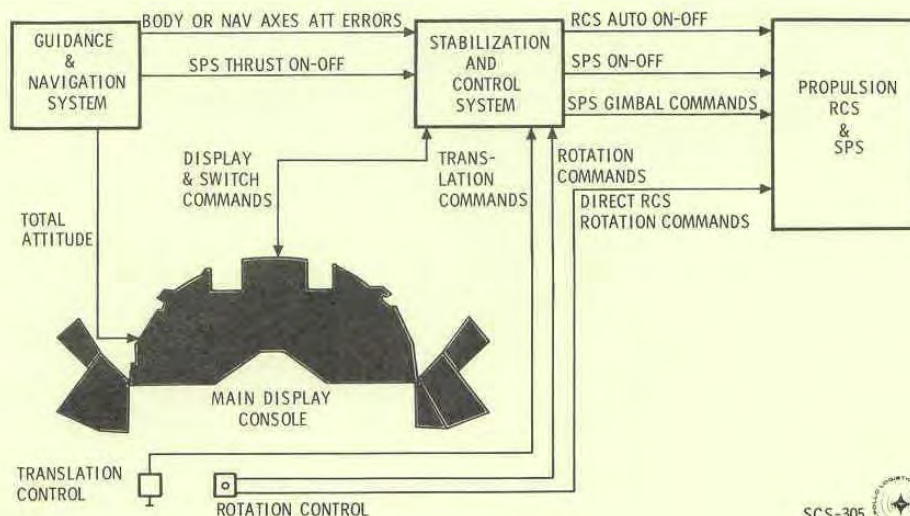



FIGURE 1-4

SCS-305  1-6

INDIVIDUALLY.

1.4 INERTIAL SENSORS

THE INERTIAL SENSORS ARE DISCUSSED ACCORDING TO THEIR OPERATING CHARACTERISTICS AND THE COMPONENTS USED TO PERFORM ALL REQUIRED FUNCTIONS INTERNAL TO THE SENSORS.

1.4.1 RATE GYRO PACKAGE

FIGURE 1-5 SHOWS THE RATE GYRO ASSEMBLY AND ITS MOUNTING BASE. IT CONSISTS OF THREE MINIATURE RATE GYROS, ORTHOGONALLY MOUNTED, TO SENSE ANGULAR RATES ABOUT THE THREE SPACECRAFT BODY AXES, AND THE ASSOCIATED ELECTRONICS REQUIRED FOR THE GYROS.

THE RATE GYRO PACKAGE ELECTRONICS IS A REPLACEABLE ASSEMBLY DESIGNATED AS PLUG-IN ELECTRONICS (PIE). THIS ASSEMBLY CONSISTS OF A WELDED MODULE, POWER TRANSFORMER, AND THREE SMRD ISOLATION TRANSFORMERS, WHICH CONVERTS THE THREE PHASE, 400 CPS POWER TO 26V, 400 CPS, SINGLE PHASE SIGNAL GENERATOR EXCITATION, AND ISOLATES THE GYRO SMRD MAGNETS FROM TRANSIENT VOLTAGES.

THE RATE GYRO PACKAGE IS DESIGNED TO BE MOUNTED IN THE SPACECRAFT WITH THE MOUNTING PLATE REFERENCE AXES ORIENTED TO SPACECRAFT BODY AXES WITHIN $\pm 1^\circ$. USE OF THE STANDARD TOOL ALLOWS REMOVAL OF THE GYRO ASSEMBLY FROM THE MOUNTING PLATE OR REPLACEMENT OF AN INDIVIDUAL GYRO IN THE GYRO ASSEMBLY. COOLING OF THE PACKAGE IS BY CONDUCTION TO THE MOUNTING PLATE WHICH IN TURN IS COOLED BY CONTACT WITH LIQUID COOLED COLD PLATE.

THE DISASSEMBLED MOUNTING BASE, GYROS, AND ELECTRONICS ARE SHOWN IN FIGURE 1-6. THE GYROS ARE SHOWN IN THEIR MOUNTED POSITIONS. THE ALIGNMENT PINS SHOWN IN THE MOUNTING BASE AID IN REPLACEMENT OF THE GYROS. THERE ARE SLOTS IN THE RING ABOUT THE GYROS THAT PERMITS OMITTING ANY ALIGNMENT PROCEDURE AFTER THE GYRO IS INSTALLED. THE CONNECTORS WILL NOT MATE UNTIL AFTER THE GYRO IS CORRECTLY ALIGNED WITH RESPECT TO THE ALIGNMENT PIN DURING THE INSTALLATION. THE GYROS ARE INTERCHANGEABLE BETWEEN THE THREE MOUNTING SLOTS FOR GYROS.

THE APOLLO RATE GYRO IS A HIGH RELIABILITY, MINIATURE COMPONENT WITH RELIABILITY AND RUGGEDNESS IN ITS MAJOR DESIGN GOALS. THE DESIGN OF THIS GYRO UTILIZES EXPERIENCE GAINED IN THE DESIGN OF SIMILAR COMPONENTS USED IN OTHER SPACE PROGRAMS, AND FEATURES A RUGGED SPRING RESTRAINT AND SELF-TEST TORQUING CIRCUITS CONSISTING OF A SELF-TEST TORQUING COIL AND A SMRD COMPLETELY ISOLATED FROM THE BASIC GYRO CIRCUITS AND FROM EACH OTHER, SO THAT FAILURE OF THE SELF-TEST CIRCUITS WILL NOT JEOPARDIZE PERFORMANCE OF THE GYRO.

1.4.1.1 PERFORMANCE CHARACTERISTICS

SOME MECHANICAL AND ELECTRICAL PERFORMANCE CHARACTERISTICS OF THE GYRO ARE:

- FULL SCALE RANGE $\pm 30^\circ/\text{SEC}$
- MAX. RATE WITHOUT DAMAGE $600^\circ/\text{SEC}$
- *RESIDUAL NULL $0.1^\circ/\text{SEC}$ ($+77^\circ\text{F}$)
- *THRESHOLD $.02^\circ/\text{SEC}$
- *RESOLUTION $0.06^\circ/\text{SEC}$

RATE GYRO PACKAGE

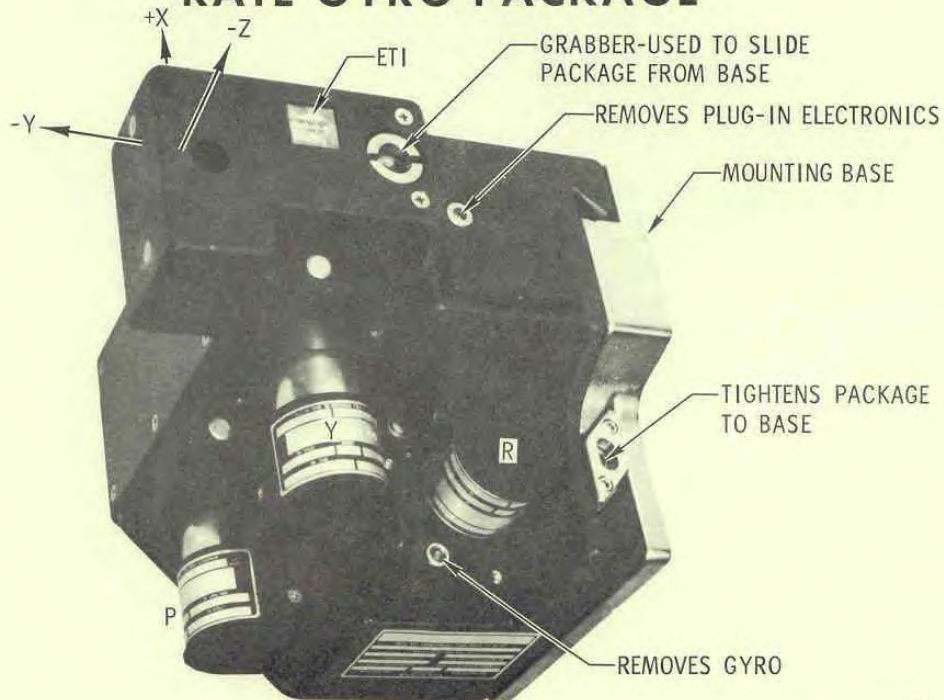


FIGURE 1-5

SCS-014B 1-8

RATE GYROS

ELECTRONICS & MOUNTING BASE SEPARATED

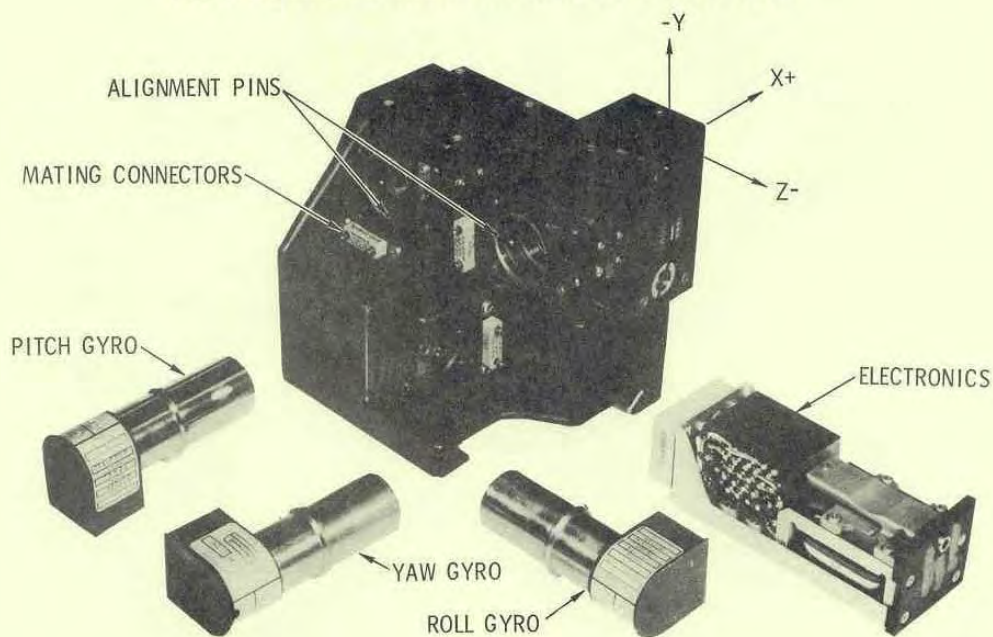


FIGURE 1-6

SCS-031 1-9

*ACCELERATION (GYROS AXES) 20G'S

*PARAMETERS DE-RATED TO PROVIDE HIGHEST RELIABILITY CONSISTENT WITH SYSTEM REQUIREMENT OF 10K HOURS (MTBF) AND 1400 HOURS SERVICE LIFE.

1.4.1.2 SPIN MOTOR

THE SPIN MOTOR USED IN THIS RATE GYRO IS A SYNCHRONOUS, THREE-PHASE HYSTERESIS MOTOR MOUNTED WITHIN THE GIMBAL SO THAT TEMPERATURE AND VIBRATIONS WILL NOT EFFECT PERFORMANCE. THE POWER ASSOCIATED WITH THE Y TO DELTA STEPDOWN TRANSFORMER FOR SPIN MOTOR EXCITATION IS 26 VOLTS, 400 CPS, THREE-PHASE. THE MAXIMUM ACCELERATION TIME FOR THE MOTOR TO REACH OPERATING SPEED IS 17 SECONDS.

1.4.1.3 GIMBAL ASSEMBLY

THIS ASSEMBLY INCLUDES THE SPIN MOTOR ASSEMBLY, PICKOFF ROTOR, TORQUER ROTOR, SMRD ASSEMBLY AND QUADRI-LEVEL SPRING (FOUR LEAF SPRING MOUNT). THIS HERMETICALLY SEALED ASSEMBLY IS SUPPORTED AT ONE END BY A LOW FRICTION, SHOCK RESISTANT BEARING AND AT THE OTHER END BY THE QUADRILEVER SPRING.

1.4.1.4 SIGNAL GENERATOR (PICKOFF)

THE PICKOFF IS A VARIABLE RELUCTANCE DEVICE USED TO CONVERT GIMBAL DISPLACEMENT TO A PROPORTIONAL ELECTRICAL OUTPUT. THE STATOR IS MOUNTED TO THE GIMBAL. THE ROTOR EXCITATION IS OBTAINED FROM THE SECONDARY OF

THE STEPDOWN TRANSFORMER IN THE POWER SUPPLY ASSEMBLY. THE SIGNAL GENERATOR OUTPUT VOLTAGE IS APPLIED AS A RATE INPUT TO THE PITCH, YAW, AND ROLL ECA'S AND TO THE DAGAPECA FOR THE FDAI RATE NEEDLE FUNCTION.

1.4.1.5 SPIN MOTOR ROTATION DETECTOR

THE SMRD IS MADE UP OF FOUR SOFT IRON DISCS, SILVER BRAZED INTO THE EDGE OF THE SPIN MOTOR AT 90° INTERVALS AND A PULSE GENERATOR (SMRD WINDINGS) MOUNTED BELOW THE TORSION SPRING. AS THE IRON DISCS PASS THE SMRD WINDINGS, THE RELUCTANCE OF THE AIR GAP IS CHANGED CAUSING A VOLTAGE TO BE INDUCED IN THE WINDINGS. THUS, A TYPICAL SMRD OUTPUT IS A SERIES OF PULSES.

THE OUTPUT OF THE SMRD IS FED BACK TO THE POWER SUPPLY ASSEMBLY WHERE IT IS ISOLATED ACROSS A TRANSFORMER. THIS SIGNAL IS SENT TO THE ROLL ECA WHERE IT IS PROCESSED FOR GROUND CHECKOUT USE.

1.4.1.6 GIMBAL TORQUER

THE GIMBAL TORQUER IS MOUNTED ALONG THE OUTPUT AXIS. THE STATOR IS WOUND TO PRODUCE A TORQUE ON THE ROTOR LOCATED WITHIN THE STATOR ON THE GIMBAL OUTPUT AXIS. THE STATOR WINDING IS MADE UP OF PATTERN AND CONTROL FIELD COILS. THUS, A DC OR AC EXCITATION APPLIED TO BOTH WINDINGS WILL CAUSE ALTERNATE POLARIZATION. REVERSAL OF CONTROL FIELD EXCITATION WILL REVERSE THE DIRECTION OF RESULTING TORQUE. IN ORDER TO OBTAIN LINEAR TORQUING, THE PATTERN WINDING CURRENT IS KEPT CONSTANT WHILE THE CONTROL FIELD CURRENT IS VARIED. THEREFORE, +28 VOLTS DC IS USED FOR PATTERN EXCITATION

I-10

DURING BENCH MAINTENANCE OR CALIBRATION.

1.4.1.7 QUADRILEVER SPRING

THIS TYPE OF SPRING MOUNT PROVIDES TORSION RESTRAINT WITH RADIAL SUPPORT FOR THE GIMBAL. THE FOUR LEAVES OF THE SPRING PROVIDE HIGH TRANSVERSE STIFFNESS, ELIMINATING BEARING SUPPORT AROUND THE TORSION SPRING. THUS, GYRO THRESHOLD AND RESOLUTION ARE IMPROVED BY REDUCING OVERALL BEARING FRICTION.

1.4.2 ATTITUDE GYRO ACCELEROMETER PACKAGE

FIGURE 1-7 SHOWS THE ATTITUDE GYRO ACCELEROMETER PACKAGE AND ITS MOUNTING BASE. IT CONSISTS OF THREE "SINGLE DEGREE OF FREEDOM" INTEGRATING GYROS, MOUNTED ORTHOGONALLY TO SENSE ANGULAR RATES ABOUT THE THREE SPACECRAFT BODY AXES, AND A PENDULOUS ACCELEROMETER, MOUNTED ON THE SPACECRAFT BODY X AXIS, TO SENSE POSITIVE ACCELERATIONS IMPARTED TO THE SPACECRAFT.

THE ATTITUDE GYRO ACCELEROMETER PACKAGE IS DESIGNED TO BE MOUNTED IN THE SPACECRAFT WITH THE MOUNTING PLATE REFERENCE AXES ORIENTED TO SPACECRAFT BODY AXES WITHIN ± 10 ARC MINUTES. THE GYRO INPUT AXES WILL BE ALIGNED WITHIN ± 10 ARC MINUTES OF THE REFERENCE AXES ON THE MOUNTING PLATE, AND THE ACCELEROMETER SENSITIVE AXES WITHIN ± 10 ARC MINUTES OF THE X AXIS OF THE PLATE. USE OF THE STANDARD TOOL ALLOWS REMOVAL OF THE ATTITUDE GYRO ACCELEROMETER ASSEMBLY FROM THE MOUNTING PLATE OR REPLACEMENT OF AN INDIVIDUAL GYRO OR THE ACCELEROMETER. COOLING OF THE PACKAGE IS BY CONDUCTION TO THE MOUNTING PLATE WHICH IN TURN IS COOLED BY CONTACT WITH A LIQUID

COOLED COLDPLATE.

1.4.2.1 PERFORMANCE CHARACTERISTICS

SOME MECHANICAL AND ELECTRICAL PERFORMANCE CHARACTERISTICS ARE:

GYRO

INPUT AXIS FREEDOM	$\pm 20^\circ$ MINIMUM
COMMAND RATE	$\pm 25^\circ/\text{SEC}$
GIMBAL FREEDOM	$\pm 4.64^\circ$
THRESHOLD	$\pm 0.1^\circ$
ACCELERATION (GYRO AXES)	20 G'S

ACCELEROMETER

PENDULUM TRAVEL	± 5.0 MR
THRESHOLD	$1.0 \times 10^{-4} \text{G}$
RANGE	-0.1G TO +2G
NULL TORQUE	$1.0 \times 10^{-4} \text{G}$
NULL UNCERTAINTY	$2.0 \times 10^{-4} \text{G}$

1.4.3 BODY MOUNTED ATTITUDE GYRO

THE FOLLOWING DISCUSSION DESCRIBES THE ATTITUDE GYRO (BMAG COMPONENTS SHOWN IN FIGURE 1-8).

INPUT TURNING RATES ABOUT THE INPUT AXIS PRODUCE A GYROSCOPIC PRECESSIONAL TORQUE ABOUT THE OUTPUT (GIMBAL) AXIS WHICH IS PROPORTIONAL TO THE PRODUCT OF THE INPUT TURNING RATE AND THE GYROSCOPIC ELEMENTS ANGULAR MOMENTUM. DUE TO LAMINAR SHEAR OF THE VISCOUS

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ATTITUDE GYRO ACCELEROMETER PACKAGE

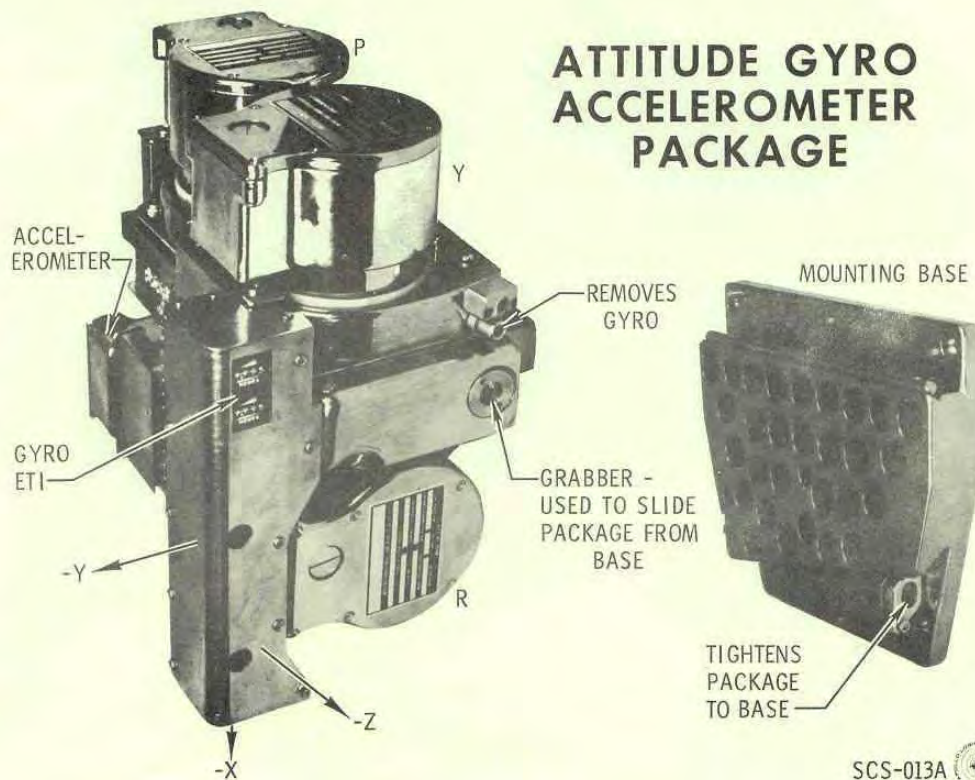


FIGURE 1-7

TYPICAL FLOATED INTEGRATING GYRO

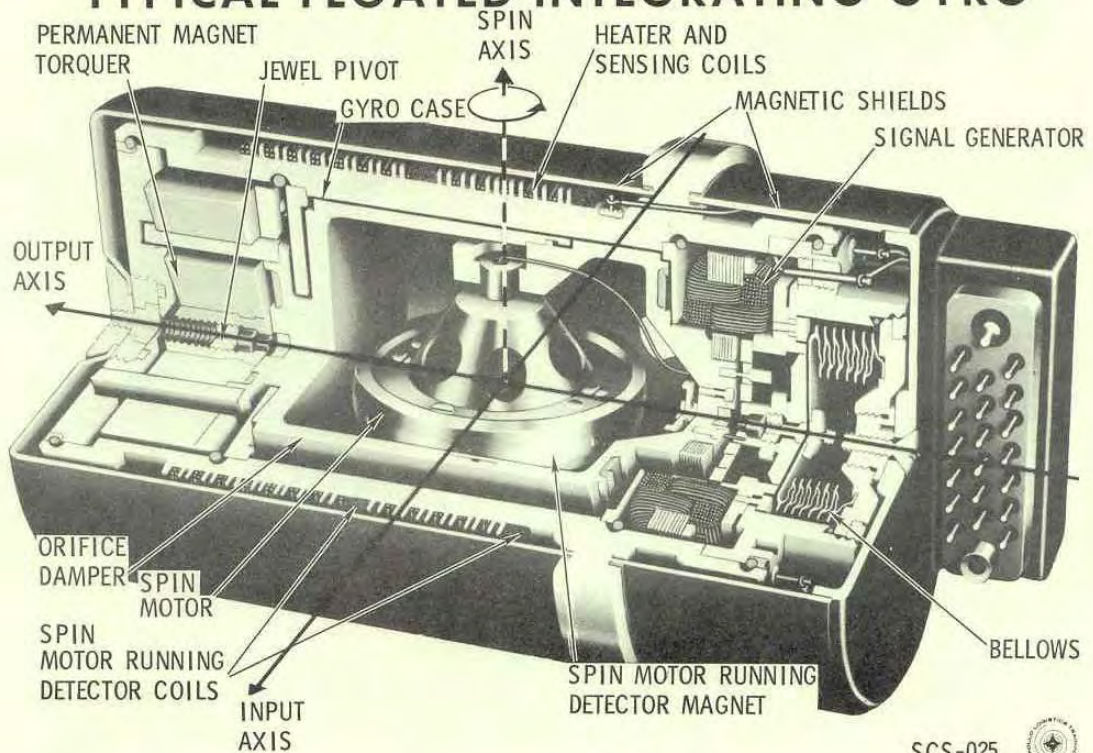


FIGURE 1-8

FLOTATION FLUID BETWEEN THE GIMBAL AND ITS CONCENTRIC CASE, VISCOUS RESTRAINT TORQUES ARE PRODUCED WHICH ARE PROPORTIONAL TO THE GIMBAL ANGULAR VELOCITY. THE GIMBAL ACCELERATES TO AN ANGULAR RATE AT WHICH THE VISCOUS RESTRAINT TORQUE BALANCES OUT THE PRECESSIONAL TORQUE. THE GIMBAL IS THUS TURNING AT A RATE PROPORTIONAL TO THE APPLIED INPUT, AND THE GIMBAL DISPLACEMENT IS A TIME INTEGRAL FUNCTION OF THE APPLIED TORQUE. THE SIGNAL GENERATOR PRODUCES AN OUTPUT VOLTAGE WHICH IS A DIRECT FUNCTION OF THE ANGULAR DISPLACEMENT OF THE GIMBAL. COMMAND INPUTS TO THE GYRO TORQUE GENERATOR DEVELOP TORQUE AT THE GIMBAL, AND COMMAND GIMBAL RESPONSE SIMILAR TO THAT DESCRIBED FOR GYRO INPUTS.

1.4.3.1 SPIN MOTOR

THE SPIN MOTOR IS A SYNCHRONOUS, THREE PHASE, 400 CPS HYSTERESIS MOTOR POWERED BY 13.6 VOLTS, 400 CPS FROM A SUPPLY IN THE DAGAPECA. THE SPIN MOTOR WILL OBTAIN A SYNCHRONOUS SPEED OF 24,000 RPM IN APPROXIMATELY 25 SECONDS.

1.4.3.2 GIMBAL ASSEMBLY

THE GIMBAL ASSEMBLY CONSISTS OF THE SIGNAL GENERATOR, TORQUE GENERATOR, AND EUTECTIC BALANCE PAN.

THE SIGNAL GENERATOR CONSISTS OF A SKEIN WOUND, 16 POLE, LAMINATED STATOR, AND AN EIGHT POLE LAMINATED ROTOR WHICH GATES THE FLUX LINKING THE STATOR POLES. THE STATOR HAS FOUR WINDINGS, THEY ARE: SIGNAL GENERATOR PRIMARY, SIGNAL GENERATOR SECONDARY, G INSENSITIVE DRIFT RATE PRIMARY AND G INSENSITIVE DRIFT RATE

SECONDARY. THE SIGNAL GENERATOR INDICATES ANGULAR POSITION OF THE GIMBAL WITH RESPECT TO THE CASE AND IS CAPABLE OF DETECTING DISPLACEMENTS OF LESS THAN 2 SECONDS OF ARC. THE G INSENSITIVE DRIFT RATE APPLIES A FIXED TORQUE TO NULL OUT G INSENSITIVE DRIFT RATE TO A NET VALUE LESS THAN 2°/HOUR DURING AN EARTH ORBIT MISSION AFTER AN INITIAL TRIM TO A DRIFT RATE OF 0.1°/HOUR.

THE TORQUER GENERATOR CONSISTS OF A HIGHLY STABLE ALNICO DELTA V PERMANENT MAGNET ASSEMBLY MOUNTED TO THE GYRO CASE, AND AN ENCAPSULATED MOVING COIL MOUNTED ON THE GIMBAL ASSEMBLY ALONG THE GYRO OUTPUT AXIS. DIRECT OR PULSED CURRENTS PASSED THROUGH FLEX LEADS TO THE COIL WILL DEVELOP A TORQUE ABOUT THE OUTPUT AXIS, ENABLING THE TORQUE GENERATOR TO HOLD THE GIMBAL AT SIGNAL GENERATOR NULL FOR ANY INPUT IN THE RANGE OF ZERO TO $\pm 25^\circ/\text{SECOND}$.

THE EUTECTIC BALANCE PAN CONSISTS OF A SMALL DISK WOUND WITH A HEATER AND FILLED WITH AN EUTECTIC ALLOY. THE BALANCE PAN IS MOUNTED ON THE OUTPUT AXIS ALLOWING DYNAMIC BALANCING OF THE GYRO AFTER ASSEMBLY.

1.4.3.4 ORIFICE DAMPER

ORIFICE DAMPING IS A TECHNIQUE FOR PROVIDING WIDE INPUT ANGULAR FREEDOMS USING RELATIVELY LOW VISCOSITY FLUOROLUBE AND PRACTICAL DAMPING GAP THICKNESS. THE ORIFICE DAMPER (PADDLE DAMPER) IS A COMBINATION OF TWO PAIRS OF PADDLES, ONE PAIR EXTENDING FROM THE CASE WALL AND THE OTHER FROM THE GIMBAL DIAMETER, RESULTING IN A GIMBAL ROTATION WHICH IS SMALLER THAN THE INPUT

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AXIS ROTATION.

1.4.3.5 TEMPERATURE CONTROL CIRCUIT

THE GYRO TEMPERATURE IS CONTROLLED BY A TEMPERATURE SENSING ELEMENT AND BUILT IN HEATER, WHICH WHEN CONNECTED AS ONE ARM OF A WHEATSTONE BRIDGE AND AMPLIFIER CONTROLLING A RELAY, THE TEMPERATURE OF THE GYRO IS HELD TO $170^\circ \pm 2^\circ\text{F}$. THE CASE HEATER CONSISTS OF TWO SECTIONS, ONE FOR WARMUP AND THE OTHER FOR NOMINAL CONTROL. WHEN THE GYRO REACHES OPERATING TEMPERATURE, A RELAY KEYED TO THE TEMPERATURE CONTROL BRIDGE WILL SWITCH AUTOMATICALLY TO THE NORMAL HEATER CIRCUIT.

1.4.3.6 SPIN MOTOR ROTATION DETECTOR

THE SMRD CONSISTS OF A PAIR OF SOFT IRON DISCS, SILVER BRAZED INTO THE EDGE OF THE SPIN MOTOR, AND A PAIR OF PICKUP COILS WOUND AROUND THE OUTSIDE OF THE GYRO CASE. AS THE IRON DISCS PASS THE PICKUP COILS, THE RELUCTANCE OF THE AIR GAP IS CHANGED CAUSING A VOLTAGE TO BE INDUCED.

1.4.4 ACCELEROMETER

INPUT ACCELERATIONS TO THE ACCELEROMETER CAUSE DISPLACEMENT OF THE PENDULOUS MASS RELATIVE TO THE CASE, INDUCING A SIGNAL IN THE MOVING COIL OF A DIFFERENTIAL TRANSFORMER PICKOFF. THIS SIGNAL IS FED INTO A SERVO AMPLIFIER WHERE IT IS AMPLIFIED, DEMODULATED, AND FED BACK AS DC TORQUER CURRENT. TORQUE BALANCE IS ESTABLISHED IN THE PRESENCE OF STEADY INPUT ACCELERATIONS SO THAT THE FEEDBACK CURRENT PROVIDES A

LINEAR MEASURE OF ACCELERATION. THE FOLLOWING DISCUSSION DESCRIBES THE ACCELEROMETER COMPONENTS SHOWN IN FIGURE 1-9.

1.4.4.1 PENDULOUS ELEMENT

THE PENDULOUS ELEMENT IS ISOLATED FROM THE INSTRUMENT CASE BY MEANS OF A PAIR OF FIXTURES, OR HINGED PIVOTS. THE PIVOTS, FREE TO DEFLECT IN ONLY ONE PLANE, OFFER EXTREME RIGIDITY TO DEFLECTION IN EACH OF THE OTHER TWO ORTHOGONAL PLANES.

1.4.4.2 SIGNAL GENERATOR

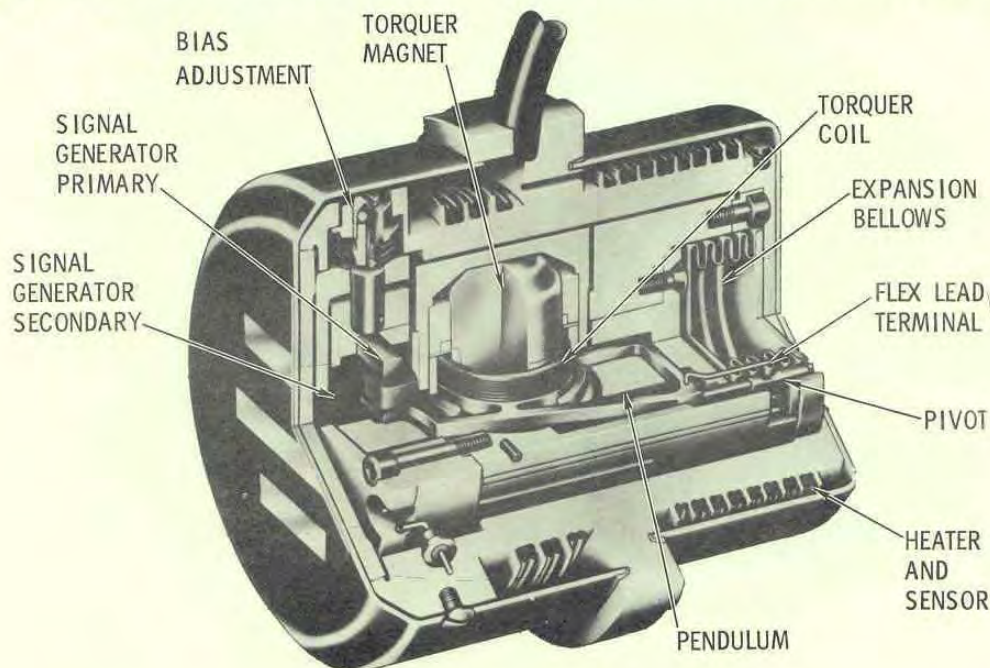
THE SIGNAL GENERATOR MOUNTED AT THE APEX OF THE PENDULUM FRAME, PROVIDING MAXIMUM ANGULAR SENSITIVITY, IS EXCITED BY A 28.8 KC EXCITATION VOLTAGE. THE SECONDARY IS A MOVING COIL PICKOFF WITH A FERRITE COIL FOR FLUX CONCENTRATION WHICH PROVIDES THE PHASE SENSITIVE OUTPUT SIGNALS.

1.4.4.3 TORQUER

RESTORING TORQUES REQUIRED TO MAINTAIN A TORQUE BALANCED CONDITION RESULT FROM DC CURRENT FLOW THROUGH THE TORQUER COILS. THE TORQUER DESIGN UTILIZES THE PRINCIPLE EMPLOYED IN ELECTRO DYNAMIC LOUD SPEAKERS, IN WHICH THE MOVING COIL IS LOCATED WITHIN A RADIAL FLUX GAP. THE TORQUER UTILIZES A PAIR OF COILS, COAXIALLY POSITIONED ON THE PENDULUM FRAME.

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DG 1770 HINGED PENDULUM ACCELEROMETER



SCS-028

FIGURE 1-9

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1.4.4.4 TEMPERATURE CONTROL

TO PROVIDE THE REQUIRED VISCOUS DAMPING, THE ENTIRE INSTRUMENT HOUSING IS FILLED WITH A SILICONE TYPE OIL.

THE ACCELEROMETER CAN OPERATE OVER A 20°F TEMPERATURE VARIATION AND MAINTAIN A RELATIVELY CONSTANT SCALE FACTOR BY MEANS OF A SIMPLE COMPENSATOR. BECAUSE OF THE ACCURACY REQUIRED, A HEATER AND TEMPERATURE SENSOR IS USED TO MAINTAIN THE TEMPERATURE AT $170^{\circ} \pm 2^{\circ}\text{F}$.

1.5 ELECTRONIC CONTROL ASSEMBLIES

THE ECA'S ARE INDIVIDUAL CHASSIS WITH CARD MODULES THAT ARE REPLACEABLE AT THE FACTORY ONLY BECAUSE OF THE HUMIDITY PROOF CARD CONNECTORS. THEY ARE MOUNTED ON THE S/C COLD PLATE TO CONDUCT THE ELECTRONICALLY GENERATED HEAT AWAY FROM THE PACKAGES. TELEMETRY CONDITIONING EQUIPMENT IS PROVIDED IN EACH UNIT AS ARE FRONT PANEL CONNECTORS FOR PRELAUNCH CHECKOUT.

1.5.1 PITCH, ROLL, AND YAW ELECTRONIC CONTROL ASSEMBLIES

THE PITCH, ROLL, AND YAW ECA'S ARE SIMILAR WITH THE EXCEPTION THAT THE ECA-R DOES NOT CONTAIN THRUST VECTOR CONTROL CIRCUITRY. EACH ECA PERFORMS THE FOLLOWING FUNCTIONS:

- A. PROVIDE A MEANS TO SELECT THE MODES AND CONFIGURATION OF THE CONTROL SYSTEM OPERATION FROM EXTERNALLY SUPPLIED SWITCHING

SIGNALS.

- B. ACCEPT INPUT CONTROL SIGNALS AND TRANSFORM THEM INTO SUITABLE OUTPUT COMMANDS FOR THE REACTION CONTROL SYSTEM ENGINES OR TO THE SERVICE MODULE PROPULSION SYSTEM ENGINE GIMBALS.
- C. PROVIDE INDIVIDUAL VOLTAGE SOURCES NOT AVAILABLE FROM THE SPACECRAFT POWER SYSTEM.

THE ROLL, PITCH, AND YAW ECA'S ACCEPT CONTROL SIGNAL COMMANDS FROM THE G&N SYSTEM, THE RATE GYRO PACKAGE, THE ROTATION AND TRANSLATION CONTROLS, AND THE BMAG'S. THE CONTROL OUTPUTS ARE SIGNALS TO THE SERVICE AND COMMAND MODULE REACTION CONTROL SYSTEM ENGINES AND THE SERVICE PROPULSION SYSTEM ENGINE (GIMBAL ACTUATOR MAGNETIC CLUTCHES). THE MAIN SWITCHING INTERFACES ARE WITH THE SCS CONTROL PANEL, SPACECRAFT SEPARATION SYSTEMS, AND POWER SWITCHES.

1.5.2 AUXILIARY ELECTRONIC CONTROL ASSEMBLY

THE AUXILIARY ELECTRONIC CONTROL ASSEMBLY CONTAINS CIRCUITRY TO MECHANIZE THE ATTITUDE GYRO COUPLING UNIT AND THE SERVICE PROPULSION SYSTEM ENGINE THRUST ON/OFF CONTROL FUNCTION.

THE FUNCTION OF THE AGCU LOOP IS TO CONVERT BMAG ATTITUDE OUTPUTS TO SUITABLE SCS ATTITUDE DISPLAYS. THIS LOOP CAN BE INITIALLY ALIGNED TO THE G&N SYSTEM INERTIAL COORDINATES (IMU GIMBAL ANGLES). IT ALSO

MUST TRANSFORM ATTITUDE SET DIAL INFORMATION INTO BODY AXES INFORMATION. THE DISPLAY ON THE FDAI ATTITUDE ERROR NEEDLES WILL BE REFERENCED TO S/C BODY AXES. THE DISPLAY ON THE FDAI ATTITUDE RATE NEEDLES WILL BE REFERENCED TO BODY AXES. IN THE SCS LOCAL VERTICAL MODE, THE AGCU PROVIDES AN ORBITAL RATE TORQUING SIGNAL TO THE BMAG'S TO MAINTAIN S/C ATTITUDE WITH RESPECT TO A LOCAL VERTICAL.

THE SPS ENGINE ON/OFF CONTROL FUNCTION PROVIDES CIRCUITRY TO ACCEPT AND CONDITION ON/OFF COMMANDS FROM THE SCS OR THE G&N SYSTEM AND OFF COMMANDS FROM THE DELTA V DISPLAY ELECTRONICS. THE OUTPUT FROM THIS CIRCUITRY WILL INITIATE OR TERMINATE SPS ENGINE THRUSTING.

1.5.3 DISPLAY AND ATTITUDE GYRO ACCELEROMETER PACKAGE ELECTRONIC CONTROL ASSEMBLY (DAGAPECA)

THE DAGAPECA PROVIDES THE ELECTRONICS ASSOCIATED WITH THE SCS DISPLAYS, THE BMAG'S, AND THE ACCELEROMETER.

THE DISPLAY ELECTRONICS PORTION OF THE DAGAPECA PROVIDES CIRCUITRY TO:

- A. ACCEPT AND CONDITION TOTAL ATTITUDE SIGNALS FROM THE G&N SYSTEM AND THE AGCU FOR USE IN POSITIONING THE FDAI ATTITUDE BALL.
- B. ACCEPT THE CONDITION ATTITUDE ERROR SIGNALS FROM THE G&N SYSTEM AND THE SCS

FOR DISPLACING THE FDAI ATTITUDE ERROR INDICATORS.

- C. ACCEPT AND CONDITION ANGULAR VELOCITY SIGNALS FROM THE RATE GYRO PACKAGE FOR DISPLACING THE FDAI ANGULAR VELOCITY INDICATORS.
- D. ACCEPT AND CONDITION ENGINE GIMBAL POSITION SIGNALS FROM THE SPS ENGINE ACTUATOR POSITION TRANSDUCERS FOR POSITIONING THE GIMBAL POSITION INDICATORS ON THE AS/GPD.
- E. ACCEPT THE CONDITION ACCELERATION SIGNALS FROM AGAP ELECTRONICS PORTION OF THE DAGAPECA FOR THE DELTA V DISPLAY.

THE AGAP ELECTRONICS PORTION OF THE DAGAPECA PROVIDES THE CIRCUITRY TO:

- A. ACCEPT AND CONDITION BMAG INPUTS FOR THE AGCU.
- B. ACCEPT AND CONDITION AGCU TORQUING COMMANDS TO THE BMAG'S.
- C. CONTROL BMAG AND ACCELEROMETER TEMPERATURES.
- D. CONTROL AND CONDITION THE ACCELEROMETER REBALANCE LOOP AND INPUTS TO THE INTEGRATOR DURING ENTRY.
- E. SUPPLY EXCITATION VOLTAGES TO THE BMAG'S AND THE ACCELEROMETER.
- F. CONDITION THE BMAG AND ACCELEROMETER OUTPUTS FOR THE TELEMETRY SYSTEMS.

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1.6 SCS CONTROL PANEL

THE SCS CONTROL PANEL PROVIDES CONTROL OVER THE FOLLOWING SCS FUNCTIONS:

- A. CONTROL MODE SELECTION SWITCHES (4)
- B. ATT DEADBAND SELECT SWITCH
- C. 0.05g ENTRY SWITCH
- D. BACKUP RATE SELECTION SWITCHES (3)
- E. CHANNEL ENABLE SWITCHES (4)
- F. DIRECT MODE SELECTION
- G. LIMIT CYCLE SELECTION

THE MODE CONTROL SWITCHES ALLOW SELECTION OF ONE OF THE FOLLOWING MODES:

- A. SCS ATTITUDE CONTROL
- B. SCS LOCAL VERTICAL
- C. G&N ATTITUDE CONTROL
- D. MONITOR
- E. G&N DELTA V
- F. SCS DELTA V
- G. G&N ENTRY
- H. SCS ENTRY

THE ATT DEADBAND SWITCH PROVIDES TWO LEVELS OF ATTITUDE DEADBANDS IN ALL THREE ROTATION AXES OF THE S/C.

THE BACKUP RATE SELECTION SWITCHES PROVIDE INDIVIDUAL SELECTION OF A REDUNDANT RATE SIGNAL SOURCE.

THE CHANNEL ENABLE SWITCHES PROVIDE AN ELECTRICAL ENABLE OF S/M OR C/M RCS BY CHANNELS (E.G., PITCH, YAW, AND ROLL JETS). DIRECT MANUAL CONTROL OF THE RCS IS NOT AFFECTED BY THE ENABLE FUNCTION.

1.7 MANUAL CONTROL

THE MANUAL CONTROLS PERMIT SIX DEGREES OF COMMANDABLE VELOCITIES AND FOR ACCELERATION TO PERFORM ALL MANEUVERS ON THE APOLLO MISSION.

1.7.1 THREE AXES ROTATION CONTROL

THE THREE AXES ROTATION CONTROL IS A HAND OPERATED STICK TYPE ASSEMBLY CONTAINING TRANSDUCERS AND SWITCHES FOR A SIMULTANEOUS CONTROL OF ANGULAR RATES ABOUT THE SPACECRAFT PITCH, ROLL, AND YAW AXES. THE CONTROL IS DETACHABLE FROM THE CREW SEATS FOR USE AT OTHER LOCATIONS WITHIN THE COMMAND MODULE. BREAKOUT SWITCHES ENERGIZE SYNCHRONIZING CIRCUITS WITHIN THE SCS WHEN THE S/C IS TO BE MANUALLY MANEUVERED. THE S/C ANGULAR RATES CAN BE COMMANDED WITH THE CONTROL. DIRECT SWITCHES ARE PROVIDED IN EACH AXIS TO CONTROL THE RCS SOLENOIDS BY BYPASSING THE SCS ELECTRONICS AND ROUTING THE COMMAND DIRECTLY TO THE RCS. TWO ROTATION CONTROLS ARE PROVIDED AND BOTH MAY BE USED SIMULTANEOUSLY IF NECESSARY. A MECHANICAL LOCKING DEVICE IS PROVIDED TO PREVENT INADVERTANT MOVEMENT OF THE CONTROL.

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1.7.2 TRANSLATION CONTROL

THE TRANSLATION CONTROL IS HAND OPERATED T HANDLE ASSEMBLY CONTAINING SWITCHES FOR CONTROL OF TRANSLATIONAL VELOCITIES ALONG THE SPACECRAFT BODY AXES, CREW INITIATED ABORTS, AND TO OPEN THE ATTITUDE HOLD CONTROL LOOPS AND SELECT MANUAL THRUST VECTOR CONTROL. TRANSLATION MANEUVERS ARE INTRODUCED BY THE ASTRONAUTS'S APPLICATION OF FORCE TO THE T HANDLE IN THE DESIRED DIRECTION OF MOTION. ABORT COMMANDS AND MANUAL COMMAND MODES ARE INITIATED BY ROTARY MOTION OF THE T HANDLE. THE CONTROL INITIATES TRANSLATION COMMANDS THROUGH ON/OFF SWITCHES RATHER THAN PROPORTIONAL TRANSDUCERS. THE TRANSLATION CONTROL CONTAINS A LOCKING MECHANISM TO PREVENT INADVERTENT STICK MOTION. TWO CONTROLS ARE PRESENTLY PROVIDED FOR THE LEFT ARM REST OF THE COMMANDER'S AND SYSTEMS ENGINEER'S SEATS.

1.8 SCS DISPLAYS

THE SCS DISPLAYS PROVIDE INFORMATION TO THE CREW FOR MANUAL INPUTS.

1.8.1 FLIGHT DIRECTOR ATTITUDE INDICATOR

THE ATTITUDE DISPLAY PORTION OF THE FDAI IS A SERVO DRIVEN GIMBALLED BALL WITH FULL AND CONTINUOUS BI-DIRECTIONAL ROTATION CAPABILITIES IN PITCH, YAW, AND ROLL. AN INDICATION OF ATTITUDE IS PROVIDED BY OBSERVATION OF THE BALL MARKINGS IN RELATION TO TWO INDICES. A BODY AXES INDEX AND NAVIGATION AXES INDEX. THE BALL UTILIZES A FIXED VEHICLE-MOVING HORIZON CONCEPT. SIGNALS TO DRIVE THE BALL ARE PROCESSED IN THE

DAGAPECA ACCORDING TO DATA RECEIVED FROM THE AGCU IN THE AUXILIARY ECA FOR SCS CONTROL MODES, AND FROM THE IMU GIMBAL RESOLVERS DURING G&N CONTROL MODES. AN INDICATION OF IMU GIMBAL ANGLE LIMITATIONS IS PROVIDED ON THE BALL TO AVOID MANEUVERING THE SPACECRAFT THROUGH ANGLES WHICH WOULD CAUSE AN IMU GIMBAL LOCK. PITCH IS INDICATED BY GREAT CIRCLE LINES ON THE BALL, YAW BY MINOR CIRCLES LINES, AND ROLL BY A SEPARATE ROLL "BUG" ABOUT THE PERIPHERY OF THE BALL. THE BALL MAY BE ALIGNED TO A NEW REFERENCE THROUGH THE AGCU LOOP USING THE FDAI ALIGN SWITCH ON THE AS/GPD.

THE ATTITUDE ERROR PORTION OF THE FDAI CONSISTS OF THREE "FLY-TO" NEEDLE INDICATORS THAT DISPLAY ATTITUDE ERROR IN BODY AXES OR, DURING G&N ENTRY, NAVIGATION AXES. THE ATTITUDE ERROR SIGNALS MAY ORIGINATE IN THE G&N SYSTEM OR THE SCS DEPENDING ON THE OPERATIONAL MODE. THE ATTITUDE NEEDLES CAN DISPLAY THE ERRORS BETWEEN S/C AND THE COMMAND ATTITUDES DIALED INTO THE ATTITUDE SET DIALS ON THE AS/GPD. WHEN HOLDING AN INERTIAL ATTITUDE, THE ATTITUDE ERRORS DISPLAYED REPRESENTS THE S/C DRIFT FROM THE COMMANDED ATTITUDE WITHIN THE DEADBAND LIMITS. THE RANGE OF DISPLAYED ATTITUDE ERRORS IS CHANGED ACCORDING TO THE SELECTED MODES.

THE ANGULAR VELOCITY INDICATORS ARE THREE "FLY-TO" NEEDLE TYPE DISPLAYS MOUNTED ABOUT THE PERIPHERY OF THE FDAI TO INDICATE ANGULAR ROTATION RATES ABOUT S/C BODY AXES. THE NORMAL SIGNAL INPUT TO THE ANGULAR VELOCITY INDICATORS ARE BODY RATES DERIVED FROM THE SCS RATE GYROS. HOWEVER, WHEN A BACKUP RATE SOURCE IS SELECTED, THESE INDICATORS DISPLAY BODY RATES DERIVED FROM THE

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DERIVED FROM THE BMAG'S. THE RANGE OF THE RATE DISPLAY ALSO CHANGES WITH THE SELECTED MODE.

1.8.2 ATTITUDE SET/GIMBAL POSITION DISPLAY

THE ATTITUDE SET/GIMBAL POSITION DISPLAY PROVIDES AN INDICATION OF SPS ENGINE GIMBAL YAW AND PITCH POSITION. THUMBWHEELS ARE PROVIDED TO MANUALLY POSITION THE ENGINE GIMBALS PRIOR TO INITIATING A DELTA V MANEUVER. THIS FUNCTION IS REQUIRED TO APPROXIMATELY ALIGN THE SPS ENGINE'S THRUST VECTOR THROUGH THE SPACECRAFT'S CENTER OF GRAVITY. GIMBAL POSITION INDICATOR SIGNALS ARE DERIVED FROM THE SPS ENGINE GIMBAL POSITION TRANSDUCERS. COMMANDS TO THESE GIMBALS ARE PROCESSED BY THE SCS ELECTRONIC CONTROL ASSEMBLIES.

IN ADDITION TO THE ENGINE GIMBAL DISPLAYS AND CONTROLS, THE AS/GPD CONTAINS TWO SWITCHES. THE ATT SET SWITCH, IN CONJUNCTION WITH THE DIALS AND THUMBWHEELS, CAN BE USED TO INSERT NEW COMMANDED ATTITUDE ORIENTATIONS THAT WILL APPEAR AS ATTITUDE ERROR INDICATIONS ON THE FDAI. THE FDAI ALIGN SWITCH PROVIDES ALIGNMENT OF THE AGCU AND THUS THE FDAI BALL TO A NEW REFERENCE DETERMINED BY THE READING ON THE PITCH, YAW, AND ROLL THUMBWHEELS.

1.8.3 DELTA V DISPLAY

THE DELTA V DISPLAY PROVIDES INDICATIONS OF VELOCITY CHANGES AFTER ASCENT, AND AUTOMATIC BACKUP AND MANUAL CONTROL OF VELOCITY CHANGES. THE DELTA V SET SWITCH PROVIDES SLEWING CONTROL OF THE DELTA V

REMAINING DIGITAL DISPLAY TO PRESET THE DESIRED VELOCITY IN FT./SEC. AS THE SPACECRAFT ACCELERATES IN THE +X DIRECTION, THE DELTA V REMAINING DISPLAY DECREASES AS A FUNCTION OF THE INTEGRATED SCS ACCELEROMETER SIGNAL.

THE DIRECT ULLAGE SWITCH IS USED TO PERFORM A BACKUP +X ACCELERATION USING THE DIRECT SOLENOIDS IN THE RCS PRIOR TO IGNITION OF THE SPS ENGINE.

THE THRUST CONTROL SWITCH PROVIDES ARMING POWER TO THE SPS ENGINE PROPELLANT VALVES FOR NORMAL IGNITION OF THE SPS ENGINE. IT ALSO PROVIDES A BACKUP THRUST OFF COMMAND TO THE G&N OR SCS AUTOMATIC THRUST OFF COMMAND. THE SWITCH ALSO PROVIDES A DIRECT ON COMMAND TO THE SPS ENGINE.

THE THRUST ON SWITCH IS ILLUMINATED AT ALL TIMES WHEN THE SCS OR G&N HAS A THRUST ON COMMAND. IT ALSO PERMITS THE ASTRONAUT TO PERFORM THE MANUAL INPUT TO COMMAND THRUST ON IN THE SCS DELTA V MODE. THE AUTOMATIC THRUST OFF COMMAND IN THE SCS DELTA V MODE IS COMMANDED WHEN THE DELTA V REMAINING DISPLAY READING IS ZERO OR LESS.

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SECTION II

CONTROLS AND DISPLAYS

2.1 INTRODUCTION

THE SCS CONTROLS AND DISPLAYS ARE DESIGNED TO ALLOW UTILIZATION OF MAN IN THE CONTROL LOOP. HE IS PROVIDED WITH THE CAPABILITY TO MONITOR AND EVALUATE GROSS MALFUNCTIONS FOR AUTOMATIC ATTITUDE CONTROL MANEUVERS. AT HIS PEROGATIVE, HE CAN MANUALLY FLY THE SPACECRAFT.

2.2 SCS CONTROL PANEL

THE CONTROL PANEL SHOWN IN FIGURE 2-1 CONTAINS THE TOGGLE SWITCHES REQUIRED FOR CONFIGURATION OF THE SCS INTO ITS EIGHT OPERATING MODES, CONTROL ENABLING FUNCTIONS, REDUNDANT RATE GYRO SELECTION, DIRECT MODE ENABLING, AND ATTITUDE PERFORMANCE (DEAD-BAND, LIMIT CYCLE, AND ETC.) SELECTION. THE SCS CONTROL SWITCHES ARE LOCATED ON THE MAIN DISPLAY CONSOLE JUST FORWARD AND ABOVE THE TRANSLATION CONTROL ON THE COMMANDER'S LEFT ARM REST. THIS LOCATION PERMITS LEFT HAND SWITCHING FOR SCS FUNCTIONS IN A FULLY PRESSURIZED SPACE SUIT.

2.2.1 MODE SELECTION

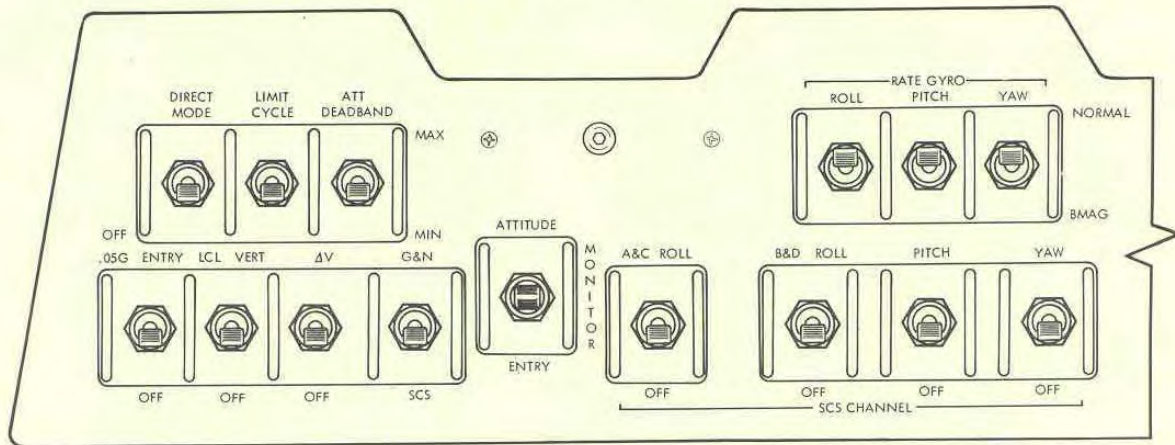
THE MODE SELECTION IS CONTROLLED BY FOUR SWITCHES. THE FIRST ORDER SELECTION IS PERFORMED BY

THE G&N-SCS SWITCH. IT SELECTS THE SOURCE OF CONTROL AND DISPLAY INFORMATION FOR TOTAL ATTITUDE DISPLAY, ATTITUDE ERROR DISPLAY, AND CONTROL INPUTS. THE THREE POSITION SWITCH LABELED ATTITUDE-MONITOR-ENTRY CONTROLS THE BASIC SELECTION OF DISPLAY SCALE FACTORS, MANEUVER RATE CAPABILITY, LEVEL OF RATE DAMPING, AND ENABLES SELECTION OF ADDITIONAL MODES IN THE ATTITUDE AND ENTRY POSITIONS. THE DELTA V SWITCH WILL BE USED TO MODIFY THE ATTITUDE POSITION (G&N OR SCS) AND SELECT THE DESIRED DELTA V MODE (G&N OR SCS). THE LCL VERT SWITCH WILL MODIFY THE SCS AND ATTITUDE POSITION OF THE FIRST TWO SWITCHES TO GENERATE THE CORRECT CONFIGURATION FOR MAINTAINING A LOCAL VERTICAL ATTITUDE WHILE IN A EARTH ORBIT. THE ENTRY POSITION OF THE THREE POSITION SWITCH WILL PERMIT OPERATION OF THE .05G SWITCH TO SELECT THE REQUIRED CHANGES IN THE SCS CONFIGURATION TO ACHIEVE THE CORRECT ATTITUDE CONTROL FOR THE AERODYNAMIC PHASE OF EARTH ENTRY. THERE ARE EIGHT SELECTABLE MODES AS SHOWN IN TABLE 2-1. IT LISTS THE MODE SELECTED VERSUS THE SWITCH POSITION. FIGURE 2-2 GIVES THE SWITCH OPERATION THAT IS REQUIRED TO PROVIDE THE MODE SELECTION.

TABLE 2-1. OPERATING MODE VS SELECTION SWITCH POSITIONS

MODE	SW #1	SW #2	SW #3	SW #4
MONITOR	G&N	MONITOR	OFF	OFF

SCS CONTROL PANEL



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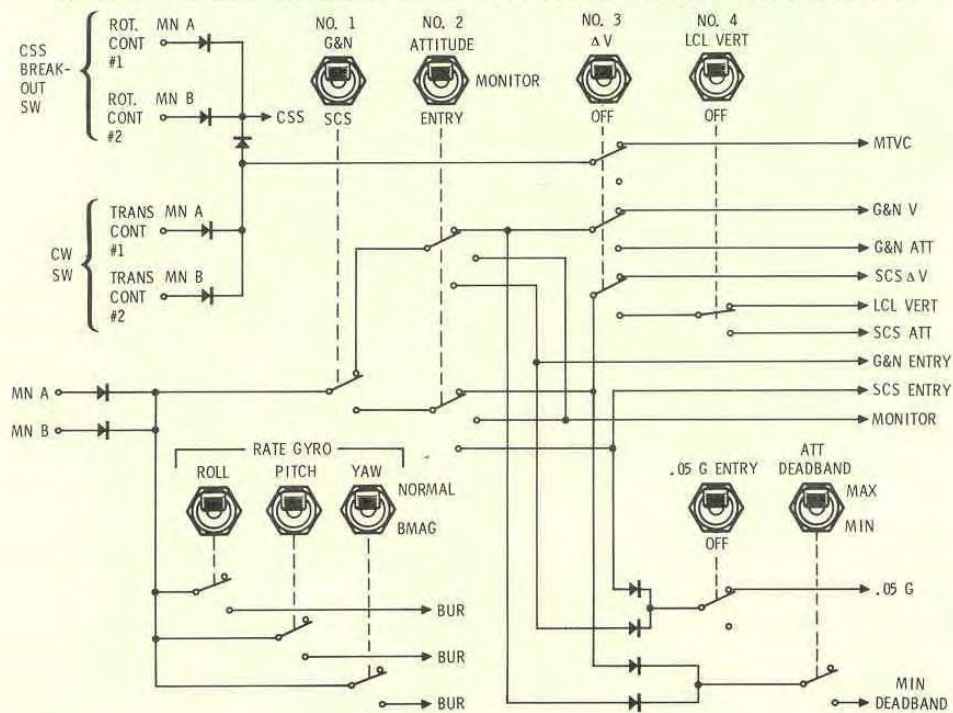
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FIGURE 2-1

2-2

SCS CONTROL PANEL SWITCHING



SCS-703B



FIGURE 2-2

2-3

TABLE 2-1. OPERATING MODE VS SELECTION SWITCH POSITIONS (CONT'D)

MODE	SW #1	SW #2	SW #3	SW #4
G&N ATT. CONT.	G&N	ATTITUDE	OFF	OFF
G&N DELTA V	G&N	ATTITUDE	DELTA V	OFF
G&N ENTRY	G&N	ENTRY	OFF	OFF
SCS LOCAL VERT	SCS	ATTITUDE	OFF	LOC VERT
SCS ATT. CONT.	SCS	ATTITUDE	OFF	OFF
SCS DELTA V	SCS	ATTITUDE	DELTA V	OFF
SCS ENTRY	SCS	ENTRY	OFF	OFF

2.2.1.1 MONITOR MODE

THE MONITOR MODE OF OPERATION WILL BE FOR THE LAUNCH PHASE OF THE NORMAL APOLLO MISSIONS. IT WILL PROVIDE AUTOMATIC RATE DAMPING OF THE S/C FOR THE CONTINGENCIES NORMALLY CONSIDERED IN THE LAUNCH PHASES IF ACTIVATED BY THE SEQUENTIAL EVENTS CONTROL SYSTEM. IT ALSO PROVIDES A RATE DAMPED MODE ONLY WHEN DESIRED IN THE MISSION. THE DISPLAYS ARE CONTROLLED BY THE G&N AND THE SCS RATE GYROS. TRANSLATIONS ALONG THE X, Y, AND Z AXES ARE ALSO PROVIDED IN THIS MODE FOR THE C/M-S/M CONFIGURATION. ADDITIONAL USE MAY BE INCORPORATED

AS THE EXACT MECHANIZATION FOR ORBIT WITH THE SIVB ATTACHED TO THE S/C AS DEFINED.

2.2.1.2 G&N ATTITUDE CONTROL MODE

THE G&N ATTITUDE CONTROL MODE CAN BE USED DURING ORBIT PERIODS BETWEEN ORBIT INJECTION AND ENTRY. THE GUIDANCE SYSTEM MUST BE FUNCTIONING DURING THIS MODE. THE FUNCTIONS AVAILABLE INCLUDE THE CAPABILITY OF AUTOMATIC ATTITUDE HOLD, MANUAL AND AUTOMATIC ATTITUDE MANEUVERS, AND TRANSLATIONS ALONG THE X, Y, OR Z AXES. HOWEVER, ATTITUDE HOLD WILL BE THE NORMAL FUNCTION OF THIS MODE.

2.2.1.3 G&N DELTA V MODE

THE G&N DELTA V MODE IS SELECTED WHEN A VELOCITY CHANGE, REQUIRING THE USE OF THE SERVICE PROPULSION SYSTEM, IS TO BE MADE AND THE G&N SYSTEM IS OPERATIONAL. IN THIS MODE, THE G&N SYSTEM WILL CONTROL THE ATTITUDE AND VELOCITY CHANGES NECESSARY TO CORRECT THE S/C TRAJECTORY AS REQUIRED. THIS IS THE PRIMARY MODE OF CONTROL FOR VELOCITY CORRECTIONS WITH THE SERVICE PROPULSION SYSTEM. TRANSLATION CONTROL IS PROVIDED IN THIS MODE EXCEPT WHEN THE SPS ENGINE IS THRUSTING.

2.2.1.4 G&N ENTRY MODE

THE G&N ENTRY MODE IS USED TO PERFORM A PROGRAMMED AUTOMATIC ENTRY THROUGH THE EARTH'S ATMOSPHERE

TO A SELECTED LANDING SITE. THE PROGRAM IS INITIATED PRIOR TO .05G SENSING AND REQUIRES CREW ACTION TO CONFIGURE THE SCS ELECTRONICS FOR ENTRY AERODYNAMIC CONDITIONS. THE AUTOMATIC PROGRAM CONTROLS SPACECRAFT RANGE AND AZIMUTH BY COMMANDS TO THE ROLL AXIS ELECTRONICS OF THE SCS. THE G&N ENTRY MODE IS THE PRIMARY OPERATING MODE FOR ENTRY. A CLOCKWISE ROTATION OF THE TRANSLATION CONTROL GIVES THE CREW THE CAPABILITY TO MANUALLY FLY THE G&N COMMANDS.

2.2.1.5 SCS LOCAL VERTICAL MODE

THE SCS LOCAL VERTICAL MODE IS A SPECIAL CASE OF ATTITUDE HOLD USING THE SCS. IT WOULD BE USED IN ORBITAL PERIODS TO HOLD THE S/C AT SOME APPROXIMATELY FIXED ATTITUDE WITH RESPECT TO THE LOCAL VERTICAL OF THE EARTH. THE S/C WILL BE ORIENTED TO THE DESIRED ATTITUDE AND DIRECTION, WITH RESPECT TO THE ORBITAL PATH, BEFORE INITIATING THIS MODE OF OPERATION. TRANSLATION CONTROL IS AVAILABLE IN THIS MODE, BUT NOT CONSIDERED DESIRABLE FOR THE NORMAL FUNCTION THIS MODE PERFORMS.

2.2.1.6 SCS ATTITUDE CONTROL MODE

THE SCS ATTITUDE CONTROL MODE OF OPERATION CAN BE USED DURING THE ORBITAL PHASE OF THE MISSION. IN THIS MODE, THE G&N SYSTEM NEED NOT BE FUNCTIONAL. THE CAPABILITIES OF THIS MODE ARE AUTOMATIC ATTITUDE HOLD, MANUAL ATTITUDE MANEUVERS, AND TRANSLATION ALONG THE VEHICLE BODY AXES. ATTITUDE CONTROL WILL BE THE NORMAL FUNCTION OF THIS MODE.

2.2.1.7 SCS DELTA V MODE

THE SCS DELTA V MODE OF OPERATION PERFORMS INERTIALLY ORIENTED THRUSTING MANEUVERS WITH THE SERVICE PROPULSION SYSTEM BY CHANGING THE VEHICLE ATTITUDE TO KEEP THE THRUST VECTOR ORIENTATION INERTIALLY FIXED. IT WILL ALSO MAINTAIN CROSS AXIS VELOCITY WITHIN THE MANEUVER ACCURACY REQUIRED. THIS MODE OF OPERATION CAN PERFORM, OR COMPLETE, ALL THRUSTING MANEUVERS IN THE APOLLO MISSION WHERE INERTIALLY FIXED THRUST VECTOR ORIENTATION WILL CONFORM TO THE MISSION TRAJECTORY REQUIREMENTS.

THE SCS DELTA V MODE IS A BACKUP TO THE G&N DELTA V MODE FOR CONTROL OF THE SERVICE PROPULSION SYSTEM WHEN PERFORMING DELTA V MANEUVERS.

AN ADDITIONAL THRUST VECTOR CONTROL FUNCTION IS NOW INCORPORATED FOR THE MANNED SPACECRAFT. IT PROVIDES FOR MANUAL THRUST VECTOR CONTROL FROM THE ROTATION CONTROL WITH THE SELECTION OF EITHER G&N OR SCS DELTA V MODES AND A CW ROTATION OF THE TRANSLATION CONTROL. IT PERMITS DIRECT CONTROL FROM THE ROTATION CONTROL TO THE SERVO DRIVE AMPLIFIER #2 IN THE THRUST VECTOR CONTROL ELECTRONICS FOR GIMBALLING THE SERVICE PROPULSION ENGINE.

2.2.1.8 SCS ENTRY

THE SCS ENTRY MODE IS A MANUAL BACKUP MODE FOR THE G&N ENTRY MODE. THE ASTRONAUT CAN USE MANUAL PROPORTIONAL RATE CONTROL OR THE MANUAL DIRECT SYSTEM TO "FLY" A SAFE ENTRY. DISPLAYS WILL BE PROVIDED TO

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EVALUATE THE ENTRY TRAJECTORY. THE DISPLAYED INDICATIONS PROVIDE THE CUES FOR ATTITUDE CONTROL INPUTS REQUIRED TO PERFORM A SAFE ENTRY. NO RANGE OR AZIMUTH CONTROL IS REQUIRED IN THE SCS ENTRY MODE.

2.2.2 RATE GYRO SELECTION

RATE GYRO SELECTION CONSISTS OF THREE, TWO POSITION TOGGLE SWITCHES. THE TWO POSITIONS ARE NORMAL AND BMAG. IN THE NORMAL POSITION, THE SCS DISPLAYS AND ELECTRONICS OBTAIN RATE INPUT SIGNALS FROM THE RATE GYRO PACKAGE. THE BMAG POSITION WILL CONVERT THE SELECTED BMAG (PITCH, ROLL, OR YAW) TO A RATE GYRO AND INSERT ITS SIGNALS INTO THE SCS DISPLAYS AND ELECTRONICS IN PLACE OF THE NORMAL RATE GYRO FOR THE SELECTED AXES (PITCH, ROLL, OR YAW). ONE OR ALL THREE SWITCHES CAN BE PLACED IN THE BMAG POSITION, AS REQUIRED, SHOULD CONTINGENCIES ARRIVE. THE AGCU WILL NOT BE OPERATIONAL WITH ONE BMAG IN THE CAGED CONFIGURATION.

2.2.3 CHANNEL ENABLE SWITCHES

THE CHANNEL ENABLE FUNCTION IS DESIRABLE IN SEGMENTS OF THE MISSION WHERE NO STRICT ATTITUDE CONTROL IS REQUIRED. THE CHANNEL ENABLE SWITCH CAN BE PLACED TO THE OFF POSITION AND REMOVE AUTOMATIC ATTITUDE CONTROL AND PROPORTIONAL RATE MANEUVER CAPABILITIES. ATTITUDE CONTROL CAN BE USED TO SET UP CONSTANT ANGULAR VELOCITIES ABOUT ONE OR MORE AXES; AND THEN BY PLACING THE CHANNEL ENABLE SWITCHES TO THE OFF POSITION, IT WILL PERMIT THE ANGULAR VELOCITIES TO CONTINUE WHEN THE ROTATION CONTROL IS RETURNED TO NEUTRAL WITH ZERO COMMAND OUTPUT. THE FOUR CHANNEL ENABLE SWITCHES ARE

TWO POSITION TOGGLE SWITCHES LABELED A&C ROLL, B&D ROLL PITCH, AND YAW. EACH CHANNEL ENABLE SWITCH WILL CONTROL FOUR REACTION CONTROL ENGINES. THEREFORE, TWO SWITCHES ARE REQUIRED FOR THE ROLL CHANNEL. A&C ROLL WILL BE INEFFECTIVE AFTER C/M-S/M SEPARATION BECAUSE OF A REDUCTION IN THE NUMBER OF ROLL REACTION CONTROL ENGINES AND REMOVAL OF TRANSLATION REQUIREMENTS AFTER SEPARATION OF THE C/M-S/M. THE CHANNEL ENABLE FUNCTIONS WILL NOT INHIBIT THE MANUAL DIRECT MODE WHEN IN THE OFF POSITION.

2.2.4 ATTITUDE DEADBAND SWITCH

THE ATTITUDE DEADBAND SELECTION ENABLES CONSERVATION OF REACTION CONTROL SYSTEM FUEL AND OXIDIZER, AS REQUIRED ON THE MISSION, BY SELECTION OF THE AMOUNT OF DRIFT PERMISSIBLE IN THE ATTITUDE HOLD MODES. IT IS A TWO POSITION TOGGLE SWITCH FOR SELECTING A MAX POSITION WHICH PERMITS A NOMINAL MOVEMENT OF $\pm 5^\circ$ ABOUT THE DESIRED ATTITUDE, AND A MIN POSITION WHICH PERMITS A NOMINAL MOVEMENT OF $\pm 0.5^\circ$ ABOUT THE DESIRED ATTITUDE BEFORE SIGNALS WILL BE PROCESSED THROUGH THE SCS FOR REDUCING THE ATTITUDE ERROR. THE THREE POSITION SWITCH LABELED ATTITUDE, MONITOR, AND ENTRY MUST BE IN THE ATTITUDE POSITION TO SELECT THE MIN POSITIONS OF THE ATT DEADBAND. WHEN THE THREE POSITION SWITCH IS IN EITHER OF THE OTHER TWO POSITIONS, ONLY THE MAX DEADBAND IS PROVIDED.

2.2.5 .05G ENTRY SWITCH

THE .05G ENTRY SWITCH ENABLES THE NECESSARY GAIN, DISPLAY, AND CROSS COUPLING CHANGES THROUGHOUT THE SYSTEM REQUIRED AT .05G. IT IS A TWO POSITION TOGGLE

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SWITCH AND IT IS FUNCTIONAL ONLY WHEN THE THREE POSITION TOGGLE SWITCH LABELED ATTITUDE, MONITOR, AND ENTRY IS IN THE ENTRY POSITION.

2.2.6 LIMIT CYCLE SWITCH

THE LIMIT CYCLE SWITCH IS A TWO POSITION TOGGLE SWITCH TO REMOVE PSEUDO RATE IN ALL THREE AXES MANUALLY. PSEUDO RATE WILL BE REMOVED FOR ROTATION AND TRANSLATION MANEUVERS AUTOMATICALLY WITH THE MANUAL OVERRIDE CAPABILITY. IT ALSO PERMITS REMOVING PSEUDO RATE WHERE NOT DESIRED FOR OTHER SEGMENTS OF THE APOLLO MISSION.

2.2.7 DIRECT MODE SWITCH

THE DIRECT MODE SWITCH IS A TWO POSITION, DOUBLE POLE, TOGGLE SWITCH WHICH PROVIDES POWER TO THE DIRECT SWITCHES IN THE ROTATION CONTROL. ROTATION CONTROL NO. 1 RECEIVES POWER FROM DC BUS A AND ROTATION CONTROL NO. 2 RECEIVES POWER FROM DC BUS B. THERE CAN BE NO DIRECT ROTATION COMMANDS INITIATED WHEN THE DIRECT MODE SWITCH IS IN THE OFF POSITION. THEREFORE, THE SWITCH WILL BE PLACED IN THE DIRECT MODE POSITION FOR CRITICAL PHASES OF THE MISSION SUCH AS ENTRY.

2.3 FLIGHT DIRECTOR ATTITUDE INDICATOR

THE FLIGHT DIRECTOR ATTITUDE INDICATOR (FDAI) COMBINES THREE DISPLAY FUNCTIONS PERTAINING TO SPACECRAFT ORIENTATION. TOTAL ATTITUDE, ATTITUDE ERRORS, AND BODY ANGULAR RATES ARE INDICATED FOR THE PITCH,

ROLL, AND YAW AXES. THE FDAI IS SHOWN ON FIGURE 2-3.

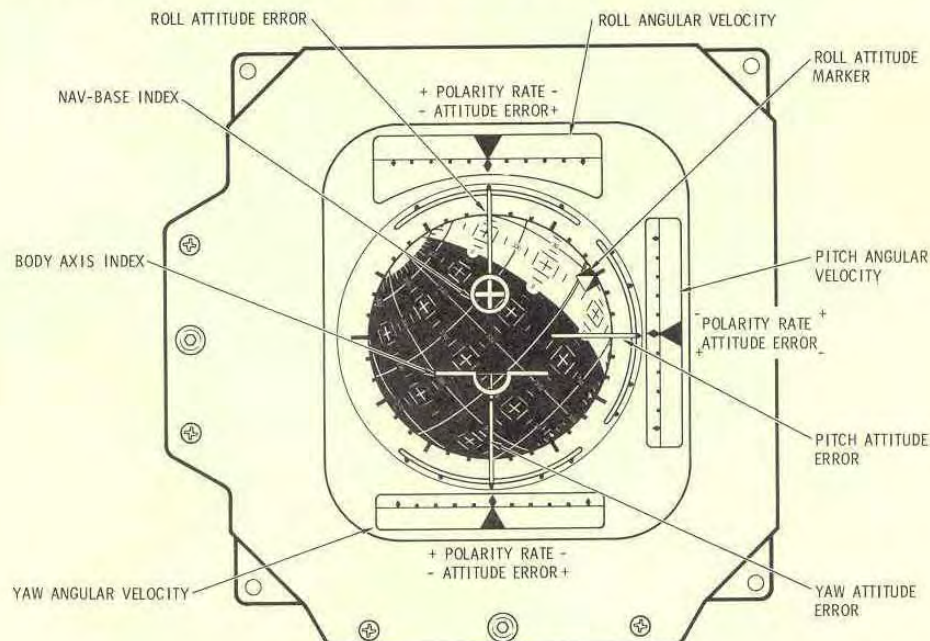
2.3.1 TOTAL ATTITUDE

TOTAL ATTITUDE IS DISPLAYED ON THE GIMBALED ATTITUDE BALL. IT HAS 360° OF FREEDOM IN THE PITCH, ROLL, AND YAW AXES. THE BALL IS MARKED IN PITCH FROM POLE TO POLE SIMILAR TO LONGITUDE MARKINGS ON THE GLOBE, AND IN YAW FROM $270^\circ - 0 - 90^\circ$ BY MARKINGS PLACED PERPENDICULAR TO THE PITCH MARKINGS, SIMILAR TO THE LATITUDE MARKINGS ON A GLOBE. ROLL IS MARKED FROM 0° TO 359° IN 10° INCREMENTS IN A CCW DIRECTION ABOUT THE CASE SURROUNDING THE BALL.

THE ATTITUDE BALL IS POSITIONED FROM TWO SOURCES OF DATA (FIGURE 2-4). IN THE MONITOR MODE AND ALL G&N MODES, TOTAL ATTITUDE IS OBTAINED FROM THE GUIDANCE AND NAVIGATION SYSTEM IMU GIMBAL ANGLE OUTPUTS. THEREFORE, THE ATTITUDE BALL IS AN IMU GIMBAL ANGLE REPEATER WHEN THE G&N SYSTEM IS PROVIDING THE ATTITUDE INFORMATION. THERE ARE TWO INDICES ON THE FACE OF THE INSTRUMENT. THE \sim SYMBOL REPRESENTS THE BODY AXES ORIENTATION WITH RESPECT TO THE IMU STABLE ELEMENT. THE \oplus SYMBOL REPRESENTS THE NAVIGATION AXES DISPLACEMENT FROM THE IMU STABLE ELEMENT. THE TWO SYMBOLS ARE DISPLACED BY APPROXIMATELY 33° IN THE VERTICAL OR PITCH DIRECTION BECAUSE OF THE ANGULAR OFFSET BETWEEN THE BODY AND NAVIGATION AXES OF THE SPACECRAFT. THE NAVIGATION AXES SYMBOL AND RED CIRCULAR POLE MARKINGS ON THE YAW AXIS OF THE BALL SERVE AS A GIMBAL LOCK INDICATOR WHEN THE IMU IS OPERATING. THE CREW MUST INSURE THAT THE NAVIGATION AXES SYMBOL DOES NOT ENTER THE

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FLIGHT DIRECTOR ATTITUDE INDICATOR



NOTES:

1. ATTITUDE ERROR = ATTITUDE DESIRED - ACTUAL ATTITUDE.
2. THE BALL IS OF THE INSIDE-OUT CONVENTION.
3. EULER ANGLE CONVENTION IS PITCH, YAW, ROLL.
4. THE BALL ATTITUDE SHOWN IS PITCH 345° , YAW 335° , AND ROLL 300° , WITH RESPECT TO THE NAVIGATION BASE INDEX.

FIGURE 2-3

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FDAI INPUT DATA

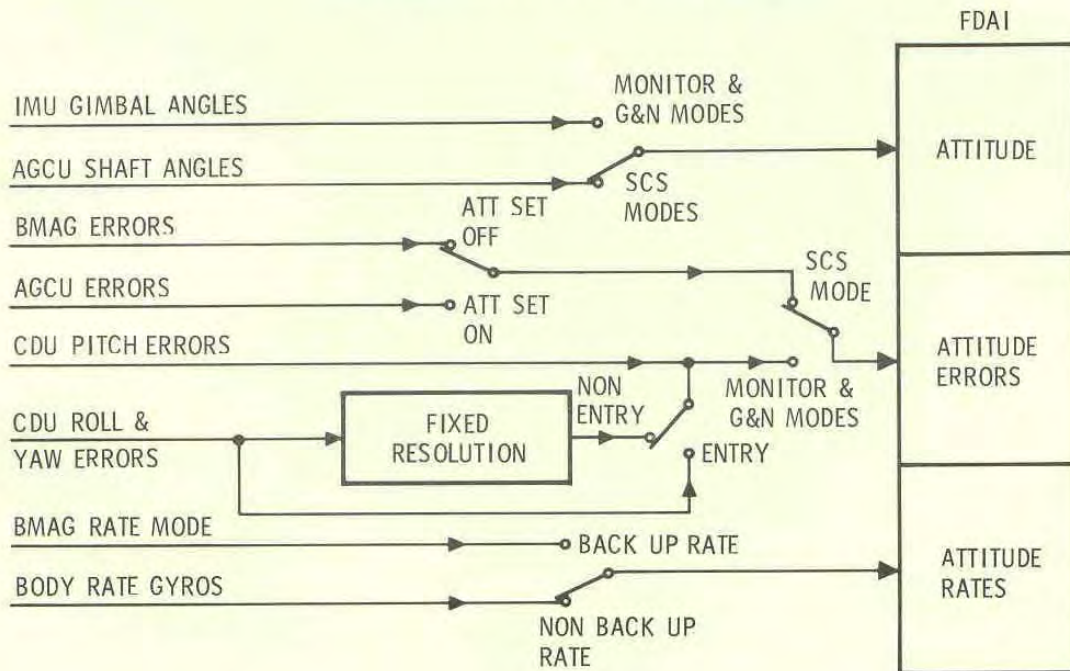


FIGURE 2-4

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RED CIRCULAR POLE (GIMBAL LOCK) MARKING ON THE YAW AXIS. THE ATTITUDE BALL THEN SERVES TWO FUNCTIONS IN THE G&N CONTROL MODES; AS AN IMU GIMBAL ANGLE REPEATER, AND AS AN INDICATOR TO JUDGE MANEUVERS AND TO AVOID GIMBAL LOCK CONDITION OF THE IMU PLATFORM GIMBALS.

THE SECOND SOURCE OF DISPLAY INFORMATION IS OBTAINED FROM THE ATTITUDE GYRO COUPLING UNIT (AGCU). THE THREE SHAFT ANGLE RESOLVERS IN THE AGCU PROVIDE INFORMATION FOR ATTITUDE BALL POSITIONING COMPARABLE TO THE IMU GIMBAL INFORMATION. WHERE THE IMU INFORMATION REPRESENTED ONLY THE ANGULAR DISPLACEMENT BETWEEN THE IMU STABLE ELEMENT AND THE SPACECRAFT. THE AGCU INFORMATION PROVIDES A STRAPDOWN BACKUP INERTIAL REFERENCE SYSTEM AND CAN BE DIRECTED TO PRESENT INFORMATION THAT IS IDENTICAL TO IMU INFORMATION, OR REPRESENT AN ENTIRELY DIFFERENT INERTIAL REFERENCE SYSTEM. THEREFORE, IT WILL BE IMPORTANT TO BE COGNIZANT OF THE INFORMATION SOURCE WHEN EVALUATING DISPLAYED ATTITUDE ORIENTATION.

2.3.2 ATTITUDE ERRORS

THE ATTITUDE ERRORS ARE DISPLAYED BY THE ATTITUDE ERROR NEEDLES OF THE FDAI. THE ROLL ERROR INDICATOR IS AT THE TOP, PITCH ON THE RIGHT, AND YAW AT THE BOTTOM WITH THE NEEDLES MOVING OVER THE FACE OF THE BALL. THE FULL SCALE DEFLECTION VALUE OF THE ATTITUDE ERROR NEEDLES ARE LISTED IN TABLE 2-2 FOR THE OPERATING MODES.

TABLE 2-2. OPERATING MODE VS ATTITUDE ERROR FULL SCALE DEFLECTION VALUE

MODES	ROLL	PITCH	YAW
MONITOR	$\pm 25^\circ$	$\pm 15^\circ$	$\pm 15^\circ$
SCS & G&N ENTRY	$\pm 25^\circ$	$\pm 5^\circ$	$\pm 5^\circ$
ALL OTHER MODES	$\pm 5^\circ$	$\pm 5^\circ$	$\pm 5^\circ$

THE ATTITUDE ERROR INFORMATION IS DERIVED FROM THE COUPLING DISPLAY UNIT (CDU) IN THE G&N MODES OF OPERATION AND FROM THE GMAG'S IN THE SCS MODES OF OPERATION (FIGURE 2-4). ATTITUDE SET AND FDAI ALIGN ARE TWO SPECIAL CASES, WHERE THE ATTITUDE ERROR IS DERIVED FROM THE AGCU FOR PERFORMING MANEUVERS, OR ALIGNING THE BACKUP INERTIAL REFERENCE SYSTEM TO A NEW OR DESIRED ATTITUDE WITH RESPECT TO A GIVEN INERTIAL REFERENCE. THE CREW WILL BE REQUIRED TO UNDERSTAND THE MODES AND REACTION OF THE ATTITUDE ERROR DISPLAYS FOR EACH MODE TO PROPERLY INTERPRET THE ERROR INDICATOR.

2.3.3 ATTITUDE RATES

THE ATTITUDE RATES ARE DISPLAYED ABOUT THE FACE OF THE FDAI WITH ROLL AT THE TOP, PITCH ON THE RIGHT SIDE, AND YAW AT THE BOTTOM. THE MAGNITUDE OF THE RATE DISPLAY SCALES ARE NOT MARKED BECAUSE FULL

SCALE DEFLECTION VALUE WILL CHANGE ACCORDING TO OPERATING MODE OF THE SCS. THE FULL SCALE DEFLECTION VALUE FOR EACH OPERATING MODE IS GIVEN IN TABLE 2-3.

TABLE 2-3. MODES VS RATE DISPLAY SCALE VALUE

MODES	ROLL	PITCH	YAW
MONITOR	$\pm 25^\circ/\text{SEC}$	$\pm 5^\circ/\text{SEC}$	$\pm 5^\circ/\text{SEC}$
SCS LCL VERT SCS & G&N ATT CONT	$\pm 1^\circ/\text{SEC}$	$\pm 1^\circ/\text{SEC}$	$\pm 1^\circ/\text{SEC}$
SCS & G&N DELTA V	$\pm 5^\circ/\text{SEC}$	$\pm 5^\circ/\text{SEC}$	$\pm 5^\circ/\text{SEC}$
SCS & G&N ENTRY	$\pm 25^\circ/\text{SEC}$	$\pm 5^\circ/\text{SEC}$	$\pm 5^\circ/\text{SEC}$

THE RATES DISPLAYED ARE TRUE S/C ROTATION RATES DISPLAYED ON A "FLY-TO" RATE NEEDLE AND WILL NORMALLY BE OBTAINED FROM SPRING RESTRAINED RATE GYROS FOR ALL OPERATING MODES (FIGURE 2-4). A SECOND SOURCE OF RATE INFORMATION IS OBTAINED FROM THE BODY MOUNTED ATTITUDE GYROS (BMAG) WHEN THEY ARE CAGED FOR RATE GYRO OPERATIONS AND THE RATE GYRO SELECTION SWITCH FOR THE APPROPRIATE CHANNEL (ROLL, PITCH, OR YAW) IS IN THE BMAG POSITION.

IN THIS CONFIGURATION, RATE DAMPING HAS PRIORITY OVER ATTITUDE HOLD FUNCTIONS BECAUSE IT IS REMOVED, AND SINCE ATTITUDE ERRORS WILL NOT BE AVAILABLE FROM THE BMAG'S, ATTITUDE RATES WILL BE DISPLAYED.

2.4 ATTITUDE SET/GIMBAL POSITION DISPLAY

THE ATTITUDE SET/GIMBAL POSITION DISPLAY (FIGURE 2-5) PROVIDES TWO DISTINCT SCS FUNCTIONS. THE GIMBAL POSITION SECTION PROVIDES VISUAL DISPLAY AND MANUAL CONTROL OF THE SPS ENGINE GIMBAL ANGLES. THE ATTITUDE SET SECTION IS USED TO SET INERTIAL REFERENCE COMMANDS INTO THE ATTITUDE GYRO COUPLING UNIT.

2.4.1 GIMBAL POSITION DISPLAY

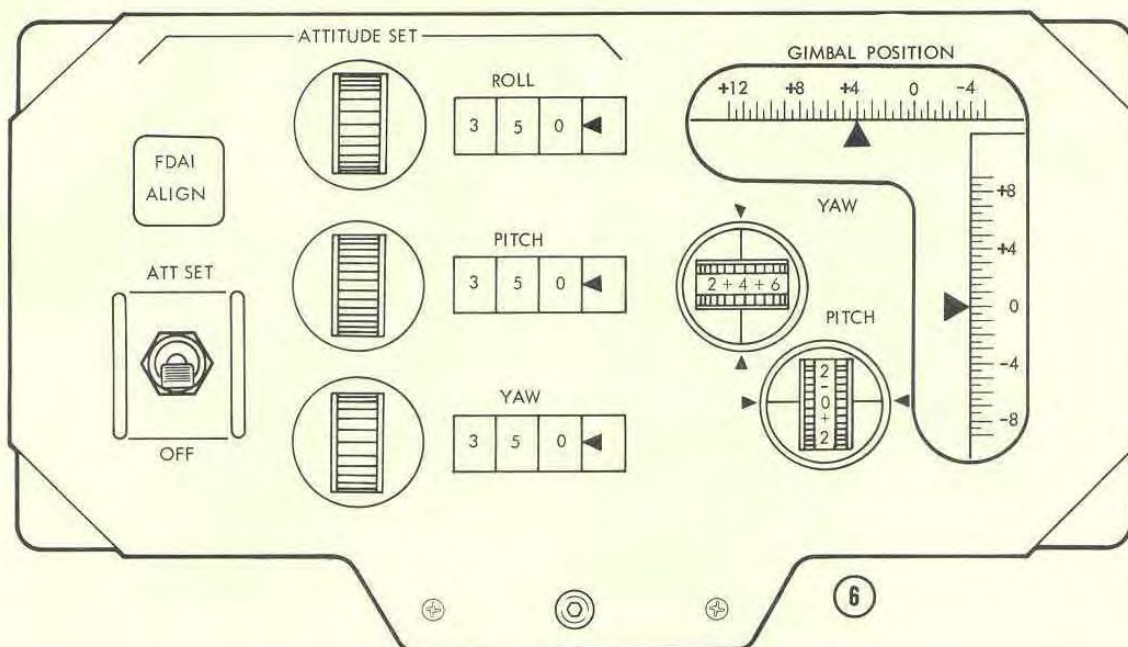
THE GIMBAL POSITION DISPLAY PROVIDES AN ACCURATE INDICATION OF THE PRESENT SPS ENGINE GIMBAL ANGLE SO THAT THE ENGINE THRUST VECTOR CAN BE POSITIONED TO ACT THROUGH THE CENTER OF GRAVITY OF THE SPACECRAFT. THE PITCH GIMBAL INDICATOR HAS A RANGE OF $\pm 8^\circ$ ABOUT ZERO, MEASURED IN THE X-Z PLANE FROM THE X AXIS. THE YAW GIMBAL INDICATOR HAS A RANGE OF $\pm 8^\circ$ ABOUT THE $+4^\circ$ POINT, MEASURED IN THE X-Y PLANE. THE INHERENT OFFSET CENTER OF GRAVITY IN THE S/C CAUSES THE GIMBAL NULL OR CENTER POINT IN THE YAW AXIS TO BE $+4^\circ$.

2.4.2 GIMBAL POSITION TRIM CONTROLS

THE GIMBAL POSITION CONTROL THUMBWHEELS ARE USED TO POSITION THE SPS ENGINE GIMBALS PRIOR TO ALL THRUSTING PHASES. THE PITCH AND YAW GIMBAL POSITION CONTROLS GENERATE THE POSITION COMMANDS TO THE RESPECTIVE GIMBAL POSITIONING LOOPS. THE TRIM CONTROL WILL BE ADJUSTED PRIOR TO EACH SPS FIRING AND THE PROPER ENGINE POSITION VERIFIED FROM THE VISUAL DISPLAY. THE INITIAL POSITIONING ERROR SHOULD BE SMALL TO PREVENT A MOMENT ARM FROM

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ATTITUDE SET/GIMBAL POSITION DISPLAY



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FIGURE 2-5

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CAUSING UNDESIRABLE ROTATIONAL MOVEMENTS ABOUT THE S/C CENTER OF GRAVITY. THE ALIGNMENT ERROR SHOULD BE LESS THAN AN APPROXIMATE VALUE OF .5°. THE THUMBWHEELS ARE MARKED WITH GIMBAL ANGLE VALUES. THE ANGLE MARKED ON THE THUMBWHEEL REPRESENTS THE APPROXIMATE COMMAND GIMBAL TRIM ANGLE. THEY REPRESENT A GROSS COMPARISON OF THE DISPLAY READING AND CANNOT BE USED AS A COMPARATOR FOR DISPLAY ACCURACY WITHOUT ADDITIONAL, MORE PRECISE DATA.

2.4.3 ATTITUDE SET CONTROLS AND INDICATORS

THE THREE ATTITUDE SET THUMBWHEELS AND ADJACENT INDICATORS PROVIDE MANUAL UPDATING CAPABILITIES OF THE ARS. THE AGCU RESOLVER SHAFT ANGLE IS COMPARED IN THE INDICATOR WITH THE SHAFT POSITION REFERENCE OF THE INDICATOR RESOLVER. THE RESULTANT DIFFERENTIAL SIGNAL MAY BE USED TO ALIGN THE AGCU AND FDAI, OR THE DIFFERENTIAL SIGNAL CAN BE DISPLAYED ON THE ATTITUDE ERROR INDICATORS FOR MANUALLY MANEUVERING; THE S/C TO THE NEW DESIRED ATTITUDE.

2.4.4 ATTITUDE SET SWITCH

THE TWO POSITIONS OF THE ATT SET SWITCH ARE ATT SET AND OFF. THE ATT SET POSITION PROVIDES AN AGCU SIGNAL TO THE ATTITUDE ERROR INDICATORS THAT WILL DISPLAY THE DIFFERENCE BETWEEN THE S/C ATTITUDE INDICATED ON THE FDAI AND THE DESIRED ATTITUDE SET ON THE THUMBWHEELS OF THE AS/GPD. THIS WILL PERMIT THE CREW TO ALIGN, OR UPDATE, THE AGCU TO ANY REFERENCE FRAME OR

DETERMINE S/C ATTITUDE DISPLACEMENT FROM A CHOSEN REFERENCE FRAME.

2.4.5 FDAI ALIGN

THE FDAI ALIGN SWITCH IS A PUSH TO MAKE SWITCH USED TO INITIATE ALIGNMENT OF THE AGCU. THE SWITCH MUST BE DEPRESSED UNTIL ALIGNMENT IS ACCOMPLISHED.

2.5 DELTA V DISPLAY

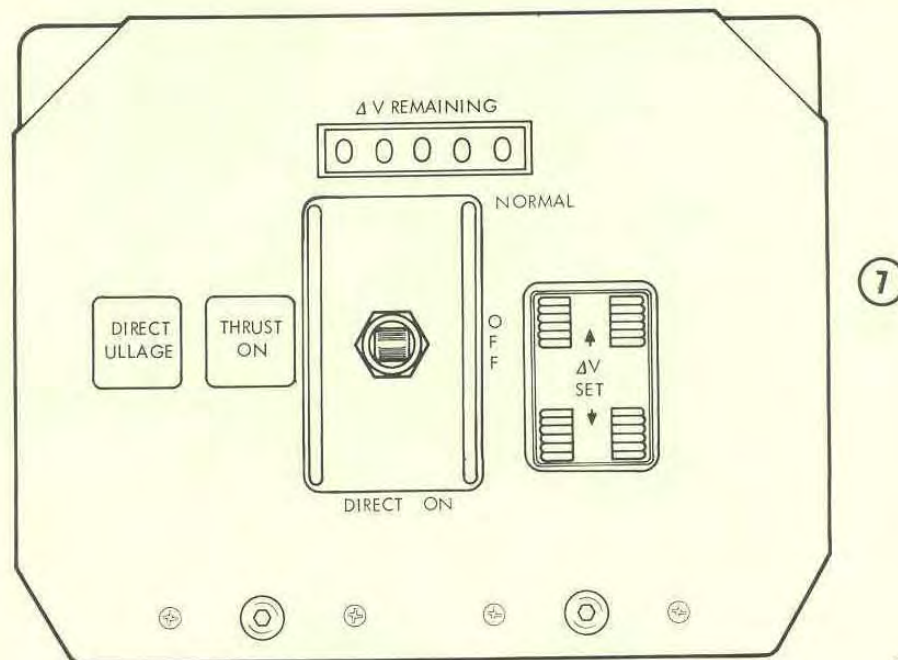
THE DELTA V DISPLAY, AS SHOWN ON FIGURE 2-6, IS USED TO MONITOR THE THRUSTING VELOCITY IMPARTED TO THE S/C BY THE SERVICE PROPULSION SYSTEM AND %X TRANS-LATIONS. THIS PANEL ENABLES THE CREW TO SET IN THE REQUIRED VELOCITY CORRECTION TO BE ATTAINED BY THRUSTING, PERFORM MANUAL BACKUP TO AUTOMATIC ENGINE FIRE COMMAND, MANUAL BACKUP TO THE AUTOMATIC THRUST OFF COM-MANDS, AND PROVIDES A REDUNDANT DIRECT ULLAGE CAPABIL-ITY.

2.5.1 DELTA V REMAINING

THE DELTA V REMAINING INDICATOR WILL DISPLAY THE VELOCITY CORRECTION (IN FEET PER SECOND) TO BE AT-TAINED BY THRUSTING WITH THE SERVICE PROPULSION SYSTEM DURING A DELTA V MANEUVER. IT IS A DIGITAL INDICATOR WHICH IS STEPPED IN $\frac{1}{4}$ FEET PER SECOND INCREMENTS. THE INDICATING RANGE IS FROM -1,000 (99,000) TO 12,999 FEET PER SECOND. IN A THRUSTING SEQUENCE, AN AUTO-MATIC THRUST OFF COMMAND SHOULD BE GENERATED BY THE

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ΔV DISPLAY



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FIGURE 2-6

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SCS OR G&N, DEPENDING UPON THE OPERATING MODE. WHEN THE DELTA V REMAINING INDICATOR REACHES 00,000 FEET PER SECOND, IT GENERATES A THRUST OFF COMMAND; AND THE INDICATOR WILL CONTINUE TO COUNT IN A MINUS DIRECTION TABULATING THE VELOCITY IMPARTED TO THE S/C BY THE RESIDUAL THRUST FROM THE SERVICE PROPULSION SYSTEM.

2.5.2 DELTA V SET

THE DELTA V SET SWITCH IS A SLEW COMMAND SWITCH TO DRIVE THE DELTA V REMAINING INDICATOR. IT IS THE ONLY METHOD BY WHICH THE DELTA V REMAINING INDICATOR CAN BE SET OR CHANGED WITHOUT ACCELERATING. THE DELTA V SET SWITCH HAS TWO COMMANDABLE DRIVE RATES. THE SOFT STOP IN EACH DIRECTION REPRESENTS A DRIVE RATE OF ± 2 FEET PER SECOND FOR EACH SECOND THE SWITCH IS DEPRESSED. THE HARD STOP, WHICH IS BEYOND THE SOFT STOP, WILL COMMAND A DRIVE RATE OF ± 65 FEET PER SECOND FOR EACH SECOND THE SWITCH IS DEPRESSED.

2.5.3 THRUST CONTROL SWITCH

THE THRUST CONTROL SWITCH IS A LEVER LOCK, THREE POSITION TOGGLE SWITCH. THE CENTER POSITION IS OFF. TO SELECT EITHER OF THE OTHER TWO POSITIONS, THE ENLARGED END OF THE SWITCH MUST BE DISPLACED LATALLY FROM THE DISPLAY PANEL BEFORE THE SWITCH CAN BE MOVED UP OR DOWN. THE UP POSITION IS NORMAL. IN THIS POSITION, THE APOLLO GUIDANCE COMPUTER OR THE THRUST ON SWITCH CAN ENERGIZE THE FUEL AND OXIDIZER SOLENOIDS IN THE SERVICE PROPULSION SYSTEM PROVIDING ALL OTHER LOGIC STEPS HAVE BEEN COMPLETED. THE DOWN OR DIRECT ON

POSITION ENERGIZES THE SPS SOLENOIDS IN THE SERVICE PROPULSION SYSTEM BY PASSING ALL ELECTRONICS AND LOGIC CIRCUITS. THE THRUST CONTROL SWITCH TOGGLES BACK TO THE OFF POSITION WITH NO RESTRICTIONS.

2.5.4 THRUST ON SWITCH

THE THRUST ON SWITCH IS A MOMENTARY CONTACT TYPE SWITCH FOR MANUAL THRUST ON LOGIC COMMAND TO THE SERVICE PROPULSION SYSTEM ENGINE IN THE SCS DELTA V MODE. ILLUMINATION OF THE THRUST ON SWITCH PROVIDES AN INDICATION OF SERVICE PROPULSION ENGINE IGNITION COMMANDED BY THE THRUST CONTROL LOGIC. THE SWITCH WILL REMAIN ILLUMINATED AT ALL TIMES WHEN A LOGIC THRUST ON COMMAND EXISTS AND WILL BE EXTINGUISHED WHEN THE LOGIC THRUST OFF COMMAND IS DETECTED. THE THRUST ON COMMAND CAN ORIGINATE FROM THE APOLLO GUIDANCE COMPUTER OR THE MOMENTARY THRUST ON SWITCH.

2.5.5 DIRECT ULLAGE

THE DIRECT ULLAGE SWITCH WILL PROVIDE A DIRECT BACKUP TO THE TRANSLATION CONTROL NORMALLY USED TO INITIATE AN ULLAGE MANEUVER (POSITIVE X TRANSLATION) PRIOR TO SPS ENGINE IGNITION. IF USED, THE VEHICLE WILL TRANSLATE WITH NO ATTITUDE HOLD CONTROL UNTIL SPS ENGINE IGNITION.

2.6 ROTATION AND TRANSLATION CONTROLS

IN ADDITION TO THE CAPABILITY OF COMMANDING SPECIFIC ATTITUDES THROUGH THE KEYBOARD OF THE GUIDANCE

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COMPUTER, THE ASTRONAUTS ARE ABLE TO MANUALLY COMMAND SPECIFIC ATTITUDES OR ATTITUDE CHANGE RATES DURING THE MISSION. TRANSLATION CONTROL IS REQUIRED FOR DOCKING PRACTICE IN EARTH ORBIT AND BACKUP FOR DE-ORBIT WITH COMPLETE SPS FAILURES. A PAIR OF MANUAL ROTATION AND TRANSLATION CONTROL ARE PROVIDED FOR THE ASTRONAUTS USE WHERE REQUIRED IN THE COMMAND MODULE.

ALL ROTATION CONTROLS CAN BE REMOVED FROM THE SEATS BUT HAVE A PERMANENT CABLE CONNECTING THEM TO THE CONTROL SYSTEM OR DIRECTLY TO THE REACTION JETS (MANUAL DIRECT CONTROL).

ALL CONTROLS HAVE A MECHANICAL LOCK TO PREVENT INADVERTENT INITIATION OF COMMANDS DURING RELOCATION OR STORAGE. A VISUAL CUE IS PROVIDED TO ASCERTAIN THE STATUS OF THE LOCK.

2.6.1 ROTATION CONTROL

THE ROTATION CONTROLS (FIGURE 2-7) ARE DESIGNED FOR RIGHT HAND USE AND CAN GENERATE INPUTS IN EITHER PROPORTIONAL RATE OR DIRECT COMMANDS TO THE SCS ATTITUDE CONTROL SYSTEM FOR THE ROLL, PITCH, AND YAW CHANNELS SIMULTANEOUSLY OR INDIVIDUALLY. MANUAL DIRECT OPERATION OF ONE AXIS WILL NOT AFFECT PROPORTIONAL RATE OPERATION IN THE OTHER TWO AXES.

THE COMMAND INPUT AXES ARE SHOWN IN FIGURE 2-7 WITH THE OFFSET COMFORT ANGLES FOR RIGHT HAND USE. THE DIRECT COMMAND SWITCHES ARE CLOSED APPROXIMATELY

ONE DEGREE SHORT OF FULL TRAVEL IN EACH AXIS. THE ROLL AXIS OF CONTROL HAS SOFT STOPS INCORPORATED BEFORE THE DIRECT SWITCHES ARE CLOSED. THE SOFT STOPS PREVENT INADVERTENT DIRECT COMMANDS FROM INTERRUPTING MANUAL PROPORTIONAL RATE COMMANDS DURING MANUAL ENTRY CONTROL. THERE ARE NO SOFT STOPS IN THE PITCH AND YAW AXES OF THE ROTATION CONTROLS.

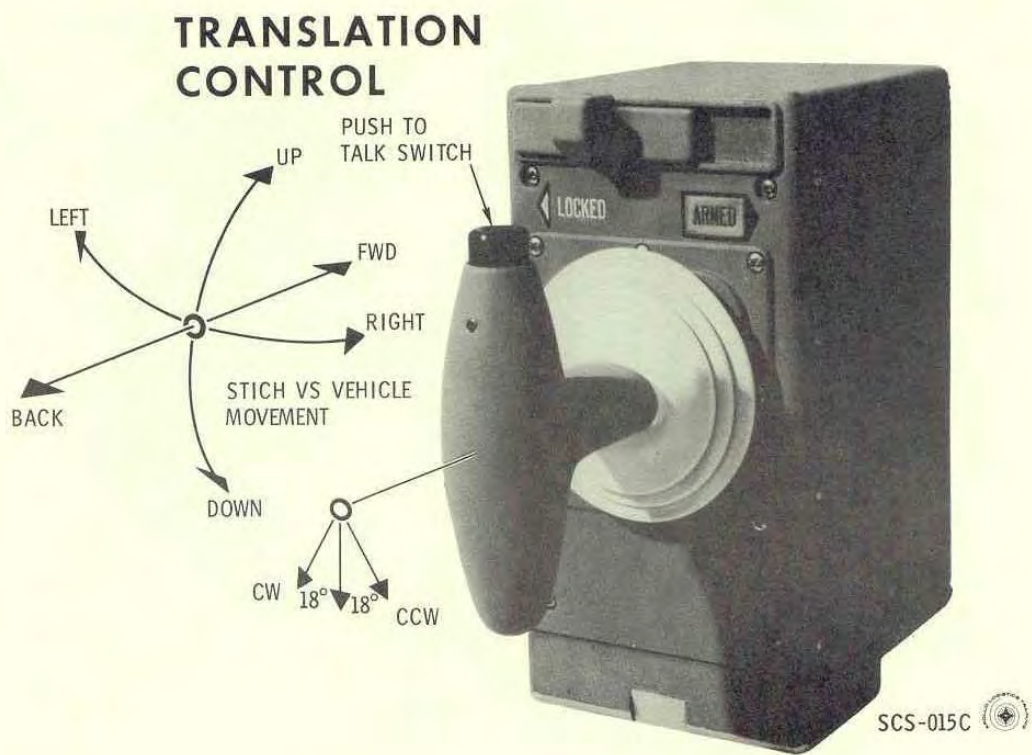
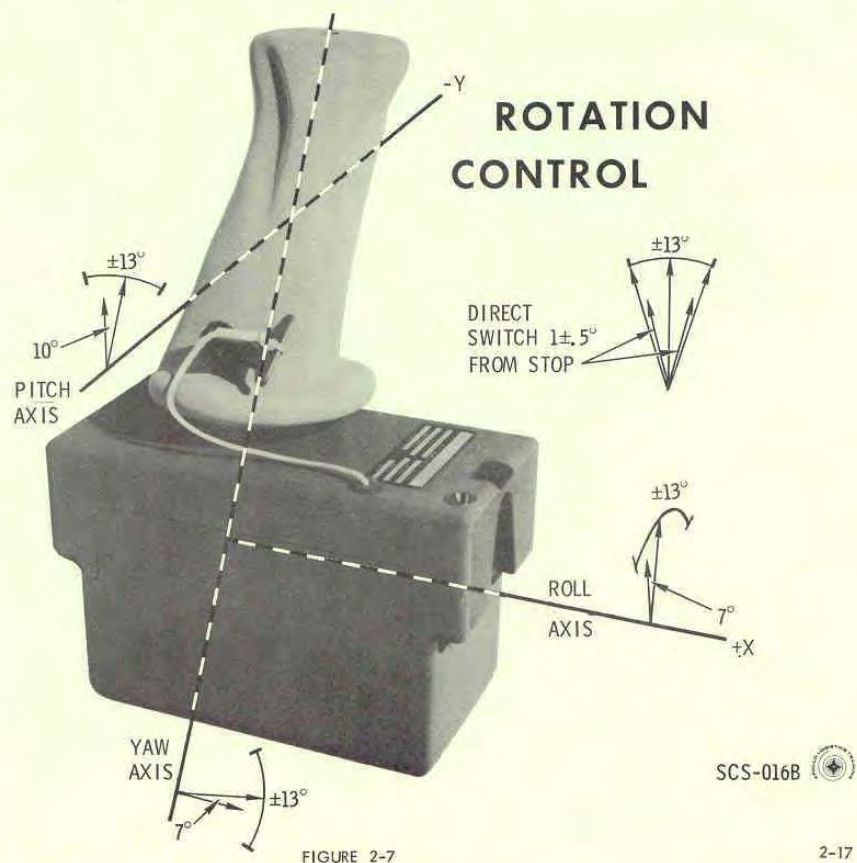
THE ROTATION CONTROLS ARE HELD IN THE CENTER OR NEUTRAL POSITION BY SPRING FORCE GRADIENTS. THE ANGULAR DISPLACEMENT IS DIRECTLY RELATED TO THE DISPLACEMENT FORCE APPLIED. BREAKOUT SWITCHES ARE PROVIDED IN EACH CONTROL AXIS TO SYNC THE SCS FOR MANUAL CONTROL INPUTS FROM THE ROTATION CONTROL.

2.6.2 TRANSLATION CONTROL

TRANSLATION CONTROL IS PROVIDED THROUGH THE S/M RCS AND, THEREFORE, IS AVAILABLE PRIOR TO S/M-C/M SEPARATION ONLY. THE TRANSLATION CONTROL (FIGURE 2-8) IS A "T" HANDLE CONFIGURATION WITH UP-DOWN, RIGHT-LEFT, AND IN-OUT MOTIONS PROVIDING MULTIPLE OR SINGULAR AXES TRANSLATIONS SIMULTANEOUSLY. TRANSLATION COMMAND CAN BE INITIATED SIMULTANEOUSLY THAT WILL RESULT IN A COMPOSITE MANEUVER. THE POSITIVE X TRANSLATION WILL BE CALLED AN ULLAGE MANEUVER WHEN PERFORMED PRIOR TO A FIRING OF THE SPS ENGINE.

THE COUNTERCLOCKWISE AND CLOCKWISE SWITCHES WILL BE USED TO PROVIDE SWITCHING INPUTS TO THE SCS AND MASTER EVENTS SEQUENCE CONTROLLER.

2-16



THE COUNTERCLOCKWISE ROTATION OF THE "T" HANDLE WILL PERFORM A MANUALLY INITIATED ABORT FOR ALL BOOSTER PHASES OF THE APOLLO MISSION IF ADDITIONAL MAIN CONTROL PANEL SWITCHES ARE IN THE CORRECT POSITIONS. THE COUNTERCLOCKWISE SWITCH WILL ALSO PROVIDE A BACKUP TO NORMAL SEPARATION OF THE C/M-S/M FROM THE BOOSTER AFTER ALL STAGES ARE EXPENDED IF ADDITIONAL SWITCHES ON THE MAIN CONTROL PANEL ARE IN THE CORRECT POSITIONS.

THE CLOCKWISE ROTATION OF THE "T" HANDLE WILL OPEN THE ATTITUDE LOOPS IN THE ATTITUDE CONTROL SUBSYSTEM FOR ALL OPERATING MODES. RATE STABILIZATION AND MANUAL PROPORTIONAL RATE CONTROL WILL STILL BE AVAILABLE. IN THE DELTA V MODES, THE CLOCKWISE SWITCH WILL ACTIVATE THE MANUAL THRUST VECTOR CONTROL OPERATING MODE. THIS ENABLES COMMAND INPUTS FROM THE PROPORTIONAL RATE OUTPUT OF THE ROTATION CONTROL TO REPOSITION THE GIMBALLED SPS ENGINE WHILE PERFORMING A DELTA V MANEUVER.

SPRING FORCE GRADIENTS WILL BE USED TO MAINTAIN THE "T" HANDLE IN THE NEUTRAL POSITION FOR ALL TRANSLATION COMMANDS. THE COMMANDS ARE DISCRETE AND GENERATE THE REQUIRED SYNCHRONIZATION OF THE SCS FOR TRANSLATING. FORCE GRADIENTS MUST BE OVERCOME FOR THE CLOCKWISE AND COUNTERCLOCKWISE ROTATION OF THE "T" HANDLE. A DETENT IS PROVIDED AT THE MAX CW AND CCW LIMITS OF TRAVEL FOR LOCKING THE "T" HANDLE IN THE CLOCKWISE OR COUNTERCLOCKWISE POSITIONS. A PUSH TO TALK SWITCH IS INCORPORATED ON THE "T" HANDLE FOR OPERATIONS IN THE COMMUNICATION SYSTEM. IT PROVIDES AN AUDIO TRANSMISSION IN SOME MODES OF THE COMMUNICATION SYSTEM OPERATION.

2.6.3 ATTITUDE IMPULSE CONTROL

THE ATTITUDE IMPULSE CONTROL (FIGURE 2-9) AT THE NAVIGATOR'S STATION IS USED FOR SMALL PRECISE MANEUVERS WHEN ALIGNING THE SEXTANT FOR NAVIGATION SIGHTINGS. THE ATTITUDE IMPULSE CONTROL SIGNAL GENERATION IS INTERNAL TO THE SCS BUT ACTIVATED BY EXTERNAL SWITCHES.

THE ATTITUDE IMPULSE ENABLE SWITCH ACTIVATES THE REQUIRED CIRCUITS IN THE SCS TO PERMIT MINIMUM IMPULSE OPERATION. THE SCS MUST BE IN THE G&N OR SCS ATTITUDE CONTROL MODES BEFORE THE ATTITUDE IMPULSE ENABLE WILL BE SOLENOID HELD IN THE ON POSITION.

2.7 ASSOCIATED CONTROL PANELS

THE SCS REQUIRES SWITCHING INPUTS FROM ADDITIONAL CONTROL PANELS TO PERFORM ITS REQUIRED OPERATIONS. THE ADDITIONAL CONTROL PANELS ARE WITHIN REACH OF THE COMMANDER'S CONTROL STATION. THE CONTROL PANELS WILL CONTAIN SWITCHING FUNCTIONS OTHER THAN FOR THE SCS. THEREFORE, ONLY THE SCS SWITCHING FUNCTIONS WILL BE DISCUSSED.

2.7.1 LEFT HAND CIRCUIT BREAKER PANEL

THE LEFT HAND CIRCUIT BREAKER PANEL (FIGURE 2-10) CONTAINS ONE SWITCH AND 18 CIRCUIT BREAKERS THAT OPERATE DIRECTLY INTO THE SCS SYSTEM. THE CIRCUIT BREAKER FOR YAW, PITCH, B&D ROLL, AND A&C ROLL PROVIDES DC POWER TO THE SOLENOIDS FOR THE REACTION CONTROL SYSTEM IF ADDITIONAL ENABLING HAS OCCURRED IN THE SCS. THE DC POWER WILL BE USED ONLY UPON A COMMAND FROM THE SCS ATTITUDE CONTROL SUBSYSTEM.

2-19

G&N OPTICS CONTROL PANEL 100 SERIES

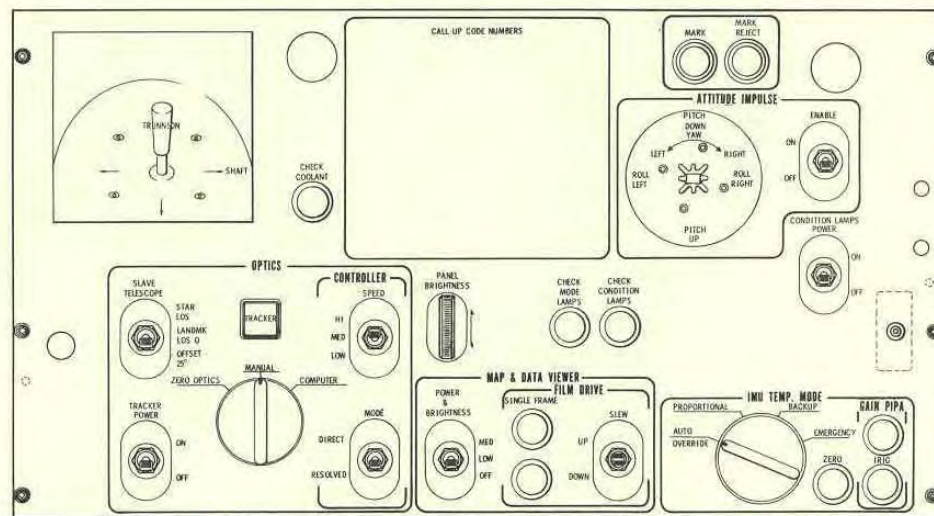


FIGURE 2-9

2-20

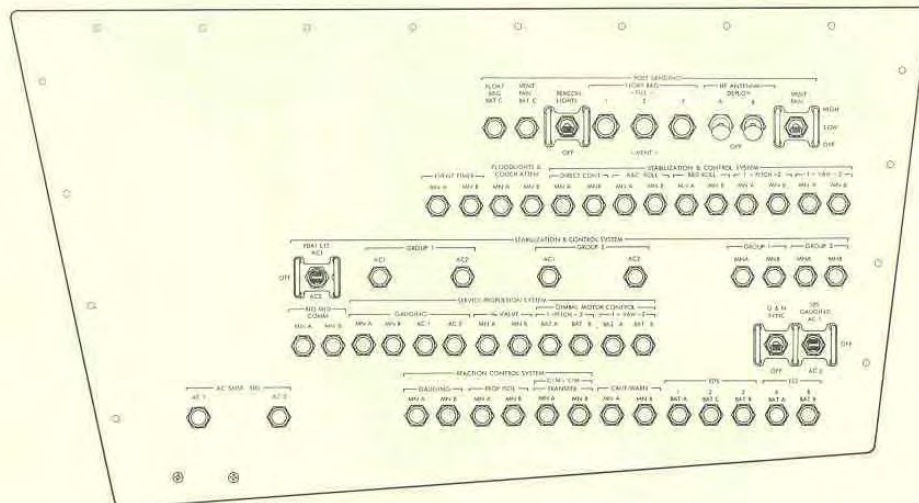


FIGURE 2-10

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THE SCS SYSTEM POWER IS DIVIDED INTO GROUP 1 AND 2. GROUP 1 WILL POWER THE CIRCUITS REQUIRED FOR THE G&N OPERATING MODES OF THE SCS. GROUP 2 WILL PROVIDE ALL THE REQUIRED SCS POWER TO PERFORM THE MANUAL THRUST VECTOR CONTROL MODE OF OPERATION AND IN SO DOING PROVIDES THE ADDITIONAL POWER REQUIRED FOR THE NORMAL SCS OPERATING MODES OF THE SCS.

GROUP 1 CIRCUIT BREAKERS MN A AND MN B, WHEN SET, WILL PROVIDE DC POWER TO THE SCS CONTROL PANEL AND MISSION SEQUENCER FOR RCS ENABLE. POWER WILL BE ROUTED THROUGH DIODES FROM BOTH BUSES SIMULTANEOUSLY. MN A CIRCUIT BREAKER WILL PROVIDE DC POWER TO TRANSLATION CONTROL #1 AND MN B CIRCUIT BREAKER WILL PROVIDE POWER TO TRANSLATION CONTROL #2 FOR COMMANDING TRANSLATION MANEUVERS. ALL AC POWER IS ROUTED THROUGH GROUP 1 POWER SWITCHES. GROUP 1 CIRCUIT BREAKERS AC 1 AND AC 2 AND THE REMAINING DC POWER IS PROVIDED INTO THE SCS BY THE GROUP 1 POWER SWITCHES LOCATED ON THE SCS POWER SWITCHES.

GROUP 2 CIRCUIT BREAKERS MN A AND MN B WILL PROVIDE THE SWITCHING POWER FOR MANUAL AND BACKUP FUNCTIONS IN THE SCS. MN A CIRCUIT BREAKER PROVIDES POWER DIRECT TO THE BREAKOUT SWITCHES IN THE ROTATION CONTROL #1 AND THE CLOCKWISE SWITCH IN THE TRANSLATION CONTROL #1. MN B CIRCUIT BREAKER PROVIDES POWER DIRECT TO THE BREAKOUT SWITCHES IN ROTATION CONTROL #2 AND CLOCKWISE SWITCH IN TRANSLATION CONTROL #2. THE INPUTS FROM AC 1 AND AC 2 CIRCUIT BREAKERS AND THE REMAINING DC POWER WILL BE SELECTABLE BY GROUP 2 OF THE SCS POWER SWITCHES ON THE SCS POWER SWITCHES.

THE DIRECT CIRCUIT BREAKER MN A AND MN B PROVIDE ALL THE REQUIRED DC POWER TO ACTUATE THE DIRECT MODES OF OPERATION. DC CIRCUIT BREAKER MN A WILL PROVIDE 28 VDC TO THE DIRECT MODE SWITCH FOR ROTATION CONTROL #1, DIRECT ULLAGE SWITCH FOR ULLAGE CAPABILITY FROM THE TWO AFT POINTING PITCH JETS (ENGINE #1 AND #2), AND THRUST CONTROL SWITCH TO ENERGIZE THE SERVICE PROPULSION SYSTEM COIL SET #1 FOR THE THRUST ON THE SERVICE PROPULSION ENGINE. DC CIRCUIT BREAKER MN B WILL PROVIDE 28 VDC TO THE DIRECT MODE SWITCH FOR ROTATION CONTROL #2, DIRECT ULLAGE SWITCH FOR ULLAGE CAPABILITY FOR THE TURN AFT POINTING YAW JETS (ENGINE #5 & #6), AND THRUST CONTROL SWITCH TO ENERGIZE THE SERVICE PROPULSION SYSTEM COIL SET #2 FOR THE THRUST ON OF THE SERVICE PROPULSION ENGINE.

THE DIRECT FUNCTIONS IN THE SCS PROVIDES POWER FOR CONTROL WITH NO ELECTRONICS BETWEEN THE DC BUSES AND THE COILS ENERGIZED.

THE G&N SYNC SWITCH IS A TWO POSITION TOGGLE SWITCH THAT IS OPERATIONAL ONLY IN THE G&N ATTITUDE CONTROL MODE OF OPERATION. IN THE ON POSITION, AND WITH THE G&N OPERATIONAL, THE G&N SYNC CIRCUIT PERMITS THE BREAKOUT SWITCH IN THE ROTATION CONTROL TO PLACE THE CDU'S IN A FOLLOW MODE. WHEN THE MANEUVER IS COMPLETED, THE NEW ATTITUDE WILL BE ACCEPTED AS THE NEW COMMAND ATTITUDE, THUS PROVIDING A MANUAL MANEUVER CAPABILITY IN THE G&N ATTITUDE CONTROL MODE.

2.7.2 SCS POWER SWITCHES

THE SCS POWER SWITCHES (FIGURE 2-11) ARE DIVIDED INTO GROUP 1 AND 2. THE SWITCHES WILL CONTROL ALL SWITCHABLE POWER REQUIRED FOR THE SCS FUNCTIONS. THEY CONTROL AC AND DC POWER WHERE REQUIRED. THE AC 1 POSITION OF EACH SWITCH WILL SELECT AC BUS 1 AND MN BUS A FOR DC POWER IF REQUIRED. THE AC 2 POSITION OF EACH SWITCH WILL SELECT AC BUS #2 AND MN BUS B FOR DC POWER INPUTS IF REQUIRED.

2.7.2.1 SCS GROUP 1 POWER SWITCHES

THE SCS GROUP 1 POWER SWITCHES PROVIDE THE SCS POWER REQUIRED TO PERFORM ALL NECESSARY CONTROL FUNCTIONS IN THE G&N OPERATING MODES OF THE SCS.

THE PARTIAL SCS POWER SWITCH IS A THREE POSITION ROTARY SWITCH. THE THREE POSITIONS ARE AC 1, OFF, AND AC 2 IN CLOCKWISE SEQUENCE. THE SWITCH PROVIDES AC & DC POWER TO THE NON-THRUST VECTOR CONTROL RATE AND ATTITUDE ELECTRONICS, ATTITUDE GYRO COUPLING UNIT, AND MISCELLANEOUS ELECTRONICS REQUIRED FOR ATTITUDE CONTROL.

THE RATE GYRO POWER SWITCH IS A THREE POSITION ROTARY SWITCH. THE THREE POSITIONS ARE AC 1, OFF, AND AC 2 IN A CLOCKWISE SEQUENCE. IT PROVIDES 3 PHASE AC POWER TO THE RATE GYRO PACKAGE AND REFERENCE FREQUENCY FOR THE RATE DISPLAY DEMODULATOR. THE TWO SCS SWITCHES COVERED THUS FAR WILL PROVIDE SUFFICIENT SCS POWER FOR ATTITUDE CONTROL WITH APPROPRIATE G&N ATTITUDE ERROR INPUT SIGNALS.

THE TVC 1 POWER SWITCH IS A THREE POSITION ROTARY SWITCH. THE THREE POSITIONS ARE AC 1, OFF, AND AC 2 IN A CLOCKWISE SEQUENCE. IT PROVIDES AC AND DC POWER TO THE THRUST VECTOR CONTROL ELECTRONICS FOR THE PITCH AND YAW CHANNELS, X AXIS ACCELEROMETER, DELTA V DISPLAY ELECTRONICS, AND THRUST ON-OFF ELECTRONICS.

2.7.2.2 SCS GROUP 2 POWER SWITCHES

THE SCS GROUP 2 POWER SWITCHES PROVIDE POWER TO THE SEGMENTS OF THE SCS SYSTEM THAT PERMIT MANUAL CREW INPUTS INTO THE SCS CONTROL AND ALL REQUIRED POWER FOR MANUAL THRUST VECTOR CONTROL.

THE ROTATION CONTROL POWER SWITCH IS A THREE POSITION TOGGLE SWITCH. THE THREE POSITIONS ARE: AC 1 OFF, AND AC 2 FROM TOP TO BOTTOM. IN THE AC 1 POSITION, PHASE A POWER IS SUPPLIED FROM AC BUS 1 TO THE ROTATION CONTROL TRANSducer TRANSFORMERS LOCATED IN THE PITCH AND YAW ELECTRONIC CONTROL ASSEMBLIES. THE TRANSFORMER IN THE PITCH ELECTRONIC CONTROL ASSEMBLY SUPPLIES EXCITATION TO THE TRANSducer IN ROTATION CONTROL #1, AND THE TRANSFORMER IN THE YAW ELECTRONICS CONTROL ASSEMBLY IS FOR THE TRANSducer OF ROTATION CONTROL #2. IT ALSO SUPPLIES REFERENCE FREQUENCY TO THE ROTATION CONTROL DEMODULATORS IN THE ROLL, PITCH AND YAW ELECTRONICS CONTROL ASSEMBLIES. THE AC 2 POSITION PROVIDES PHASE A POWER TO THE SAME CIRCUITS FROM AC BUS 2.

THE BMAG POWER SWITCH IS A THREE POSITION ROTARY SWITCH. THE THREE POSITIONS ARE AC 1, OFF, AND AC 2 IN A CLOCKWISE SEQUENCE. IT PROVIDES AC AND DC

2-23

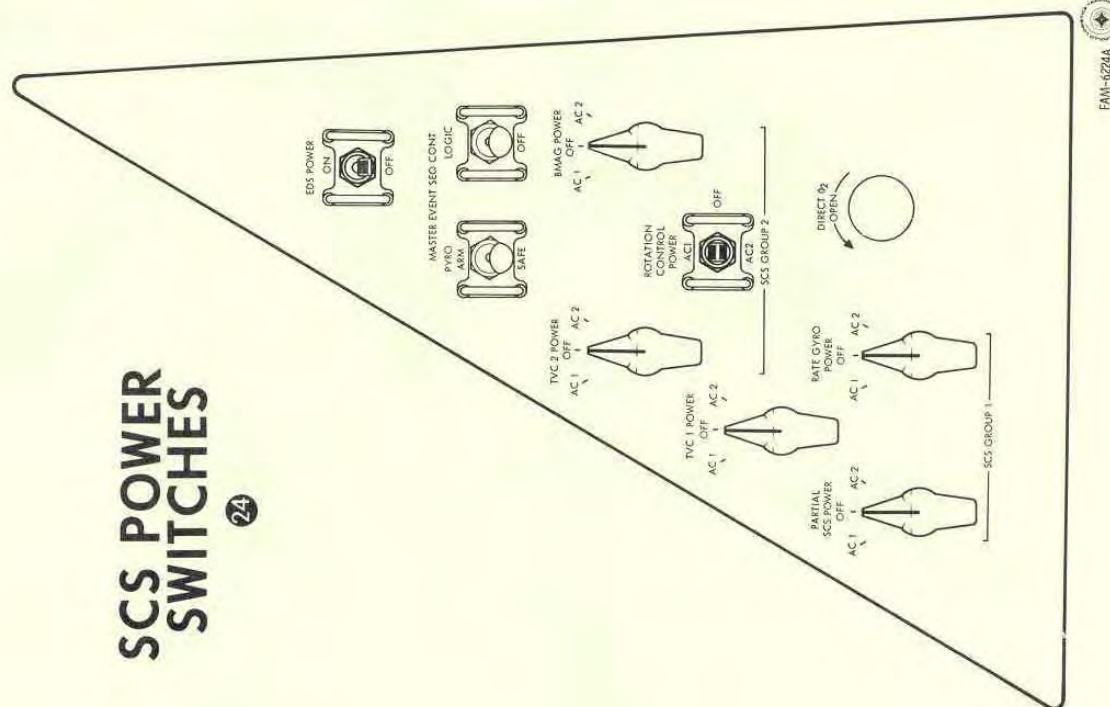


FIGURE 2-11

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POWER TO THE BODY MOUNTED ATTITUDE GYROS FOR TEMPERATURE CONTROL, SPIN MOTOR OPERATION, AND REQUIRED ELECTRONICS FOR NORMAL OPERATION. IT ALSO PROVIDES REFERENCE FREQUENCY FOR THE MANUAL THRUST VECTOR CONTROL RATE DEMODULATORS.

THE TVC 2 POWER SWITCH IS A THREE POSITION ROTARY SWITCH. THE THREE POSITIONS ARE AC 1, OFF, AND AC 2 IN A CLOCKWISE SEQUENCE. IT PROVIDES AC POWER TO ALL ELEMENTS OF THE PITCH AND YAW ELECTRONICS CONTROL ASSEMBLY USED FOR THE MANUAL THRUST VECTOR CONTROL MODE NOT ACTIVATED BY OTHER SWITCHES IN SCS GROUP 2 POWER.

2.7.3 CREW SAFETY CONTROL PANEL

THE CREW SAFETY CONTROL PANEL (FIGURE 2-12) PROVIDES SWITCHES THAT CONTROL FUNCTIONS FOR THE SCS AND REACTION CONTROL SYSTEMS. THERE ARE FIVE SWITCHES THAT PROVIDE AN INPUT DIRECTLY OR INDIRECTLY FOR NORMAL CHECKOUT AND CONTROL FUNCTIONS.

2.7.3.1 ABORT SYSTEM OXIDIZER DUMP AUTO SWITCH

THE OX DUMP AUTO SWITCH CONTROLS CIRCUITS FOR AUTOMATIC DUMPING OF THE OXIDIZER FROM LIFT OFF UNTIL APPROXIMATELY 42 SECONDS HAVE ELAPSED. AFTER THE 42 SECONDS HAVE ELAPSED FROM LIFT OFF, IT WILL BE MANUALLY PLACED IN THE RCS CMD AUTO POSITION. IN THE DOWN POSITION, THERE WILL BE ONE ENABLING INPUT FOR ACTIVATION OF THE INPUTS TO THE REACTION CONTROL SYSTEM SOLENOIDS AT ABORT OR SEPARATION BY THE SEQUENTIAL EVENTS CONTROL SYSTEM (SECS).

2.7.3.2 REACTION CONTROL SYSTEM CMD SWITCH

THE REACTION CONTROL SYSTEM CMD SWITCH IS A THREE POSITION TOGGLE SWITCH SPRING LOADED TO THE CENTER POSITION. IT IS A BACKUP CONTROL TO THE AUTOMATIC ENABLING OF THE REACTION CONTROL SYSTEM SOLENOIDS DRIVEN IN THE SCS EXCEPT FOR SIVB SEPARATION. THE CENTER POSITION OF THE TOGGLE SWITCH PERMITS THE SECS TO ENABLE THE REACTION CONTROL SYSTEM SOLENOID DRIVERS IN THE SCS WHEN THE OX DUMP AUTO IS IN THE RCS CMD AUTO POSITION. IN THE NORMAL SEPARATION PROCEDURE FROM THE SIVB OR AT OTHER TIMES IN THE MISSION AS REQUIRED, THE CMD SWITCH ENABLES THE REACTION CONTROL SYSTEM SOLENOID DRIVERS IN THE SCS WHEN MOMENTARILY PLACED IN THE ON POSITION. THE CMD SWITCH ALSO DISABLES THE REACTION CONTROL SYSTEM SOLENOID DRIVERS IN THE SCS WHEN MOMENTARILY PLACED IN THE OFF POSITION.

2.7.3.3 REACTION CONTROL SYSTEM C/M PRESS SWITCH

THE C/M PRESS IS A SPRING LOADED TO OFF TOGGLE SWITCH. MOMENTARY POSITIONING TO THE UP POSITION WILL PRESSURIZE THE C/M REACTION CONTROL SYSTEM. THE SWITCH WILL FIRE THE HELIUM PYROTECHNIC ISOLATION VALVES, THUS PRESSURIZING THE C/M PROPELLANT TANK.

2.7.3.4 REACTION CONTROL SYSTEM TRANSFER C/M SWITCH

THE TRANSFER C/M-S/M SWITCH FUNCTIONS AS A BACKUP CONTROL TO THE NORMALLY AUTOMATIC TRANSFER OF THE REACTION CONTROL SYSTEMS AFTER C/M-S/M SEPARATION. THIS SWITCH ALSO ALLOWS THE CHECKING OF BOTH REACTION

2-25

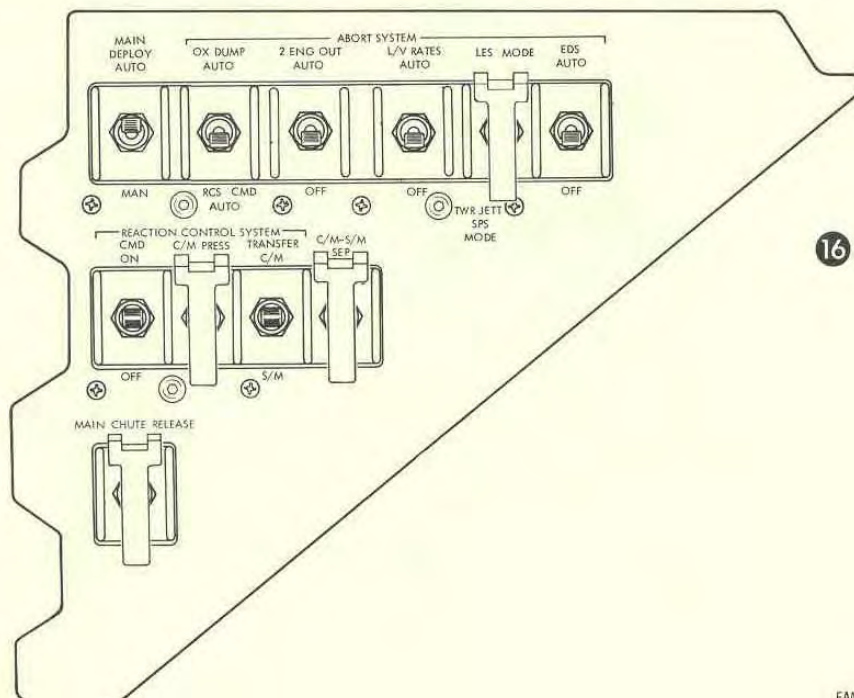


FIGURE 2-12

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2-26

CONTROL SYSTEMS PRIOR TO LAUNCH WITHOUT STAGING THE VEHICLE. THE CENTER POSITION OF THE SWITCH IS NORMAL FOR AUTOMATIC SWITCH OVER.

THE REACTION CONTROL SYSTEM C/M-S/M SEP SWITCH IS A TWO POSITION TOGGLE SWITCH SPRING LOADED TO THE OFF POSITION. MOMENTARY POSITIONING TO THE UP POSITION WILL PROVIDE NORMAL INITIATION OF THE C/M-S/M SEPARATION AND GENERATE ALL RELATED EVENTS IN ATTITUDE CONTROL CHANGE OVER TO THE C/M. IT ALSO WILL INITIATE RETRO GRADE OF THE S/M AFTER SEPARATION.

2.7.4 SERVICE PROPULSION GIMBAL ACTUATOR MOTORS

LOCATED ON THE EMERGENCY DETECTION AND GIMBAL DRIVE CONTROL PANEL ARE THE SIX SWITCHES ASSOCIATED WITH THE THRUST VECTOR CONTROL SUBSYSTEM (FIGURE 2-13). THESE SWITCHES SERVE TO ACTUATE THE GIMBAL DRIVE MOTORS OF THE SPS ENGINE GIMBALS AND ARMING OF THE SPS ROCKET ENGINE.

THE FOUR SWITCHES ON THE LEFT HAND SIDE OF THE PANEL ARE FOR GIMBAL ACTUATOR MOTOR CONTROL. THEY ARE THREE POSITION SWITCHES; THE UP POSITION START, THE CENTER POSITION ON, AND THE DOWN POSITION OFF. THE START POSITION IS MOMENTARY OR SPRING LOADED. THE TWO SWITCHES IN THIS GROUP ON THE LEFT HAND END ARE FOR CONTROL OF THE MOTORS IN THE PITCH ACTUATOR. THE TWO ON THE RIGHT HAND END OF THE GROUP ARE FOR CONTROL OF THE MOTORS IN THE YAW ACTUATOR. THE NUMBER 1 INDICATES THE PRIMARY MOTOR IN THE YAW AND PITCH ACTUATORS RESPECTIVELY. THE NUMBER 2 DENOTES THE SECONDARY, OR

BACKUP, MOTOR OF THE REDUNDANT ELECTRICAL SYSTEM. BOTH MOTORS WILL BE OPERATING FOR DELTA V MANEUVERS TO PROVIDE IMMEDIATE SWITCH OVER IN EVENT OF FAILURE IN THE PRIMARY MOTORS OR SELECTION OF A MANUAL THRUST VECTOR CONTROL MODE. THE TWO SWITCHES AT THE EXTREME RIGHT HAND END OF THE SIX SWITCHES ARE IDENTIFIED INJECT PRE-VALVES. THESE ARE TWO POSITION SWITCHES WITH THE UP POSITION ON AND THE DOWN POSITION OFF. THESE SWITCHES PROVIDE CONTROL TO THE ARMING VALVES OF THE SPS ROCKET ENGINE.

2.7.5 MASTER CAUTION PANELS

THE MASTER CAUTION LIGHTS ASSOCIATED WITH THE SCS PROVIDE WARNING OF FAILURES NOT EASILY DETECTED FROM DISPLAYS. THERE ARE TWO PANELS OF CAUTION LIGHTS AND THE SCS RECEIVES WARNING INDICATIONS FROM EACH. ONE PANEL IS ON THE UPPER LEFT OF CENTER ON THE MAIN CONTROL PANEL AND THE SECOND IS ON THE UPPER RIGHT OF CENTER.

2.7.5.1 AGAP Temperature Failure (FIGURE 2-14)

THE THREE BMAG HEATERS WILL KEEP THE DAMPING FLUID WITHIN GIVEN TEMPERATURE LIMITS OF $170 \pm 2^\circ\text{F}$ AFTER INITIAL WARM UP. SHOULD A HEATER FAIL IN ONE OF THE THREE BMAG'S, OTHER SOURCES WOULD BE NEEDED TO ISOLATE THE FAILED HEATER. OPERATING THE ATTITUDE GYROS WHEN THEY ARE NOT AT THEIR PROPER OPERATING TEMPERATURE COULD, IN EXTREME CASES, CAUSE CATASTROPHIC FAILURES. HOWEVER, NORMALLY DEGRADED SYSTEM PERFORMANCE WILL BE DETECTED BY OBSERVING THE VARIOUS ATTITUDE DISPLAYS BEFORE THE GYROS REACH THESE EXTREME OPERATING TEMPERATURES.

2-27

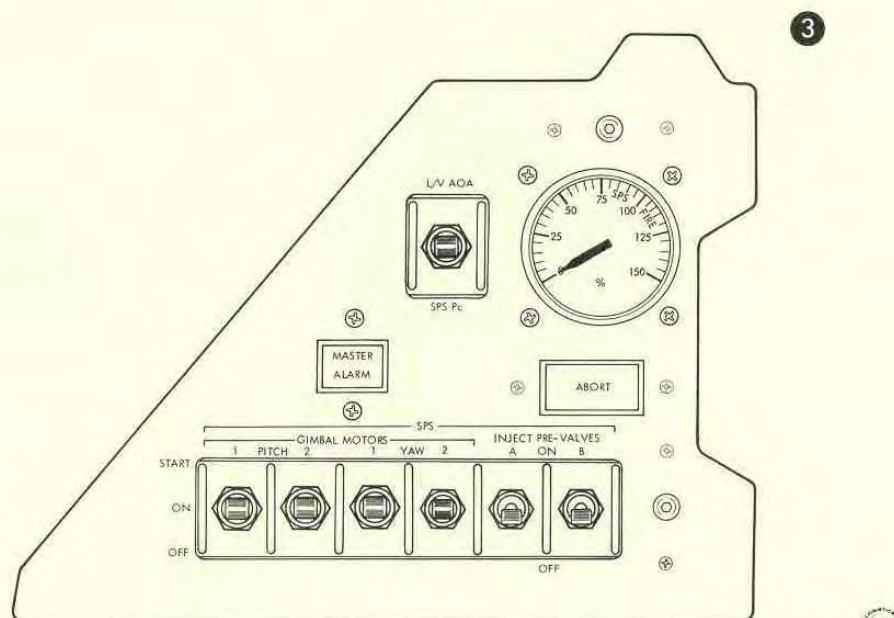


FIGURE 2-13

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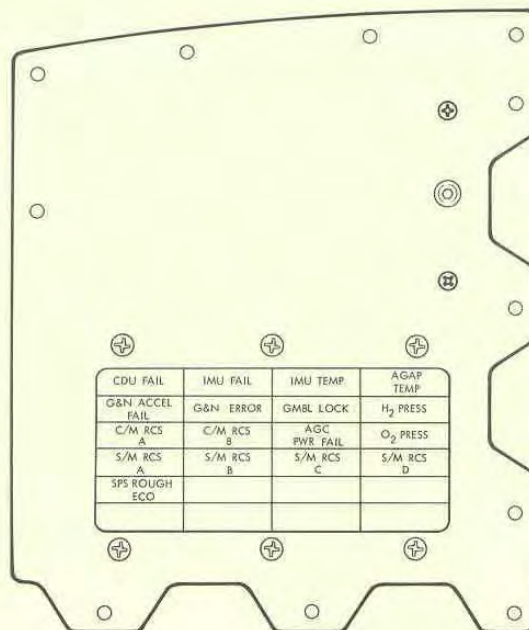


FIGURE 2-14

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2.7.5.2 SPS ROUGH ECO (FIGURE 2-14)

THE SPS ROUGH EXTERNAL COMBUSTION LIGHT IS ILLUMINATED BY THE LATCH RELAY OF THE FLIGHT COMBUSTION STABILITY MONITOR. TO EXTINGUISH THE LIGHT AFTER ILLUMINATION OCCURS, THE FCSM POWER SWITCH MUST BE PLACED TO THE RESET POSITION. WHEN THE LIGHT IS ILLUMINATED, THRUSTING WITH THE SPS ENGINE WILL BE TERMINATED UNLESS AN OVERRIDE IS USED.

2.7.5.3 GIMBAL DRIVE FAILURE LIGHTS

THE TWO GIMBAL DRIVE FAILURE CAUTION LIGHTS ARE ON THE RIGHT HAND MASTER CAUTION PANEL (FIGURE 2-15). ONE CAUTION LIGHT IS FOR THE PITCH GIMBAL FAILURE LIGHT AND THE OTHER IS THE YAW GIMBAL FAILURE LIGHT. ILLUMINATION OF EITHER CAUTION LIGHT WILL INDICATE A FAILURE OF THE PRIMARY GIMBAL DRIVE MOTOR IN THE AXIS OF CONTROL CORRESPONDING TO THE CAUTION LIGHTS. THE CAUTION LIGHTS WILL INDICATE AN UNDER OR OVER CURRENT CONDITION FOR THE INDICATED PRIMARY MOTOR. THERE IS AN AUTOMATIC SWITCH TO REMOVE POWER FROM THE FAULTY MOTOR AND THE SAME SIGNAL WILL CAUSE THE SCS TO BE SWITCHED TO ITS REDUNDANT ELECTRONICS FOR DRIVE COMMANDS TO THE REDUNDANT DC MOTOR CLUTCHES FOR GIMBAL POSITIONING COMMANDS.

2.7.6 PANEL 2

PANEL 2 PROVIDES CONTROLS TO PERFORM FDAI RATE SELFTEST, FDAI ILLUMINATION, SWITCHING FOR THE FCSM, AND THE ENTRY "G" METER.

2.7.6.1 FDAI ILLUMINATION

THE BRIGHTNESS CONTROL SELECTS THE LEVEL OF ILLUMINATION DESIRED ON THE FDAI ATTITUDE BALL. IT AUGMENTS THE CABIN LIGHTING TO REDUCE SHADOWS UNDER THE INDICES AND IMPROVE READOUT CAPABILITY.

2.7.6.2 FDAI RATE SELF TEST

THE FDAI SELF TEST SWITCH INSERTS AN INPUT TO THE RATE ELECTRONICS CAUSING A DEFLECTION OF THE RATE NEEDLES TO 4/5 FULL SCALE NEGATIVE RATE IN EACH AXIS. IT ALSO REMOVES THE RATE GYRO INPUT IF BACKUP RATE IS NOT SELECTED. IF BACKUP RATE IS NOT SELECTED, IF BACKUP RATE IS SELECTED, THE RATE SELF TEST INPUT IS SUMMED WITH THE BMAG RATE SIGNAL AND A SUMMATION OF THE TWO SIGNALS WOULD DETERMINE RATE NEEDLE DEFLECTION.

2.7.6.3 FCSM SWITCHING

THERE ARE TWO SWITCHES FOR CONTROL. THE ON-OFF-RESET SWITCH CONTROLS POWER TO THE FCSM. IN THE ON POSITION, THE FCSM WILL PERFORM ITS NORMAL FUNCTION OF TERMINATING THRUST OF THE SPS ENGINE FOR A ROUGH COMBINATION. SEVERAL CONDITIONS COULD COMBINE AND CAUSE A MOMENTARY ROUGH COMBUSTION THAT A COMPLETE SHUTDOWN AND RE-START WOULD CORRECT. THE RESET POSITION IS REQUIRED TO EXTINGUISH THE SPS ROUGH ECO LIGHT AND SET THE FCSM FOR MONITORING THE SPS ENGINE COMBUSTION UPON RESTART. THE SWITCH MUST BE IN THE ON POSITION FOR ALL MONITORING FUNCTIONS.

MASTER CAUTION

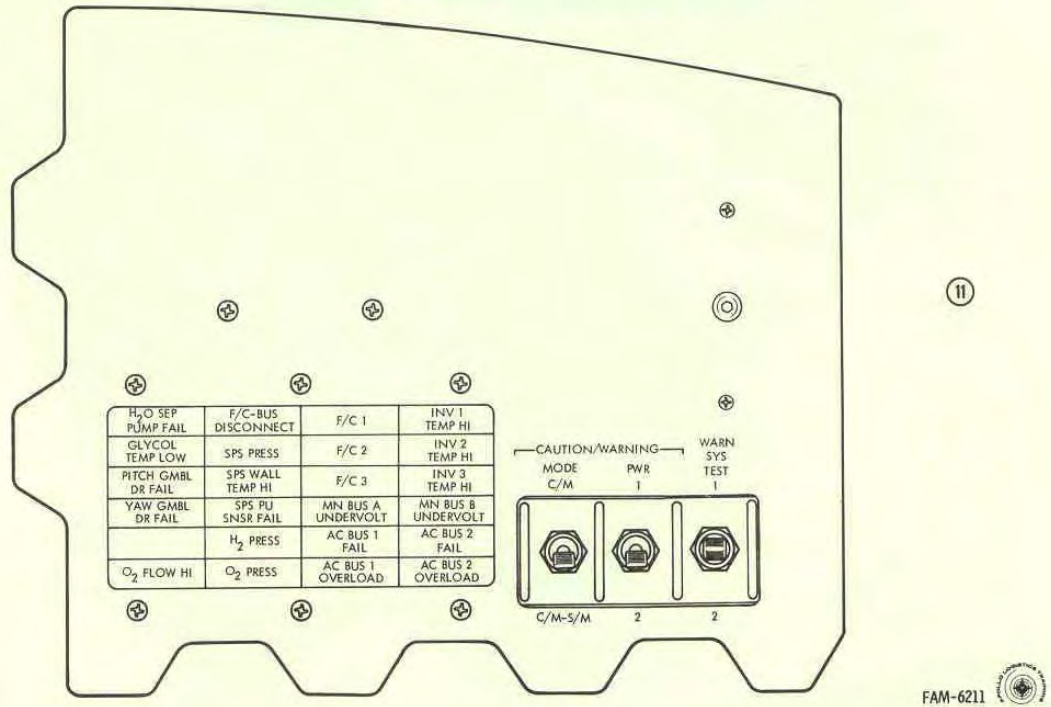


FIGURE 2-15

2-31

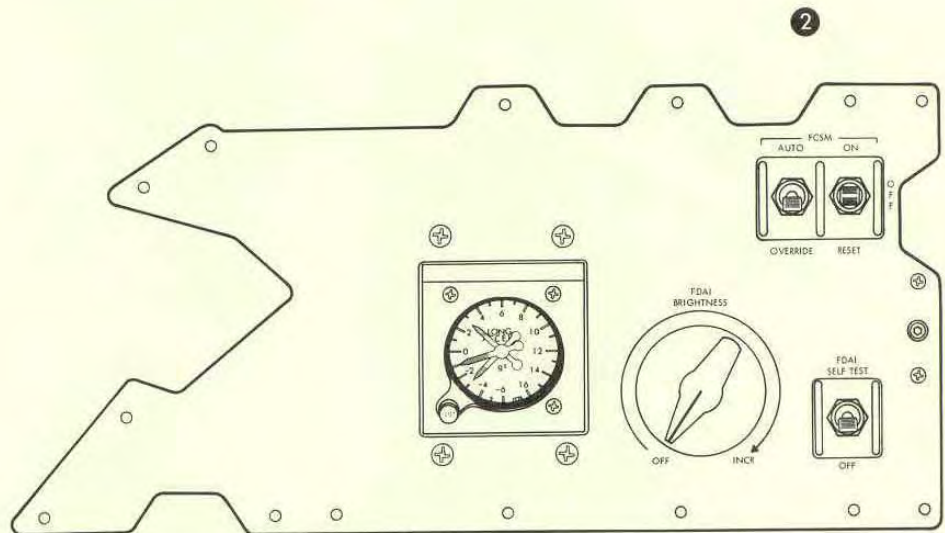


FIGURE 2-16

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THE AUTO-OVERRIDE SWITCH PROVIDES A BY-PASS OF THE FCSM FOR MALFUNCTIONS OR CREW CRITICAL FUNCTIONS. THE AUTO POSITION PERMITS THE FCSM TO PERFORM ITS NORMAL FUNCTIONS AND WOULD BE THE NORMAL POSITION. THE OVERRIDE POSITION WOULD BY-PASS THE FCSM FUNCTION AND PREVENT SPS ENGINE SHUTDOWN FOR ROUGH COMBUSTION EXCEPT FOR MANUAL CREW ACTION WITH OTHER SCS SWITCHES.

2.7.6.4 "G" METER

THE G METER IS A MECHANICAL DEVICE THAT PROVIDES A CONTINUOUS "G" FORCE INDICATION. IT HAS A READOUT SCALE MARKING OF -6 TO +16 "G'S" THE SAME G METER IS USED IN THE GEMINI. IT CONTAINS THREE READOUT NEEDLES. THE TOP NEEDLE IS THE "G" FORCE READOUT. THE LOWER TWO NEEDLES WILL PROVIDE A RECORD OF THE LARGEST NEGATIVE AND POSITIVE "G" APPLIED SINCE LAST RESET. THE RESET CONTROL SWITCH WILL RETURN BOTH MEMORY NEEDLES TO ZERO IF THE ACTUAL "G" LEVEL AT THAT TIME IS ZERO. IF NOT THE "G" FORCE APPLIED WILL DETERMINE WHICH NEEDLE DOES NOT RETURN TO ZERO BUT STOPS AT THE DISPLACE POSITION OF THE "G" NEEDLE.

THE INSTRUMENT FACE IS MOUNTED AT A 17° OFFSET FROM THE INSTRUMENT PANEL TO PROVIDE FOR ALIGNMENT OF THE SENSOR WITH THE SPACECRAFT'S 'X' BODY AXIS. THIS ROTATES THE "G" READOUT DOWN TOWARD THE ASTRONAUT AND SHOULD REDUCE READOUT PARALLEX ERROR.

APOLLO ATTITUDE REFERENCE SUBSYSTEMS

3.1 INTRODUCTION

THE ABILITY OF THE ASTRONAUT TO AID IN THE DETERMINATION OF SPACECRAFT ATTITUDE WITHIN INERTIAL SPACE MAY WELL BE A DECIDING FACTOR CONTRIBUTING TO THE SUCCESS OR FAILURE OF ANY MISSION INVOLVING FLIGHT FROM ONE INERTIAL BODY TO ANOTHER. IN APOLLO, TWO SYSTEMS ARE PROVIDED TO ASSIST THE ASTRONAUT IN THIS TASK, SEE FIGURE 3-1. EACH SYSTEM IS MECHANIZED WITH A COMPUTER, AN INERTIAL REFERENCE DEVICE, AND A READOUT DEVICE. THE PRIMARY SYSTEM IS THE GUIDANCE AND NAVIGATION SYSTEM (G&N). THE GUIDANCE AND NAVIGATION FUNCTION OF THIS SYSTEM IS MECHANIZED WITHIN TWO SEPARATE SUBSYSTEMS; THE OPTICS SUBSYSTEM, AND THE INERTIAL SUBSYSTEM. THE OPTICS PROVIDE A VARIABLE LINE OF SIGHT TELESCOPE AND A FIXED AND VARIABLE LINE OF SIGHT SEXTANT. WHEN USED IN CONJUNCTION WITH THE APOLLO GUIDANCE COMPUTER (AGC) AND THE OPTICS COUPLING DISPLAY UNIT (CDU), THIS SUBSYSTEM CAN BE USED TO DETERMINE SPACECRAFT INERTIAL ATTITUDE AND POSITION. ONCE INERTIAL ATTITUDE HAS BEEN DETERMINED, THE INERTIAL SUBSYSTEM MAY BE ALIGNED TO HOLD A REFERENCE ATTITUDE AND PROVIDE INERTIALLY REFERENCED DELTA VELOCITY OBTAINED FROM ACCELEROMETERS MOUNTED ON A THREE GIMBAL INERTIAL, OR STABLE PLATFORM. THE BACKUP ATTITUDE REFERENCE SUBSYSTEM (ARS) IS MECHANIZED WITHIN THE SCS. THIS DEVICE CAN PROVIDE AND DISPLAY ON THE FLIGHT DIRECTOR ATTITUDE INDICATOR (FDAI) ALL THE ATTITUDE DATA NORMALLY AVAILABLE FROM A THREE

GIMBAL PLATFORM, BUT IS CONFIGURED AS A MONITOR RATHER THAN A COMMAND SYSTEM, CONSEQUENTLY NO AUTOMATIC MANEUVER CAPABILITY IS PROVIDED IN THE S/C SYSTEMS. PRECISE MANUAL MANEUVERS MAY BE ACCOMPLISHED THROUGH PROPER UTILIZATION OF THE SCS CONTROLS AND DISPLAYS. THE ARS UTILIZES AN ORTHOGONAL SET OF SINGLE DEGREE OF FREEDOM GYROS TO SENSE CHANGES IN VEHICLE ATTITUDE ABOUT THE BODY AXES OF THE SPACECRAFT AND GENERATE EQUIVALENT ATTITUDE ERROR SIGNALS. THESE ERROR SIGNALS ARE SENT TO THE FLIGHT DIRECTOR ATTITUDE INDICATOR (FDAI) FOR DISPLAY, AND TO THE ARS WHERE, BY MEANS OF AN ELECTRO/MECHANICAL PROCESS, THEY ARE TRANSFORMED INTO DIRECTIONAL SINES AND COSINES AND GYRO TORQUING SIGNALS. THE DIRECTIONAL SINES AND COSINES ARE RETURNED TO THE FDAI AND ASSOCIATED ELECTRONICS, WHERE THEY ARE TRANSFORMED INTO AN EULER ANGLE READOUT WHICH IS EQUIVALENT TO THE GIMBAL ANGLE OUTPUT OF THE G&N STABLE PLATFORM. THE GYROS AND ELECTRO/MECHANICS OF THE ARS ARE MECHANIZED INTO A STRAPDOWN INERTIAL REFERENCE PACKAGE WHICH CAN PROVIDE ALL THE ATTITUDE DATA NORMALLY AVAILABLE FROM A GIMBALLED PLATFORM. THE CHART, FIGURE 3-1, COMPARES THE GIMBALLED REFERENCE SYSTEM AND THE STRAPDOWN REFERENCE SYSTEM.

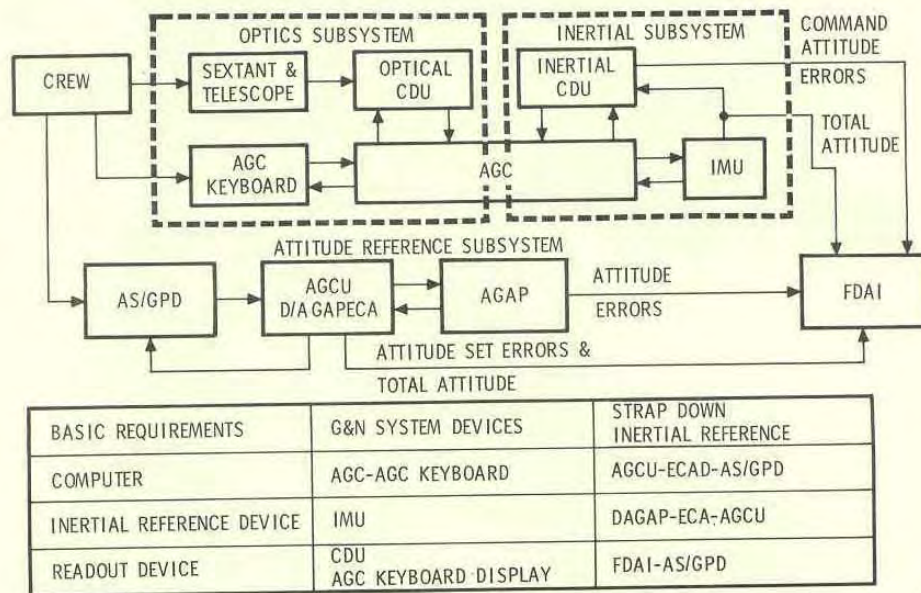
3.2 PURPOSE

THE PURPOSE OF EITHER REFERENCE SYSTEM OF THE APOLLO C/M IS TO RELATE SPACECRAFT ATTITUDE TO THE

3-1

APOLLO ATTITUDE REFERENCE SYSTEMS

GUIDANCE AND NAVIGATION SYSTEM COMPARISON



SCS-206A



FIGURE 3-1

3-2

COORDINATE SYSTEM OF AN ARBITRARILY SELECTED FIXED REFERENCE FRAME. A MATHEMATICAL SOLUTION TO THIS RELATIONSHIP WAS DEVELOPED BY THE SWISS MATHEMATICIAN, LEONHARD EULER, WHO SUMMED SUCCESSIVE ROTATIONS ABOUT ANY AXIS OF A RIGID BODY USING A THREE BY THREE MATRIX. SOLVING THIS MATRIX AFTER ANY SINGLE ROTATION OR SERIES OF ROTATIONS YIELDS THE "EULER ANGLE" ATTITUDE OF THE BODY, AS DISPLAYED ON THE FDAI, WITH RESPECT TO THE COORDINATES OF A FIXED FRAME. THE EULER ANGLE ATTITUDE OF THE BODY AFTER A SERIES OF MANEUVERS IS DEPENDENT NOT ONLY UPON THE DIRECTION AND MAGNITUDE OF BODY ROTATIONS, BUT ALSO UPON THE SEQUENCE OF ROTATION. THE IMPORTANCE OF ROTATIONAL SEQUENCE IS ILLUSTRATED BY FIGURE 3-2 AND BY THE FOLLOWING DESCRIPTION:

POSITION A - SHOWS THE ATTITUDE OF THE RIGID BODY WHEN IT IS ALIGNED TO THE FIXED REFERENCE FRAME.

POSITION B - SHOWS THE ALIGNMENT OF THE RIGID BODY AFTER A $+90^\circ$ ROLL WITH RESPECT TO THE BODY OR REFERENCE AXES.

POSITION C - DEPICTS THE BODY ATTITUDE AT THE COMPLETION OF A -90° YAW ABOUT THE REFERENCE AXES OR A -90° BODY PITCH ROTATION.

NOW FOR POSITIONS D, E, AND F OF FIGURE 3-2, HE WILL RESET THE BODY TO THE INITIAL POSITION AND PERFORM THE MANEUVER AGAIN, KEEPING THE DIRECTION AND

MAGNITUDE OF ROTATION THE SAME BUT CHANGING THE SEQUENCE OF ROTATION.

POSITION D - SHOWS THE POSITION OF ORIGIN AND IS IDENTICAL TO POSITION A.

POSITION E - SHOWS THE BODY AFTER A -90° YAW ABOUT THE BODY OR REFERENCE AXES.

POSITION F - SHOWS THE FINAL POSITION OF THE BODY AT THE COMPLETION OF A $+90^\circ$ BODY PITCH.

THE FINITE EULER ATTITUDE OF THE BODY IN EACH EXAMPLE IS NOT RELEVANT TO THIS DISCUSSION EVEN THOUGH THIS ATTITUDE COULD BE DETERMINED BY OBSERVING THE FINAL POSITION OF THE BODY WITH RESPECT TO THE REFERENCE AXES. WHAT IS IMPORTANT IS THAT THE BODY HAS A DIFFERENT ATTITUDE AT THE COMPLETION OF EACH MANEUVER SEQUENCE AND THAT ONLY THE MANEUVER SEQUENCE HAS BEEN CHANGED, THUS ILLUSTRATING THE NECESSITY OF AN EULER ANGLE DISPLAY (SUCH AS THE FDAI) OF SPACECRAFT ATTITUDE TO FACILITATE MANUAL SPACECRAFT MANEUVERS. A FIGURE, SIMILAR TO FIGURE 3-2, COULD BE DRAWN TO SHOW THAT ROTATIONAL SEQUENCING IS AS IMPORTANT FOR BODY AXES MANEUVERS AS IT IS FOR MANEUVERS ABOUT THE REFERENCE AXES; I.E., ROLL, PITCH VS. PITCH, THEN ROLL.

3-3

ROTATION OF A RIGID BODY REFERENCED TO A FIXED FRAME

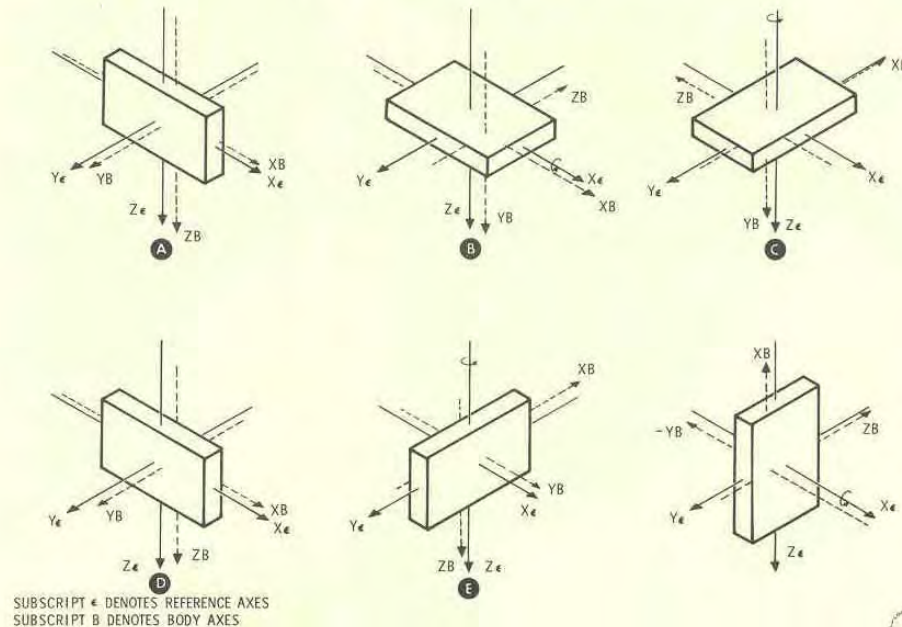



FIGURE 3-2

SCS-210A 
3-4

3.2.1 APOLLO REFERENCE AXES

THE PROBLEMS ASSOCIATED WITH MAINTAINING A REFERENCE ATTITUDE IN AN ARBITRARILY SELECTED FIXED REFERENCE FRAME IS IN REALITY MORE COMPLICATED THAN IT APPEARS IN FIGURE 3-2. THE COMPLICATION IS DUE TO THE ZERO REFERENCE OF THE NAVIGATION BASE TRIAD. THIS TRIAD IS ORIENTED SO THAT ITS X AND Z AXES ARE ROTATED 33° WITH RESPECT TO THE SPACECRAFT BODY X AND Z AXES. THE Y AXIS OF BOTH TRIADS ARE PARALLEL. THE RELATIONSHIP OF THESE AXES TO THE SPACECRAFT IS SHOWN IN FIGURE 3-3. FORTUNATELY, THE ELECTRONIC MECHANIZATION (WHICH WILL BE DISCUSSED LATER) REQUIRED TO SOLVE THE AXIAL MISALIGNMENT IS NOT UNDULY COMPLICATED AND DOES PROVIDE THE CAPABILITY OF ROTATING THE SPACECRAFT THROUGH 360° ABOUT THE YAW BODY AXIS WITHOUT GOING INTO GIMBAL LOCK. (GIMBAL LOCK IS ENCOUNTERED WHEN THE MIDDLE AND OUTER GIMBALS OF THE IMU BECOME ALIGNED. THE G&N PROVIDES A LOGIC SIGNAL TO THE MASTER CAUTION LIGHTS TO ALERT THE CREW TO AN IMPENDING GIMBAL LOCK CONDITION. IN ADDITION, THE FDAI DISPLAYS THE CRITICAL GIMBAL LOCK ZONE BY MEANS OF TWO RED 30° CIRCLES, ON THE SURFACE OF THE FDAI BALL, CENTERED ON THE Y AXIS.) THE OPTICS BASE ZERO REFERENCE IS ALSO SHOWN IN FIGURE 3-3. THE ANGLES GENERATED BY THE SHAFT AND TRUNION ARE UTILIZED IN ALIGNING THE G&N AND ARS.

3.3 FLIGHT DIRECTOR ATTITUDE INDICATOR

THE FDAI PROVIDES THE CREW WITH A VISUAL LINK TO THE OUTSIDE WORLD AND THE RELATIONSHIP OF THIS WORLD TO SPACECRAFT ROTATIONAL MANEUVERS RESULTING

FROM MANUAL OR AUTOMATIC COMMANDS. IN ADDITION, IT PROVIDES AN EXCELLENT MEANS, TO THE TRAINED OPERATOR, OF DETECTING MALFUNCTIONS IN THE ELECTRO/MECHANICAL SYSTEMS OF THE SCS AND G&N. THE DEVICE SIMULTANEOUSLY DISPLAYS ELEVEN INDEPENDENT CUES FOR REFERENCING THE BODY AND NAVIGATION AXES TO AN INERTIALLY FIXED REFERENCE. THESE INDICATIONS ARE ROLL, PITCH, AND YAW, TOTAL ATTITUDE, COMMAND ATTITUDE ERROR AND COMMAND RATE. (THE TERM COMMAND REFERS TO THE DIRECTIONAL RELATIONSHIP BETWEEN INDICATOR MOVEMENT AND CONTROL STICK DEFLECTION REQUIRED TO NULL THE INDICATOR.)

3.3.1 FDAI TOTAL ATTITUDE

THE TOTAL ATTITUDE READOUT IS OBTAINED FROM A SPHERICAL DISPLAY, OR BALL, WHICH HAS THREE SERVO DRIVEN GIMBALS THAT ARE SEQUENCED PITCH INSIDE, YAW MIDDLE, AND ROLL OUTSIDE. THESE GIMBALS HAVE FULL CONTINUOUS BI-DIRECTIONAL ROTATIONAL CAPABILITY. THE SPHERE, SEE FIGURE 3-4, IS MARKED WITH GREAT CIRCLE LINES AND SMALL CIRCLE LINES WHICH CORRESPOND TO THE LONGITUDE AND LATITUDE LINES OF A GLOBE. THERE ARE TWELVE GREAT CIRCLE LINES AND FIVE SMALL CIRCLE LINES. THE ANGULAR DISTANCE BETWEEN EACH OF THE LINES IS 30° . THE SPHERE PROVIDES INDICATIONS FROM 0° TO 360° OF EULER PITCH ATTITUDE. EULER YAW ANGLES ARE INDICATED FROM 0° TO 90° AND 270° TO 0° . PITCH AND YAW TOTAL ATTITUDE MAY BE READ FROM EITHER THE BODY AXIS INDICE, A MINATURE AIRPLANE () SHAPE, OR THE NAVIGATION AXES INDICE, A CROSS HAIR (). IF THE INSTRUMENT WERE TO INDICATE 0° PITCH AND 0° YAW, THE 0° PITCH LINE WOULD BE TANGENT TO THE HORIZONTAL CROSS HAIR OF THE NAV INDEX AND

3-5

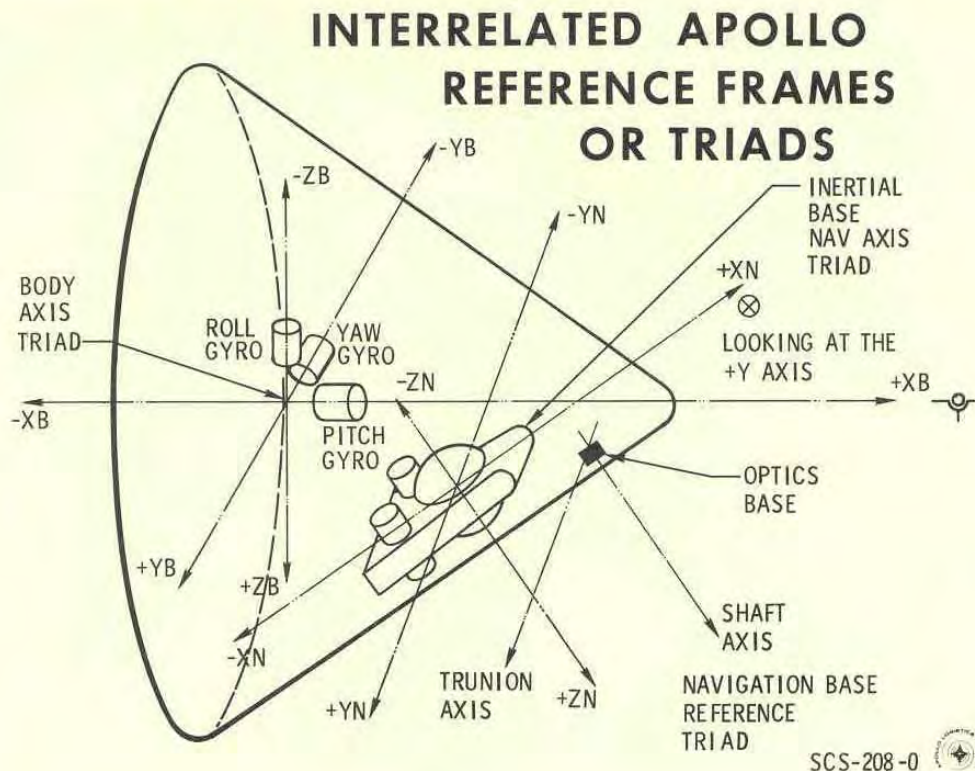
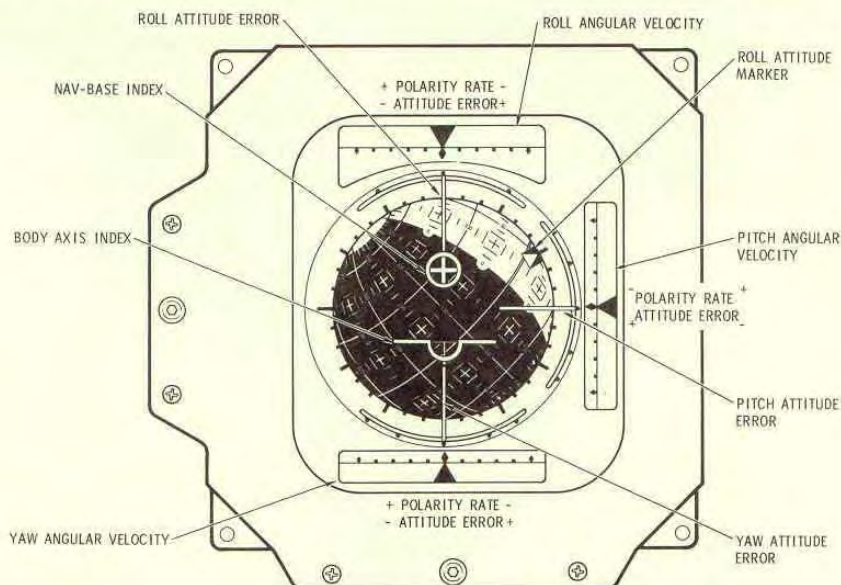


FIGURE 3-3

3-6

FLIGHT DIRECTOR ATTITUDE INDICATOR



NOTES:

1. ATTITUDE ERROR = ATTITUDE DESIRED - ACTUAL ATTITUDE.
2. THE BALL IS OF THE INSIDE-OUT CONVENTION.
3. EULER ANGLE CONVENTION IS PITCH, YAW, ROLL.
4. THE BALL ATTITUDE SHOWN IS PITCH 345°, YAW 335°, AND ROLL 300°, WITH RESPECT TO THE NAVIGATION BASE INDEX.

FIGURE 3-4

SCS-100B

3-7

THE 0° YAW LINE WOULD BE DIRECTLY UNDER THE VERTICAL CROSS HAIR OF EACH INDEX. ROLL EULER ATTITUDE IS INDICATED BY THE ROLL BUG (AN INDICATOR NEEDLE DRIVEN BY THE ROLL GIMBAL THROUGH A GEAR MECHANISM). AS THE VEHICLE ROTATES POSITIVELY OR CLOCKWISE, THE ROLL BUG IS DRIVEN COUNTERCLOCKWISE. THE EULER ROLL ANGLE IS OBTAINED FROM A BEZEL RING. THE BEZEL RING IS MARKED IN 10° INCREMENTS WHICH INCREASE POSITIVELY IN A COUNTERCLOCKWISE DIRECTION FROM THE TOP CENTER OF THE BEZEL.

3.3.1.1 FDAI TOTAL ATTITUDE DISPLAY PHILOSOPHY

A LITTLE IMAGINATION IS NEEDED TO UNDERSTAND THE RELATIONSHIP BETWEEN THE BALL AND THE OUTSIDE WORLD. FIRST, IMAGINE A SPHERICAL COORDINATE SYSTEM MARKED SIMILAR TO THE BALL BUT EXPANDED TO INFINITY. THE STARS COULD BE IDENTIFIED AND CATALOGED ACCORDING TO THEIR LOCATION ON OUR IMAGINARY SYSTEM. ASTRONAUTS COULD DETERMINE THEIR INERTIAL ATTITUDE BY SIGHTING THROUGH A TELESCOPE TO A CONVENIENT STAR. BY READING THE COORDINATES OF THIS REFERENCE STAR, FROM OUR IMAGINARY COORDINATE SYSTEM, AND KNOWING THE SIGHTING ANGLES (WITH RESPECT TO THE S/C) OF THE TELESCOPE, THE ASTRONAUT COULD DEDUCE SPACECRAFT ATTITUDE. SINCE WE REALLY DON'T HAVE A MARKED STELLAR COORDINATE SYSTEM, ONE HAS BEEN CREATED INSIDE THE SPACECRAFT ON THE FDAI BALL. AFTER PROPER ALIGNMENT, THE ANGLE OF THE SPACECRAFT BODY X, OR NAVIGATION X, AXIS IN INERTIAL SPACE MAY BE DETERMINED BY OBSERVING THE PROPER INDEX AND READING THE COORDINATES OFF THE BALL AND ROLL BUG.

SPACECRAFT MOVEMENTS, WITH RESPECT TO THE OUTSIDE WORLD, ARE PRESENTED BY THE BALL IN THE SAME MANNER AS THE TELESCOPE AND IMAGINARY COORDINATE SYSTEM, VIZ: IF THE ASTRONAUT WERE TO LOOK THROUGH A TELESCOPE AT THE OUTSIDE WORLD, THE IMAGINARY COORDINATE SYSTEM WOULD PASS ACROSS THE TELESCOPE FROM TOP TO BOTTOM AS THE SPACECRAFT ROTATES POSITIVE, OR UPWARDS. THE BALL IN THIS INSTANCE WOULD ROTATE FROM TOP TO BOTTOM. THE SAME RELATIONSHIP HOLDS TRUE FOR YAW AND ROLL ROTATIONS. THUS, THE FDAI BALL GIVES A TRUE PICTURE OF NOT ONLY THE INERTIAL ATTITUDE OF THE SPACECRAFT, BUT PRESENTS A VALID REPRESENTATION OF THE DIRECTION THE SPACECRAFT IS BEING ROTATED. INsofar AS THE ASTRONAUT IS CONCERNED, IT APPEARS THAT THE SPACECRAFT IS BEING ROTATED WHILE THE BALL REMAINS STATIONARY; THIS, HOWEVER, IS AN ILLUSION. ACTUALLY, BOTH ARE ROTATING IN THE SAME DIRECTION, THE BALL TRAVELING AT TWICE THE SPACECRAFT VELOCITY WITH RESPECT TO THE INERTIAL SPHERE OR STELLAR COORDINATE SYSTEM ABOUT ALL BUT THE EULER ROLL AXIS. IN ROLL, THE BALL MAINTAINS AN INERTIAL ATTITUDE.

3.3.2 FDAI ATTITUDE ERROR AND RATE DISPLAYS

IN ADDITION TO TOTAL ATTITUDE, THE FDAI ALSO DISPLAYS ATTITUDE ERROR AND RATE OF CHANGE IN ATTITUDE. THE ATTITUDE ERROR DISPLAY NEEDLES USE THE CENTER POINT BETWEEN THE BODY AND NAVIGATION INDICES AS ZERO OR NULL POINT FOR ALL THREE DISPLAY NEEDLES. THE ATTITUDE ERROR DISPLAYED BY THESE NEEDLES IS COMMAND SIGNAL REQUIRED TO NULL THE NEEDLE, THUS CORRECTING THE ERROR. IN A COMMAND ERROR CONFIGURATION, THE

STICK MUST BE DEFLECTED IN THE SAME DIRECTION AS THE NEEDLE, RE: IF THE YAW COMMAND ERROR NEEDLE IS DEFLECTED TO THE LEFT SIDE OF THE FDAI, THE CONTROL STICK WOULD BE ROTATED CCH. IN PITCH, IF THE NEEDLE WERE DEFLECTED UPWARDS, THE STICK WOULD BE ROTATED BACKWARD TO NULL THE NEEDLE. THE RATE NEEDLES ARE ALSO COMMAND NEEDLES AND MAY BE NULLED WITH THE CONTROL STICK IN THE SAME MANNER AS THE ATTITUDE ERROR NEEDLES. THE DISPLAYS ON THE FDAI ARE USED TO PERFORM PRECISE MANUAL ORIENTATION OF THE SPACECRAFT, MONITOR AUTOMATIC, SEMI-AUTOMATIC, OR MANUAL SPACECRAFT MANEUVERS, AND TO EVALUATE SYSTEM PERFORMANCE. IN THE APOLLO COMMAND MODULE, TWO SYSTEMS, THE GUIDANCE AND NAVIGATION SYSTEM WHICH IS PRIMARY, AND THE ATTITUDE REFERENCE SUBSYSTEM OF THE SCS PROVIDE SIGNALS TO THE FDAI.

3.4 GUIDANCE AND NAVIGATION SYSTEM MECHANIZATION

THE GUIDANCE AND NAVIGATION SYSTEM MAINTAINS THE INERTIAL OR FIXED REFERENCE FRAME THROUGH THE USE OF A STABLE PLATFORM. THIS DEVICE TAKES ADVANTAGE OF THE INERTIAL PROPERTIES OF GYROS. MOUNTED ON AN INNER BLOCK, GYROS MAINTAIN A NONROTATING REFERENCE FRAME BY DRIVING ISOLATION GIMBALS. THIS, IN EFFECT, ALLOWS THE SPACECRAFT TO MOVE OR ROTATE ABOUT THE INNER BLOCK. ACCELEROMETERS, ALSO MOUNTED ON THE INNER BLOCK, KEEP TRACK OF AND NULL ANY INERTIAL DISPLACEMENT OF THE REFERENCE FRAME BY A PROCESS OF DOUBLE INTEGRATION. G&N MECHANIZATION IS DEPICTED IN FIGURE 3-1. IT SHOWS TWO DISTINCT OPERATING LOOPS OR SUBSYSTEMS WITHIN THE G&N; THE OPTICS SUBSYSTEM AND THE NAVIGATION SUBSYSTEM. THE OPTICS ARE AUTOMATICALLY OR MANUALLY CONTROLLED,

AND, WITH THE COMPUTER, MAY BE USED BY THE ASTRONAUT IN ALIGNING THE STABLE PLATFORM AND THE ARS. THE NAVIGATION SECTION PLATFORM WILL MAINTAIN THE FIXED REFERENCE FRAME AND AUTOMATICALLY CONTROL SPACECRAFT ATTITUDE AND THRUST VECTOR ATTITUDE BY PROVIDING A COMMAND ERROR SIGNAL TO THE SCS ELECTRONICS. G&N COMMAND ERRORS ARE DERIVED BY TAKING THE ERROR BETWEEN THE SHAFT ANGLES OF THE INERTIAL MEASURING UNIT (IMU) GIMBALS AND THE SHAFT ANGLES OF THE COUPLING DISPLAY UNIT (CDU). THESE ERRORS MAY BE GENERATED EITHER BY THE COMPUTER DRIVING THE CDU SHAFTS OR BY THE SPACECRAFT MANEUVERING ABOUT THE CDU INDICATED ATTITUDE. IN THE FIRST CASE, THE COMPUTER WILL COMMAND A PARTICULAR VEHICLE ATTITUDE BY DRIVING THE CDU SHAFTS TO A NEW POSITION. THIS CAUSES THE CDU SHAFT ANGLE AND IMU GIMBAL ANGLE TO BE IN DISAGREEMENT AND GENERATES AN ATTITUDE ERROR WHICH IS SENT TO THE SCS, WHERE IT IS DISPLAYED, AND PROCESSED TO ENERGIZE THE APPROPRIATE SET OF REACTION JETS TO CORRECT THE ERROR. AS THE IMU GIMBAL POSITION APPROACHES THE CDU RESOLVER POSITION, THE MAGNITUDE OF ERROR IS REDUCED TO ZERO AND THE VEHICLE IS STABILIZED AT THE NEW ATTITUDE. SINCE THE REACTION JETS ARE NEARLY ALIGNED WITH THE SPACECRAFT BODY AXES, THE COMMANDS WHICH CAUSE THEM TO ENERGIZE MUST BE REFERENCED TO THE BODY AXES OF THE SPACECRAFT DURING NON-ATMOSPHERIC FLIGHT. G&N COMMAND ERRORS ARE TRANSFORMED TO THE BODY AXES COORDINATE SYSTEM THROUGH A FIXED RESOLVER IN THE ROLL AND YAW ERROR CHANNELS OF THE COUPLING DISPLAY UNIT. THIS RESOLVER IS BYPASSED DURING G&N ENTRY MODE SO THAT COMMANDS, SENT TO THE REACTION JETS AND DISPLAYED, ARE REFERENCED TO THE NAVIGATION AXES RATHER THAN THE BODY AXES. THIS

3-9

IS DONE TO ACCOMMODATE THE PHYSICAL OFFSET OF THE SPACECRAFT ROTATIONAL AXES DURING ATMOSPHERIC FLIGHT.

3.5 ATTITUDE REFERENCE SUBSYSTEM MECHANIZATION

THE ATTITUDE REFERENCE SUBSYSTEM, OF THE STABILIZATION AND CONTROL SYSTEM, COMPUTES AND MAINTAINS A SPACE STABLE REFERENCE FRAME FOR THE SPACECRAFT. IN THIS CASE, THE REFERENCE IS MAINTAINED BY A STRAP-DOWN PACKAGE WHICH PROVIDES THREE SINGLE DEGREE OF FREEDOM WIDE ANGLE INTEGRATING GYROS (GG248) MECHANIZED INTO A RATE LOOP WHICH MAINTAINS AN EXTREMELY LOW LEVEL OUTPUT (LESS THAN APPROXIMATELY 0.15° ATTITUDE ERROR) WHILE THE VEHICLE IS BEING MANEUVERED, UNLESS THE ROTATIONAL VELOCITIES EXCEED THE ARS LIMITS OF 5 DEG/SECOND IN PITCH AND YAW AND 20 DEG/SECOND IN ROLL. THE SYSTEM IS CAPABLE OF PROVIDING AND DISPLAYING A SHORT TERM ATTITUDE REFERENCE FOR THE SPACECRAFT. THREE SIGNAL LOOPS ARE USED; CONTROL, INFORMATION, AND LOGIC. THESE SIGNAL LOOPS ARE MECHANIZED WITHIN SIX ELECTRONIC CONTROL ASSEMBLIES OF THE ARS, FIGURE 3-5. THESE ASSEMBLIES ARE:

- A. RATE GYRO PACKAGE (RGP)
- B. ATTITUDE GYRO ACCELEROMETER PACKAGE (AGAP)
- C. ATTITUDE SET/GIMBAL POSITION DISPLAY (AS/GPD)
- D. FLIGHT DIRECTOR ATTITUDE INDICATOR (FDAI)
- E. DISPLAY ATTITUDE GYRO ACCELEROMETER PACKAGE ELECTRONIC CONTROL ASSEMBLY (DAGAPECA)
- F. ATTITUDE GYRO COUPLING UNIT (AGCU)

3.5.1 CONTROL LOOP

CONTROL LOOP ACCURACY IS THE MOST CRITICAL FACTOR AFFECTING THE SUCCESSFUL OPERATION OF THE ARS. FOR EASE OF UNDERSTANDING, THE CONTROL LOOP MAY BE MADE ANALOGOUS TO THE OPERATION OF A SERVO LOOP IN WHICH A SENSOR DETECTS A CHANGE IN ATTITUDE AND GENERATES AN EQUIVALENT ELECTRICAL SIGNAL. THIS SIGNAL IS ULTIMATELY RETURNED, AFTER PROCESSING, TO NULL OR ZERO THE SENSOR. A SINGLE AXIS MECHANIZATION OF THE CONTROL LOOP IS REPRESENTED IN FIGURE 3-6. THIS DIAGRAM SHOWS SIGNAL PROCESSING WITHIN THE ARS CONTROL LOOP. CHANGES IN SPACECRAFT ATTITUDE ARE DETECTED BY THE GYROS. THE RESULTANT SIGNAL IS CONVERTED TO THE NAVIGATION AXES REFERENCE FRAME AND SUBSEQUENTLY CONVERTED INTO A EULER ANGLE RATE, WHICH IS DEMODULATED AND AMPLIFIED BEFORE BEING APPLIED TO THE LEVEL DETECTORS. IF THE ERROR SIGNAL WERE INPHASE, THE FORWARD LEVEL DETECTOR WOULD SWITCH WHEN THE SENSED LEVEL BECAME GREATER THAN THE DEADBAND. SWITCHING THE LEVEL DETECTOR CAUSES THE STEPPER MOTOR TO STEP 0.2 DEGREES AND SENDS A TORQUING SIGNAL BACK THROUGH THE REVERSE TRANSFORMATION (EULER TO NAVIGATION TO BODY) TO TORQUE THE GYRO TO NULL, OR AT LEAST BELOW THE LEVEL DETECTOR SWITCHING POINT. THE STEPPER MOTOR AND TORQUING CIRCUITS ARE CONTROLLED BY A TIMER WHICH MAINTAINS PRECISE TORQUING PERIODS OF 40 MS IN PITCH AND YAW AND 10 MS IN ROLL FOR EACH $.2^\circ$ CHANGE IN ATTITUDE.

3-10

ATTITUDE REFERENCE SUBSYSTEM

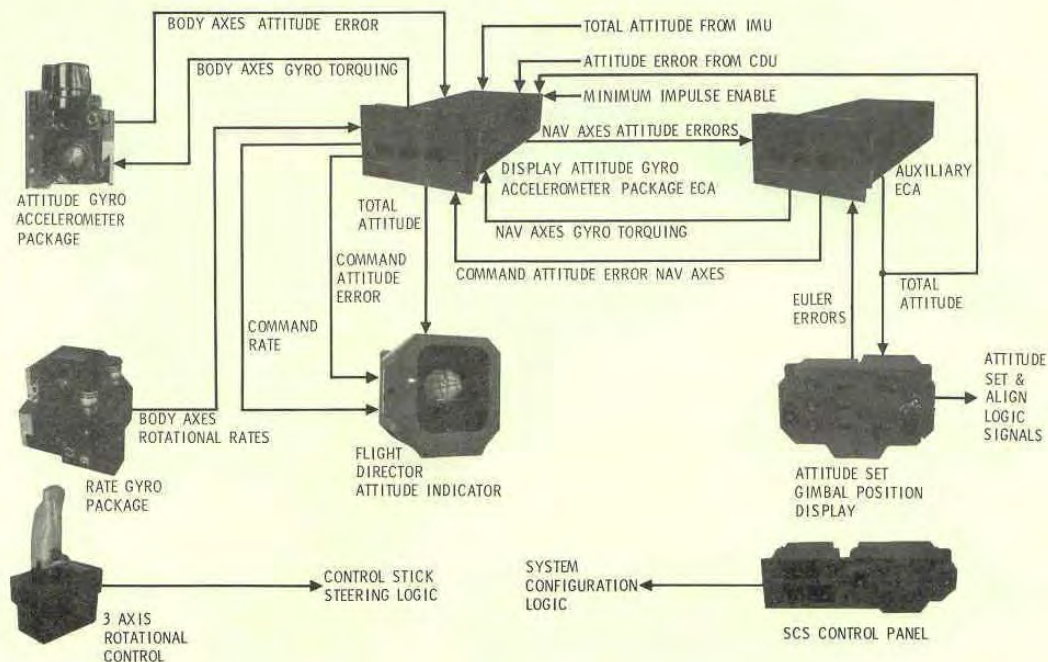


FIGURE 3-5

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3-11

ARS CONTROL LOOP

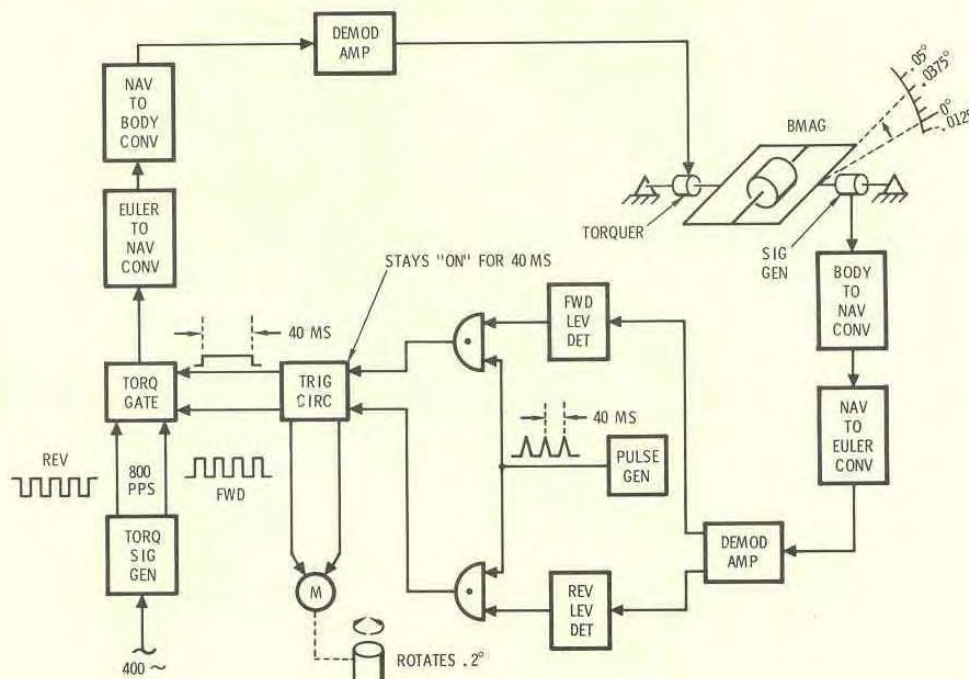


FIGURE 3-6

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3-12

3.5.2 INFORMATION LOOP

THE INFORMATION LOOP, FIGURE 3-5, OF THE ARS PROVIDES TOTAL ATTITUDE, ATTITUDE ERROR, AND RATE INFORMATION FOR THE FLIGHT DIRECTOR ATTITUDE INDICATOR. TOTAL ATTITUDE AND ATTITUDE ERROR INFORMATION MAY BE OBTAINED FROM EITHER THE GUIDANCE AND NAVIGATION SYSTEM OF THE ARS. RATE IS ALWAYS SENSED BY EITHER THE RATE GYROS OR THE ATTITUDE GYROS IN BACKUP RATE MODE. THE TERM INFORMATION LOOP IS USED BECAUSE THE ARS DISPLAY ELECTRONICS ARE USED ONLY FOR SIGNAL PROCESSING AND GAIN CONTROL REQUIRED FOR DISPLAY OF THE INPUT SIGNALS.

3.5.3 LOGIC

THE LOGIC SIGNALS REQUIRED FOR CONFIGURING THE ARS ARE DERIVED FROM FOUR SOURCES; AS/GPD, SCS CONTROL PANEL, G&N CONTROL PANEL AND THE CONTROL STICK. THE ONLY SWITCH ON THE SCS CONTROL PANEL WHICH DOES NOT AFFECT ARS CONFIGURATION IS THE ATT DEADBAND SWITCH.

3.6 ARS FUNCTIONAL DESCRIPTION

ARS MECHANIZATION AND THE G&N INTERFACE ARE REPRESENTED IN A SIMPLIFIED FUNCTIONAL SCHEMATIC, FIGURE 3-7. ALL THE FUNCTIONS AND MODES OF THE ARS MAY BE PRESENTED USING THIS DIAGRAM. THE SYSTEM IS MECHANIZED WITHIN SIX UNITS OF THE SCS. THESE UNITS HAVE ALL BEEN DISCUSSED IN SECTION ONE OF THIS STUDY GUIDE; HOWEVER, A FEW DEVICES, THE DAGAPECA, AGCU AND ATTITUDE SET SECTION OF THE AS/GPD REQUIRE SOME FURTHER

EXPLANATION TO PROVIDE CONTINUITY FOR THE DISCUSSION OF ARS MODES OF OPERATION.

3.6.1 DISPLAY AND ATTITUDE GYRO ACCELEROMETER PACKAGE ELECTRONIC CONTROL ASSEMBLY (DAGAPECA)

THE DAGAPECA IS FUNCTIONALLY DIVIDED INTO TWO SEPARATE BUT INTEGRAL UNITS WHICH MAY BE OPERATED INDEPENDENTLY. THE FIRST OF THESE UNITS, THE ATTITUDE GYRO ACCELEROMETER PACKAGE ELECTRONIC CONTROL ASSEMBLY (AGAPECA), CONTAINS THE ELECTRONICS REQUIRED TO OPERATE THE ATTITUDE GYROS AND INTERFACE WITH THE ATTITUDE GYRO COUPLING UNIT (AGCU). THE SECOND UNIT, THE DISPLAY ELECTRONIC CONTROL ASSEMBLY (DECA), PROVIDES INTERFACE ELECTRONICS BETWEEN THE SCS SENSORS AND THEIR CORRESPONDING DISPLAYS. THESE UNITS ARE MECHANIZED AS FOLLOWS:

A. AGAPECA

FUNCTION	PURPOSE
1. GYRO PREAMP	ISOLATION AND AMPLIFICATION OF ATTITUDE GYRO OUTPUTS.
2. BODY TO NAVIGATION AXIS AMPLIFIER	THE INPUT SUMMING TO THIS BUFFER AMPLIFIER IS SCALED TO PROVIDE THE FIRST CONVERSION IN THE FORWARD LOOP BY COMBINING ROLL AND YAW SIGNALS TO

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ATTITUDE REFERENCE SUBSYSTEM

FDAI/AGCU ALIGN

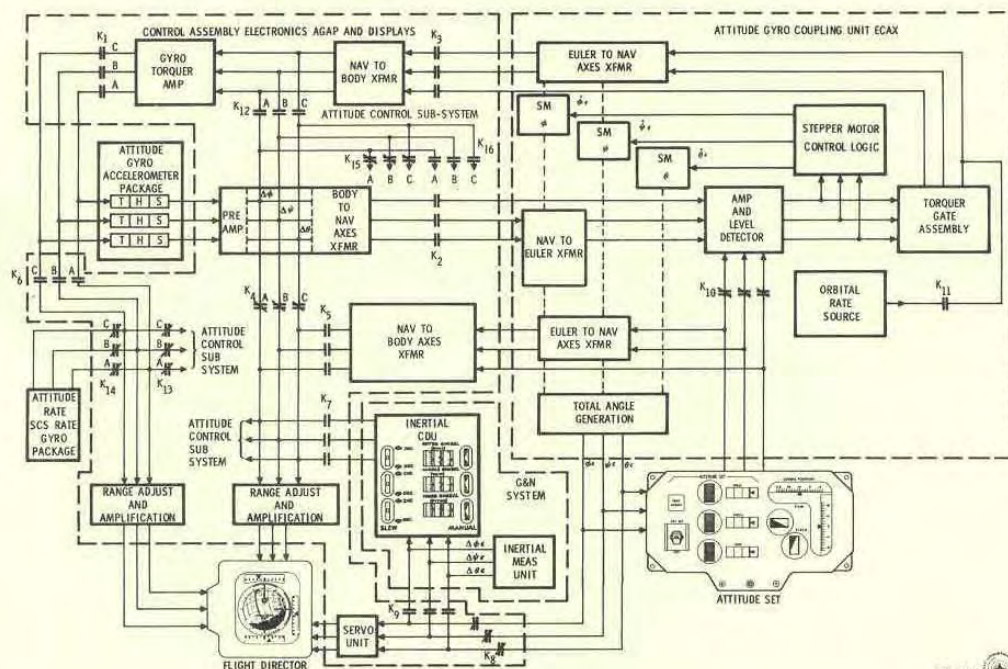


FIGURE 3-7

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3-14

TABLE 3-1. RELAY SWITCHING FUNCTIONS

RELAY	PURPOSE	RELAY	PURPOSE
K _{1ABC} *	APPLIES TORQUING SIGNALS TO THE ATTITUDE GYROS.	K ₁₀	PROVIDES AGCU SHAFT ANGLE ATTITUDE SET DIAL DIFFERENTIAL SIGNAL TO REALIGN THE AGCU AND FDAI.
K ₂	APPLIES ATTITUDE GYRO OUTPUTS TO THE AGCU.	K ₁₁	APPLIES AN ORBITAL RATE SIGNAL FOR LOCAL VERTICAL OPERATION.
K ₃	APPLIES AGCU TORQUING SIGNALS TO THE ATTITUDE GYROS.	K _{12ABC}	PROVIDE CAGING SIGNALS TO PUT THE ATTITUDE GYROS IN A RATE MODE INDIVIDUALLY OR TOGETHER DEPENDING UPON THE SELECTED MODE.
K _{4ABC}	APPLIES ATTITUDE GYRO OUTPUTS TO THE FDAI.	K _{13ABC}	K ₁₃ AND K ₁₄ HAVE CONTACTS WHICH OPERATE INDEPENDENTLY WITH CORRESPONDING BACKUP RATE SWITCH. WHEN A K ₁₃ CONTACT IS OPENED DURING BACKUP RATE, THE CORRESPONDING K ₁₄ CONTACT IS OPENED.
K ₅	ENERGIZED DURING ATTITUDE SET TO PROVIDE AN ELECTRICAL SIGNAL EQUIVALENT TO THE DIFFERENCE ANGLE BETWEEN THE AGCU RESOLVER SHAFTS POSITION AND THE ATTITUDE SET DIAL RESOLVER SHAFT POSITION.	K _{14ABC}	
K _{6ABC}	APPLIES GYRO TORQUER AMP OUTPUT TO THE FDAI COMMAND RATE ERROR NEEDLES (IN THE SELECTED AXIS).	K _{15ABC}	THESE ARE USED INDEPENDENTLY IN CONJUNCTION WITH BACKUP RATE SELECTION IN A SINGLE CHANNEL.
K ₇	APPLIES G&N ATTITUDE ERROR SIGNALS TO THE FDAI COMMAND ATTITUDE ERROR NEEDLES.	K _{16ABC}	THEY SWITCH THE GYRO PRE-AMP OUTPUT FROM THE ATTITUDE DEMODULATOR TO THE RATE DEMODULATOR IN THE SELECTED CHANNEL OR IN ALL THREE CHANNELS.
K ₈	APPLIES AGCU GENERATED DIRECTIONAL SINE AND COSINE SIGNALS TO THE FDAI BALL AND ROLL BUG.	*ABC	SUBSCRIPT DENOTES RELAY CONTACTS WHICH MAY BE ENERGIZED INDEPENDENTLY ACCORDING TO CONFIGURATION REQUIREMENTS.
K ₉	APPLIES G&N GENERATED DIRECTIONAL SINE AND COSINE SIGNALS TO THE FDAI BALL AND ROLL BUG.		

3-15

A. AGAPECA - CONTINUED

FUNCTION	PURPOSE
	OBTAIN θ_N AND θ_N ERRORS. THE PITCH BUFFER AMP REQUIRES NO CONVERSION.
3. ATTITUDE GYRO TORQUING AMPLIFIER	THIS DEVICE, THROUGH ITS SUMMING RESISTANCE SCALING, PROVIDES A NAVIGATION TO BODY AXES CONVERSION FOR TORQUING THE ATTITUDE GYROS.
B. DECA	
1. NAVIGATION TO BODY AXES CONVERSION	TO CONVERT NAVIGATION AXIS ATTITUDE ERROR SIGNALS DERIVED FROM THE AGCU TO THE BODY AXES ERROR FOR USE IN THE FDAI ATTITUDE ERROR DISPLAY.
2. RANGE ADJUST AND AMPLIFICATION	PROVIDES THE NECESSARY GAIN CHANGE TO ALLOW A VARIANCE IN FULL SCALE MAGNITUDES OF ATTITUDE ERROR AND RATE DISPLAYS OF FDAI.

3.6.2 ATTITUDE GYRO COUPLING UNIT (AGCU)

THE ATTITUDE GYRO COUPLING UNIT (AGCU) IS THE PRIMARY CONTROL DEVICE FOR THE ATTITUDE REFERENCE SUBSYSTEM. IT PERFORMS THE MAJOR PART OF ALL THE STRAP-DOWN INERTIAL REFERENCE COMPUTATIONS AND, IN ADDITION, PROVIDES THE TRANSFORMATION MATRICES REQUIRED TO DISPLAY ATTITUDE AND ATTITUDE ERROR OF THE SPACECRAFT. THE PRIMARY ELEMENTS OF THE AGCU ARE IN THE ATTITUDE GYRO TORQUING LOOP, OR CONTROL LOOP. THEY PERFORM THE FOLLOWING FUNCTIONS.

FUNCTION	PURPOSE
A. NAVIGATION TO EULER RATE TRANSFORMATION	RESOLVES PITCH AND YAW ATTITUDE ERROR TO DERIVE PITCH AND YAW RATES.
B. AGCU AMP AND LEVEL DETECTOR	GENERATES A PULSE TRAIN THAT IS EQUIVALENT TO THE TOTAL CHANGE IN S/C ATTITUDE.
C. AGCU STEPPER MOTOR CONTROL LOGIC	PROVIDES BI-DIRECTIONAL CONTROL OF RESOLVER SHAFT ANGLE.

3-16

<u>FUNCTION</u>	<u>PURPOSE</u>
D. AGCU TORQUER GATE ASSEMBLY	PROVIDES THE EULER RATE TORQUING CURRENT FOR THE ATTITUDE GYROS.
E. EULER TO NAVIGATION RATE TRANSFORMATION	CONVERTS EULER RATE, GYRO TORQUING SIGNALS TO NAVIGATION AXES COORDINATES FOR GYRO TORQUING.

THE INFORMATION LOOP SECTION OF THE AGCU IS MECHANIZED WITH FIVE OF THE EIGHT RESOLVERS. IT PROVIDES TOTAL ATTITUDE TO THE FDAI AND ATTITUDE SET DIALS OF THE AS/GPD, AND COMPUTES THE MAGNITUDE AND DIRECTION OF NAVIGATION AXIS ATTITUDE ERRORS. THESE ERRORS ARE DERIVED FROM THE DIFFERENTIAL BETWEEN AGCU SHAFT POSITION AND THE DIALED IN ATTITUDE INDICATED ON THE AS/GPD. THE LAST SECTION IS THE SCS LOCAL VERTICAL SIGNAL SOURCE THAT PROVIDES AN ORBITAL RATE SIGNAL FOR A 100 NAUTICAL MILE, CIRCULAR EARTH ORBIT.

3.7 ATTITUDE SET/GIMBAL POSITION DISPLAY (AS/GPD)

THE ATTITUDE SET PORTION OF THE ATTITUDE SET/GIMBAL POSITION DISPLAY (AS/GPD) PROVIDES THE CAPABILITY FOR REALIGNMENT OF THE AGCU AND FDAI TO COMPENSATE FOR LONG TERM DRIFT OR LOSS OF THE SCS REFERENCE ATTITUDE. IT ALSO ENABLES ADJUSTMENTS IN S/C ATTITUDE

USING THE ROTATION CONTROL AND THE FDAI COMMAND AT ATTITUDE ERROR NEEDLES. THE FUNCTIONS PROVIDED BY THE ATTITUDE SET PORTION OF THE AS/GPD ARE:

<u>FUNCTION</u>	<u>PURPOSE</u>
A. ATTITUDE SET INDICATORS AND THUMB-WHEELS	DISPLAY AND CHANGE THE REFERENCE ATTITUDE OF THE ARS FOR ALIGNMENT OR MANEUVERING PURPOSE.
B. ATT SET SWITCH	PROVIDES A MEANS OF DISPLAYING THE BODY AXES EQUIVALENT OF THE EULER ANGLE ERROR BETWEEN THE ATTITUDE DISPLAYED, ON THE ATTITUDE SET DIALS AND THE ANGLE OF THE RESOLVER SHAFTS IN THE AGCU, ON THE FDAI COMMAND ATTITUDE ERROR NEEDLES.
C. FDAI ALIGN SWITCH	ALIGNS THE AGCU RESOLVERS TO THE ATTITUDE DISPLAYED ON THE ATTITUDE SET DIALS.

3-17

3.8 ARS CONFIGURATION

THERE ARE SOME SEVENTEEN UNIQUE CONFIGURATIONS OF THE ARS. THESE CONFIGURATION CHANGES ARE GENERALLY ACCOMPLISHED THROUGH THE MODE SELECT SWITCHES, HOWEVER, OTHER SEPARATE FUNCTIONS SUCH AS MINIMUM IMPULSE, CONTROL STICK STEERING, CHANNEL DISABLE, AND ET CETRA ALSO AFFECT ARS CONFIGURATION. EACH OF THE SUCCEEDING PARAGRAPHS DISCUSSES A DIFFERENT CONFIGURATION OF THE ARS. TABLE 3-1 EXPLAINS THE FUNCTION PERFORMED BY EACH OF THE RELAYS.

3.8.1 FDAI AGCU ALIGNMENT

FDAI/AGCU ALIGNMENT ALLOWS THE ASTRONAUT TO REALIGN OR UPDATE THE ATTITUDE REFERENCE SUBSYSTEM TO COMPENSATE FOR SYSTEM DRIFT OR TO ALIGN THE ATTITUDE REFERENCE SUBSYSTEM TO ANY CHOSEN REFERENCE FRAME, EITHER CELESTIAL OR IMU. FIGURE 3-7 SHOWS THE RELAYS REQUIRED BY FDAI/AGCU ALIGN. FDAI/AGCU ALIGNMENT IS ACCOMPLISHED BY FIRST DETERMINING THE DISPLACEMENT IN EULER ANGLES OF THE SPACECRAFT NAVIGATION AXES TRIAD WITH RESPECT TO A KNOWN REFERENCE FRAME. THESE EULER ANGLES ARE THEN MANUALLY DIALED INTO THE ATTITUDE SET INDICATORS ON THE ATTITUDE SET/GIMBAL POSITION DISPLAY. DEPRESSING THE FDAI ALIGN SWITCH WILL CAUSE THE AGCU TO REALIGN ITS RESOLVERS WITH RESPECT TO THE AS/GPD. DURING ALL SCS MODES, THE FDAI ATTITUDE BALL WILL ALIGN ITSELF SO THAT PITCH AND YAW EULER ANGLES, DISPLAYED ON THE AS/GPD INDICATORS, WILL BE DISPLAYED BY THE ROLL ATTITUDE INDICATOR OR BUG WHEN THE SWITCH

IS DEPRESSED. ALIGNMENT ACCURACY AND GOOD FUNCTIONAL TEST OF THE AGCU RESOLVERS AND DRIVE CIRCUITS MAY BE DEMONSTRATED BY PLACING THE ATT SET SWITCH IN THE ON POSITION BEFORE DEPRESSING THE FDAI ALIGN SWITCH. THE ATTITUDE ERROR NEEDLES SHOULD DISPLACE AND THEN NULL AS FDAI ALIGNMENT IS COMPLETED. ALIGNMENT MAY BE ACCOMPLISHED DURING G&N ATTITUDE CONTROL MODES BUT ONLY THE AGCU WILL BE ALIGNED. THE FDAI WILL CONTINUE TO INDICATE IMU GIMBAL ANGLES AND THE ATTITUDE SET FUNCTION MAY NOT BE USED. ALIGNMENT MAY BE ACCOMPLISHED BY PRESSING THE FDAI ALIGN SWITCH AT ANY TIME DURING ANY MODE PROVIDING THE APPLICABLE POWER SWITCHES ARE IN THE ON POSITION. ALIGNMENT SHOULD NOT NORMALLY BE ACCOMPLISHED UNLESS THE SYSTEM IS DEADBANDING WITHIN THE MINIMUM $\pm .5^\circ$ DEAD AND OR IN MINIMUM IMPULSE. AT THE COMPLETION OF ALIGNMENT, THE DIFFERENCE BETWEEN SCS ARS EULER ANGLES AND THE EULER ANGLES OF THE S/C NAV AXES, WITH RESPECT TO A CHOSEN REFERENCE FRAME, SHALL BE LESS THAN $\pm 0.25^\circ$ EXCLUDING BUILT-IN MECHANICAL ERRORS OR OPERATOR ERRORS.

3.8.2 ATTITUDE SET

THE ATT SET POSITION OF THE ATT SET SWITCH PROVIDES A SIGNAL FROM THE AGCU TO THE COMMAND ATTITUDE ERROR NEEDLES TO INDICATE THE DIRECTION AND MAGNITUDES (WHEN LESS THAN $\pm 5^\circ$) OF ANY ANGULAR ERROR BETWEEN THE ATTITUDE EXISTING IN THE AGCU AND A DESIRED ATTITUDE MANUALLY SET IN THE ATTITUDE SET/GIMBAL POSITION DISPLAY. FIGURE 3-8, SHOWS THE INTERFACE SWITCHING FOR ATTITUDE SET.

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ATTITUDE REFERENCE SUBSYSTEM

ATTITUDE SET

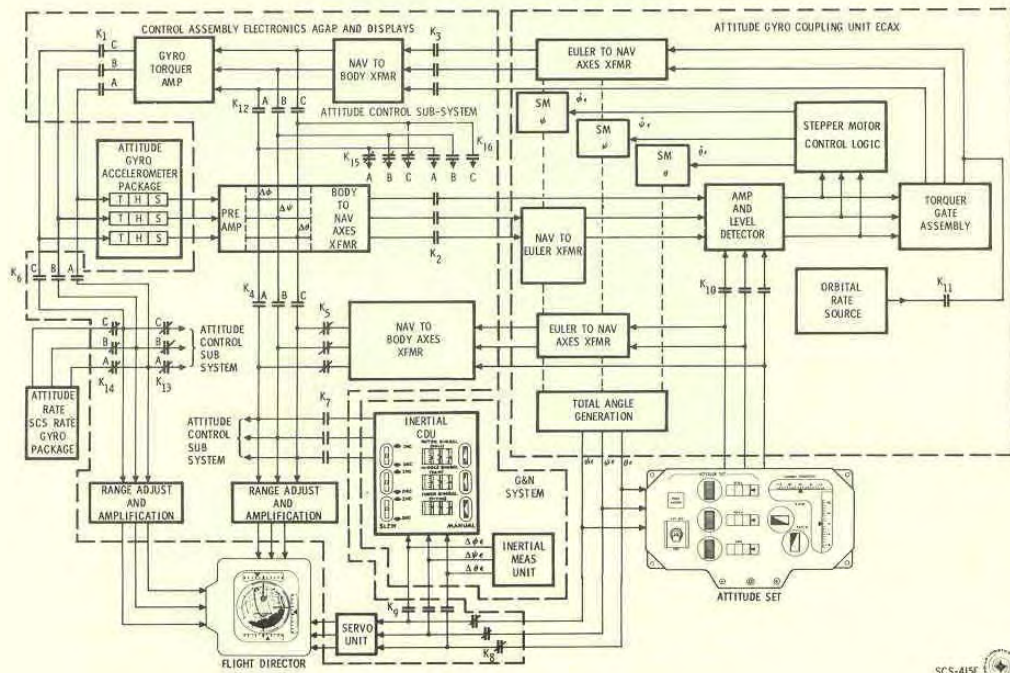


FIGURE 3-8

SCS-415F
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ATTITUDE REFERENCE SUBSYSTEM

AGCU ALIGN/ATTITUDE SET

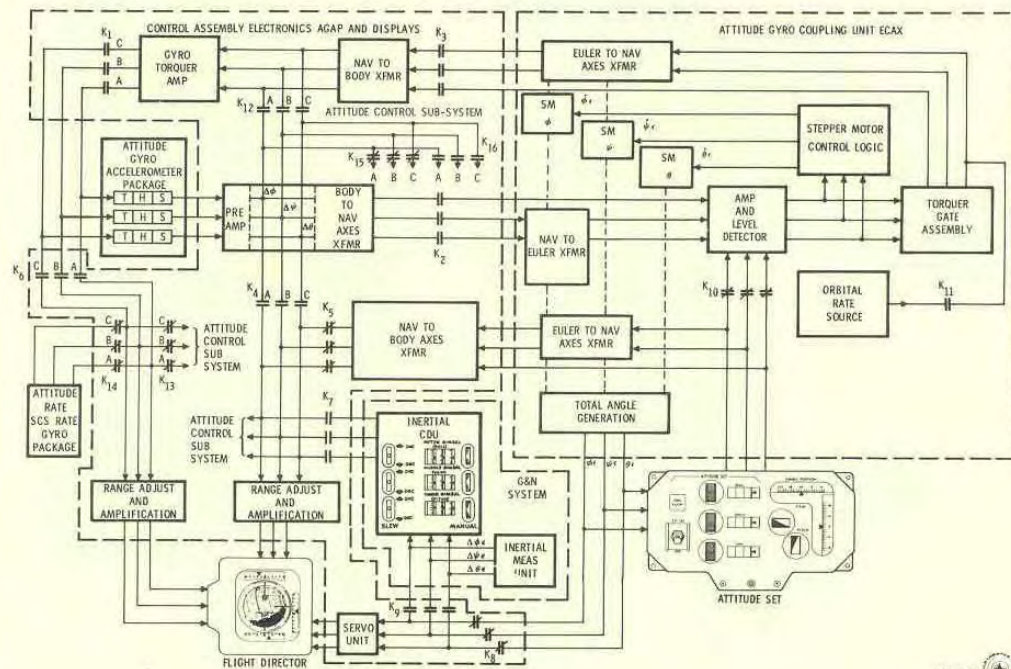


FIGURE 3-9

SCS-415F
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ATTITUDE SET IS PROVIDED TO ALLOW ACCURATE MANUAL ROTATIONAL MANEUVERING TO FACILITATE ALIGNMENT FOR DELTA V, G&N COARSE ALIGNMENT, NAVIGATION SIGHTINGS, OR REORIENTATION TO THE INITIAL SPACECRAFT ATTITUDE AFTER A SERIES OF MANUAL ROTATIONAL CONTROL INPUTS. THIS SWITCH ALSO ALLOWS THE ASTRONAUT TO MONITOR THE ACCURACY OF FDAI/AGCU ALIGNMENT DURING SCS CONTROL MODES. THE ATTITUDE SET FUNCTION MAY BE USED DURING ALL SCS MODES PRIOR TO MANUAL .05G SWITCHING. IT MAY NOT BE USED DURING ANY G&N MODE. USING ATTITUDE SET, THE VEHICLE MAY BE MANUALLY MANEUVERED, USING THE ROTATION CONTROL, TO THE ATTITUDE INDICATED ON THE ATTITUDE SET/ GIMBAL POSITION DISPLAY WITH AN ACCURACY OF $\pm 0.71^\circ$, (NOT INCLUDING MECHANICAL ALIGNMENT ERRORS IN SYSTEMS OTHER THAN THE SCS). THIS IS ACCOMPLISHED BY NULLING THE FDAI COMMAND ATTITUDE ERROR DISPLAY.

3.8.3 CONTROL STICK STEERING (CSS), MINIMUM IMPULSE, AND CHANNEL DISABLE

THESE SUB-MODES PROVIDE THE CREW WITH MANUAL CONTROL OF SPACECRAFT ATTITUDE USING PROPORTIONAL OR DIRECT REACTION JET CONTROL. FIGURE 3-10 FUNCTIONALLY SHOWS THE DATA FLOW DURING SCS ATTITUDE CONTROL AND ANY OF THE ABOVE SUB-MODES. CONTROL STICK STEERING MODE IS ENERGIZED BY MOVING THE ROTATION CONTROL STICK OUT OF DETENT. THIS ACTION CLOSSES BREAKOUT SWITCHES IN THE ROTATION CONTROL TO PROVIDE LOGIC INPUTS TO THE SUB-SYSTEMS OF THE STABILIZATION AND CONTROL SYSTEM. AT THE COMPLETION OF A MANUAL MANEUVER DURING SCS MODES THE SCS WILL HOLD THE SPACECRAFT IN ITS NEW ATTITUDE

ATTITUDE WITHIN THE SELECTED DEADBAND. IN MONITOR MODE THE SYSTEM WILL BE RATE STABILIZED HAVING NO ATTITUDE HOLD CAPABILITY. CONTROL STICK STEERING (DIRECT OR PROPORTIONAL CONTROL) MAY BE USED TO CONTROL SPACECRAFT ATTITUDE WHILE IN ANY OF THE FOLLOWING MODES:

SCS ATTITUDE CONTROL
SCS DELTA V (BEFORE ENGINE IGNITION)
G&N ATTITUDE CONTROL (WITH THE G&N SYNC SWITCH IN THE SYNC POSITION)
SCS ENTRY
MONITOR

MINIMUM IMPULSE IS USED DURING SPACECRAFT FINE ALIGNMENT, WHICH HAS BEEN PREVIOUSLY DISCUSSED. THE ARS IS CONFIGURED SO THAT IT MAY FOLLOW THE MANEUVER KEEPING THE GYROS NULLED AND MAINTAINING A VALID ATTITUDE REFERENCE.

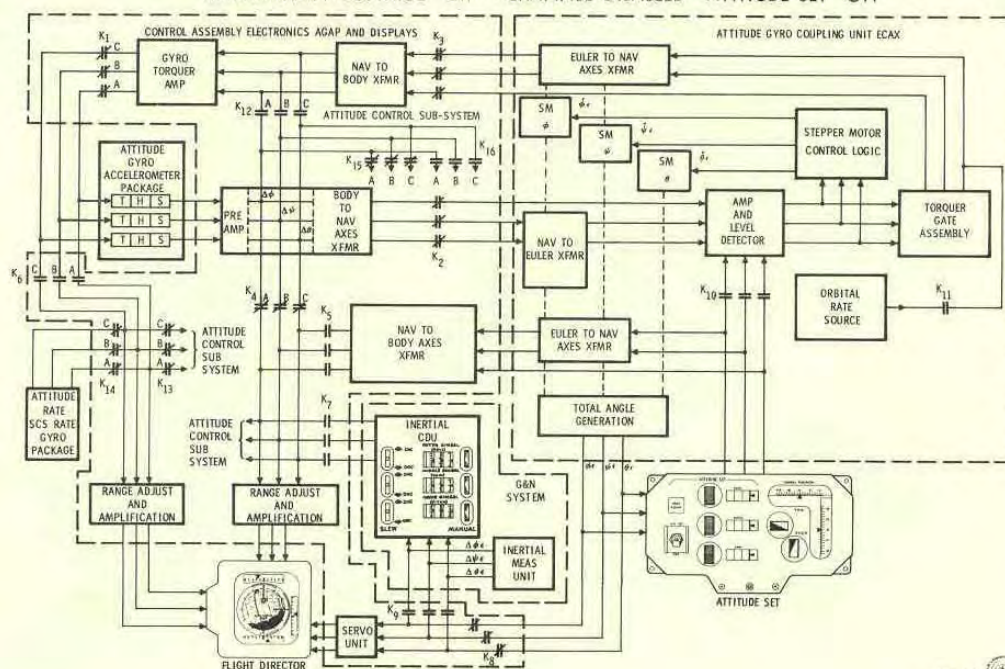
CHANNEL DISABLE MAY BE USED TO ALLOW THE ASTRONAUT TO MAKE LONG TERM MINIMUM PROPELLANT CONSUMPTION MANEUVERS. THE ROTATION CONTROL IS USED TO INITIATE A MANEUVER THEN THE CHANNEL IS TURNED OFF AND THE STICK IS RELEASED, THE VEHICLE CONTINUES TO ROTATE UNTIL THE CHANNEL IS AGAIN ENABLED.

DURING G&N ENTRY, G&N DELTA V, AND G&N ATTITUDE CONTROL (WITH THE G&N SYNC SWITCH IN THE OFF POSITION) THE SPACECRAFT ATTITUDE MAY BE CHANGED USING DIRECT OR PROPORTIONAL CONTROL, BUT THE G&N ATTITUDE SIGNALS WILL AUTOMATICALLY MANEUVER THE SPACECRAFT

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ATTITUDE REFERENCE SUBSYSTEM

CONTROL STICK STEERING (CSS)-MINIMUM IMPULSE
TRANSLATION CONTROL "CW" - CHANNEL DISABLE - ATTITUDE SET "OFF"



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FIGURE 3-10

3-22

ATTITUDE REFERENCE SUBSYSTEM

CONTROL STICK STEERING (CSS) = ATTITUDE SET "ON"

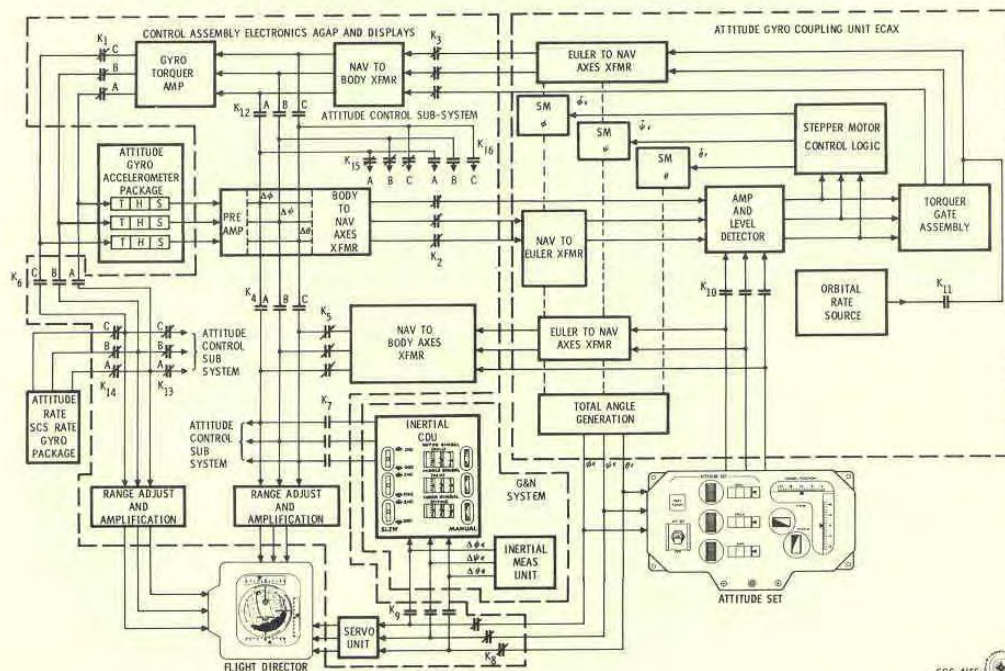


FIGURE 3-11

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3-23

BACK TO THE ORIGINAL ATTITUDE WHEN THE ROTATION CONTROL IS RETURNED TO DETENT. DURING G&N ATTITUDE CONTROL WITH G&N SYNC ON, THE SPACECRAFT WILL HOLD THE NEW ATTITUDE UNTIL THE SWITCH IS TURNED OFF. AT THIS TIME, THE COMPUTER WILL MANEUVER THE S/C TO THE ATTITUDE REQUIRED BY THE SELECTED PROGRAM.

3.8.4 Backup Rate

THE BACKUP RATE, SUB-MODE OF THE ATTITUDE REFERENCE SUBSYSTEM, FIGURE 3-12, ELECTRONICALLY CAGES ANY OR ALL OF THE ATTITUDE GYROS SO THAT THEY MAY BE USED IN PLACE OF THE RATE GYROS TO PROVIDE RATE STABILIZATION OF THE SPACECRAFT. PLACING AN ATTITUDE GYRO IN BACKUP RATE MODE WILL DISABLE THE BACKUP REFERENCE CAPABILITY OF THE AGCU. THE SELECTION OF BACKUP RATE IN ANY CHANNEL APPLIES ONLY THE RATE OUTPUT OF THE SELECTED GYRO TO THE ATTITUDE CONTROL SYSTEM FOR RATE STABILIZATION OF THE SPACECRAFT, HOWEVER, ALL THE ATTITUDE GYROS WILL BE CAGED ELECTRONICALLY IF A MANEUVER IS PERFORMED WHILE ANY GYRO IS CAGED. THE BACKUP REFERENCE CAPABILITY OF THE ARS WILL BE LOST UNTIL THE GYROS ARE UNCAGED AND THE AGCU/FDAI IS REALIGNED.

DURING THE G&N DELTA V AND SCS DELTA V MODES, THE SELECTION OF A SINGLE CHANNEL OF BACKUP RATE WILL ELECTRONICALLY CAGE ONLY THE SELECTED GYRO OR GYROS AND APPLY THEIR PREAMP OUTPUT TO THE ACS. THE RATE DISPLAY WILL BE DRIVEN BY TORQUING AMP OUTPUTS OF THE SELECTED GYROS INSTEAD OF PREAMP OUTPUTS. THE SELECTION OF BACKUP RATE IN TWO CHANNELS WILL APPLY THE OUTPUTS OF THE GYROS IN THOSE CHANNELS TO THE ATTITUDE CONTROL

SYSTEM AND FDAI. BACKUP RATE CAPABILITY IS PRESENT IN ANY CHANNEL DURING ALL SCS OR G&N CONTROL MODES.

3.8.5 Monitor Mode

THE MONITOR MODE PROVIDES A MEANS OF MONITORING SPACECRAFT ATTITUDE UTILIZING THE GUIDANCE AND NAVIGATION SYSTEM AS A REFERENCE. MANUAL PROPORTIONAL CONTROL OF SPACECRAFT ATTITUDE AND RATE STABILIZATION ARE AVAILABLE USING THE S/M REACTION CONTROL SYSTEM AFTER SIVB STAGING. MONITOR MODE WILL BE UTILIZED PRIMARILY DURING LAUNCH AND ANY TIME ONLY A RATE DAMPING MODE IS DESIRED. FIGURE 3-15 FUNCTIONALLY SHOWS THE DATA FLOW DURING MONITOR MODE.

CREW UTILIZATION OF INFORMATION DISPLAYED ON THE FLIGHT DIRECTOR ATTITUDE INDICATOR WILL DEPEND PRIMARILY UPON THE PROGRAM BEING UTILIZED IN THE APOLLO GUIDANCE COMPUTER. DURING MONITOR MODE, EITHER THE LAUNCH POLYNOMIAL OR FINE ALIGN PROGRAMS COULD BE MADE AVAILABLE TO THE AGC.

3.8.5.1 Launch Polynomial

IF THE LAUNCH POLYNOMIAL IS INSERTED IN THE APOLLO GUIDANCE COMPUTER, THE FDAI ATTITUDE ERROR NEEDLES WILL DISPLAY BODY AXES ATTITUDE ERRORS UP TO THE MAXIMUM INDICATOR READING OF 15.0° IN PITCH AND YAW, AND 25° IN ROLL. THE ATTITUDE ERRORS ARE GENERATED BY THE ANGULAR DIFFERENCE BETWEEN IMU GIMBAL ANGLES AND COMPUTER COMMANDED ATTITUDE. THE ATTITUDE BALL AND ROLL BUG WILL INDICATE IMU GIMBAL ANGLES AND

ATTITUDE REFERENCE SUBSYSTEM

BACK UP RATE-PITCH-SCS CONTROL MODES

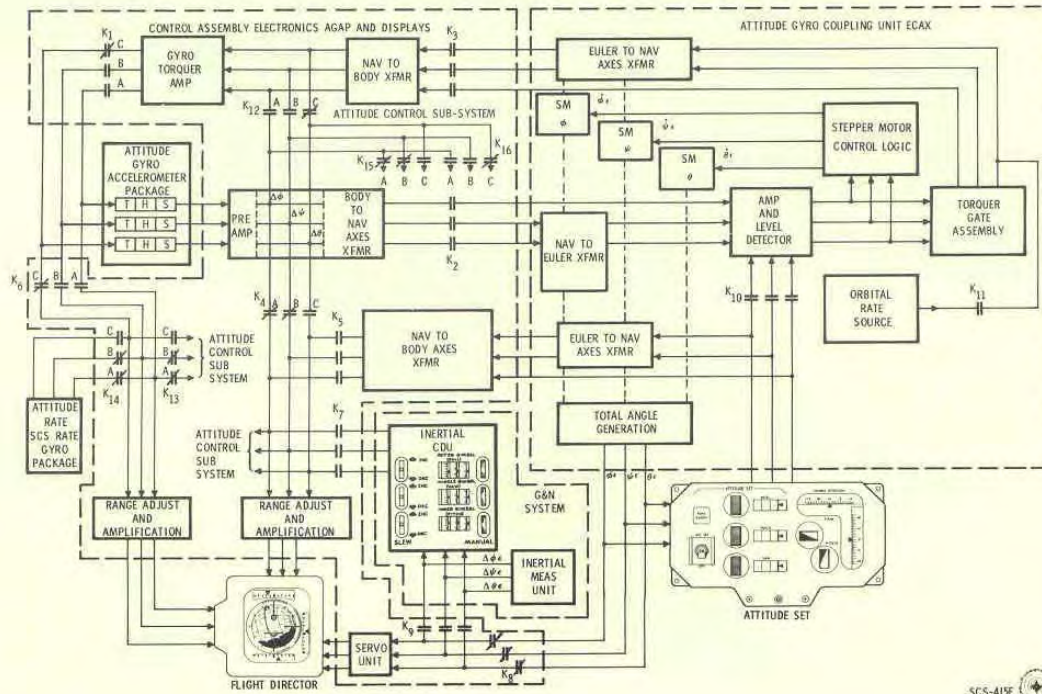


FIGURE 3-12

3-25

ATTITUDE REFERENCE SUBSYSTEM

BACK UP RATE "PITCH" AND CONTROL STICK STEERING

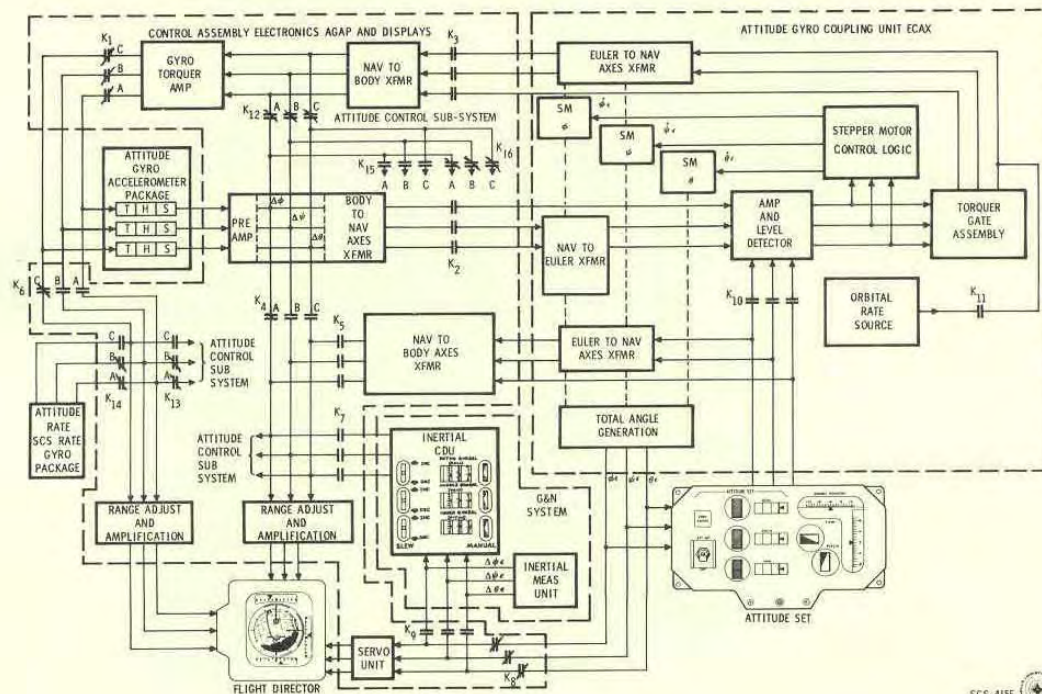


FIGURE 3-13

3-26

ATTITUDE REFERENCE SUBSYSTEM

BACK UP RATE "PITCH-YAW-ROLL" OR MANUAL TVC

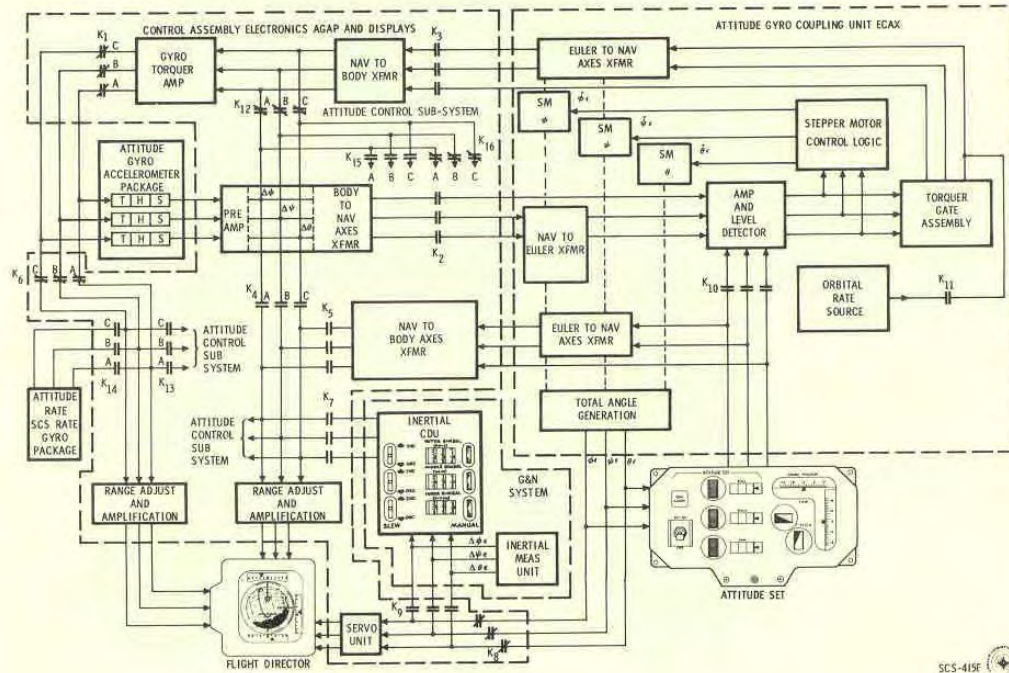


FIGURE 3-14

3-27

ATTITUDE REFERENCE SUBSYSTEM

MONITOR-G&N ATTITUDE CONTROL-G&N ENTRY-MINIMUM IMPULSE

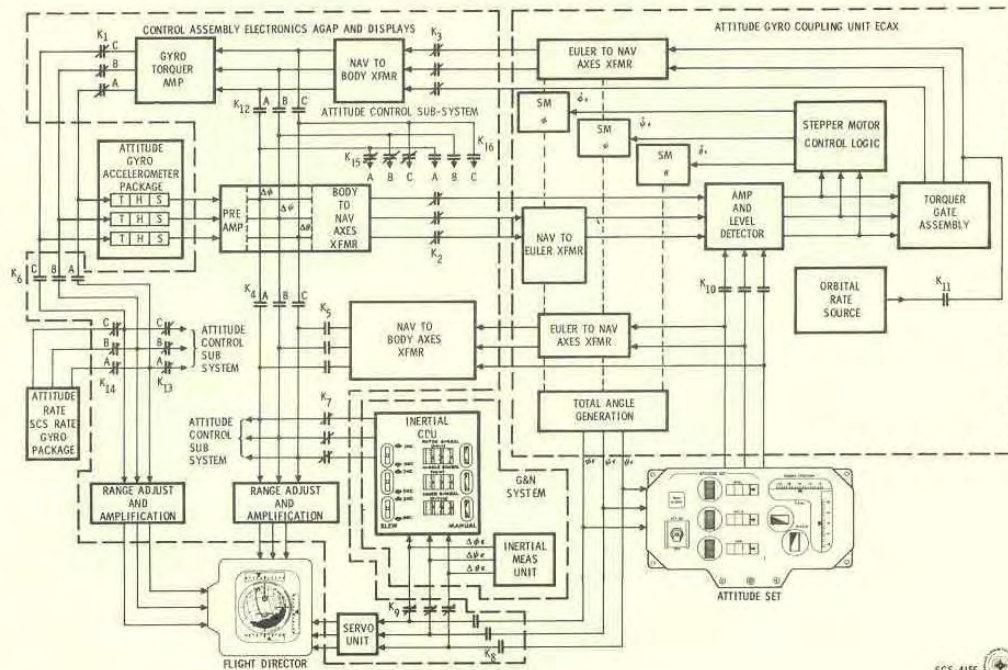


FIGURE 3-15

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THE RATE NEEDLES WILL INDICATE BODY AXES ANGULAR VELOCITY OF UP TO A MAXIMUM OF $\pm 5^\circ$ /SECOND PITCH AND YAW AND 25° /SECOND ROLL.

3.8.5.2 FINE ALIGN

IF THIS CONFIGURATION IS USED, THE ATTITUDE ERROR DISPLAY WILL INDICATE IMU GIMBAL/SPACECRAFT MISALIGNMENT, WHICH CAN BE NULLED BY CHANGING S/C ATTITUDE. S/C ATTITUDE, AS DISPLAYED ON THE BALL AFTER FINE ALIGNMENT HAS BEEN COMPLETED, WOULD BE REFERENCED TO THE VEHICLE TRUE INERTIAL ATTITUDE.

3.8.5.3 ATTITUDE REFERENCE SUBSYSTEM BACKUP

THE ATTITUDE REFERENCE SYSTEM MAY BE ALIGNED TO AGREE WITH INITIAL CONDITIONS SET UP IN THE G&N PROGRAM. DURING LAUNCH OR TRANSUNAR INJECTION, ANY CHANGE IN VEHICLE ATTITUDE WILL BE SENSED BY THE ATTITUDE GYROS. SINCE THE DISPLAY ELECTRONICS AND AGCU HAVE CLOSED THE CONTROL LOOP, THE AGCU WILL COMPUTE THE TOTAL CHANGE IN S/C ATTITUDE AND RECORD THE CHANGE IN ATTITUDE IN THE RESOLVER SHAFTS OF THE AGCU. IF AN SCS MODE WERE SELECTED DURING LAUNCH, THE ATTITUDE BALL WILL SLEW UNTIL THE ATTITUDE (PITCH AND YAW) INDICATED UNDER THE NAV INDEX, AND OPPOSITE THE ROLL BUG, WILL BE A COMPOSITE OF THE ARS INITIAL ALIGNMENT ATTITUDE PLUS ANY CHANGE IN ATTITUDE CAUSED BY LAUNCH OR TRANSUNAR INJECTION COMPUTER PROGRAMS.

3.8.5.4 MONITOR MODE UTILIZATION

THE MONITOR MODE IS A MEANS OF COMPARING THE LAUNCH AUTOMATIC COMMANDS AND VEHICLE ATTITUDE. THEREFORE, DURING MONITOR MODE, THE SCS OR G&N SYSTEM HAVE NO MEANS OF CONTROLLING SPACECRAFT ATTITUDE, EXCEPT THAT THE S/M RCS IS AVAILABLE WITH THE DIRECT MANUAL SWITCH IN THE ON POSITION AND DEFLECTION OF THE ROTATION CONTROL TO THE HARD STOPS. NO OTHER MODE SHOULD BE SELECTED DURING THE NORMAL LAUNCH PHASE. ACCURACY OF THE FDAI DURING MONITOR MODE WILL BE DEPENDENT UPON THE ACCURACY OF THE G&N SYSTEM. THE ATTITUDE REFERENCE SUBSYSTEM WILL FOLLOW G&N COMMANDED CHANGES IN ATTITUDE. ITS ACCURACY WILL BE DEPENDENT UPON THE AMOUNT OF MANEUVERING AND THE ELAPSED TIME BETWEEN ALIGNMENTS.

3.8.6 G&N ATTITUDE CONTROL - G&N ENTRY FIGURE 3-16, 17

THE SELECTION OF EITHER G&N ATTITUDE CONTROL OR G&N ENTRY MODES WILL ALLOW THE GUIDANCE AND NAVIGATION SYSTEM TO POSITION THE SPACECRAFT TO A NEW ATTITUDE AND DRIVE THE FDAI USING AUTOMATIC, SEMI-AUTOMATIC, OR MANUAL COMMANDS TO THE STABILIZATION AND CONTROL SYSTEM. THESE COMMANDS ARE:

- CHANGING SPACECRAFT ATTITUDE IN RESPONSE TO COMMANDS FROM AN AGC AUTOMATIC PROGRAM.
- CREW COMMANDED CHANGES IN SPACECRAFT ATTITUDE USING THE AGC KEYBOARD AS AN INPUT DEVICE.

3-29

ATTITUDE REFERENCE SUBSYSTEM

G&N CONTROL MODES-FDAI/AGCU ALIGN

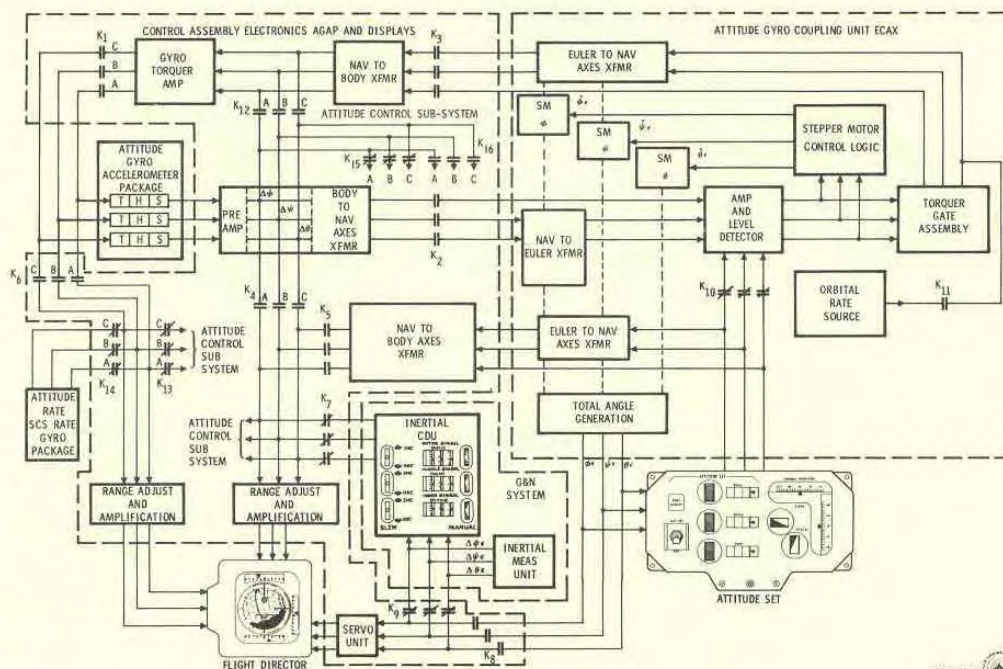


FIGURE 3-16

SCS-415F
-2
-3 3-30

ATTITUDE REFERENCE SUBSYSTEM

G&N CONTROL MODES-BACK UP RATE "YAW"

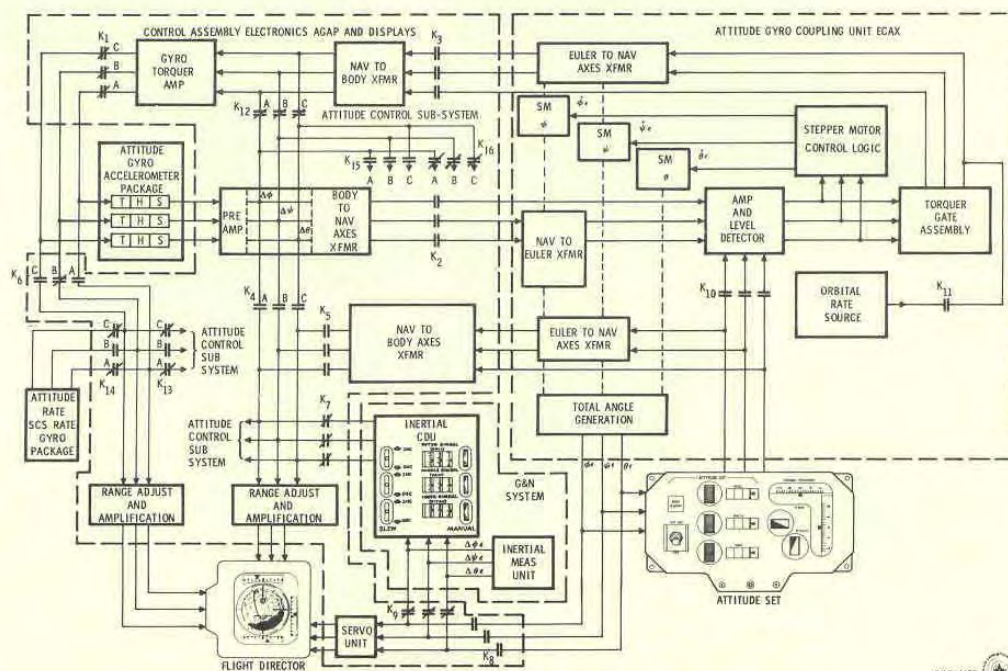


FIGURE 3-17

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-5 3-31

- C. SPACECRAFT ATTITUDE CHANGES COMMANDED MANUALLY BY PLACING THE G&N SYSTEM IN CDU MANUAL AND REPOSITIONING THE CDU SET KNOBS, OR BY PLACING THE G&N SYNC SWITCH IN THE SYNC POSITION AND USING THE ROTATION CONTROL. (THE LATTER TYPE OF MANUAL COMMAND MAY ONLY BE USED DURING G&N ATTITUDE CONTROL MODE).

D. G&N MANUAL ENTRY

THE FDAI TOTAL ATTITUDE INDICATORS ARE POSITIONED BY SIGNALS FROM THE IMU WHICH REPRESENT IMU GIMBAL ANGLES. THE COMMAND ATTITUDE ERROR NEEDLES REPRESENT THE MAGNITUDE OF THE DIFFERENCE BETWEEN IMU GIMBAL ANGLES AND CDU POSITION. IF THE CDU'S ARE BEING REPOSITIONED BY THE COMPUTER, AN ELECTRICAL SIGNAL WOULD BE GENERATED TO DRIVE THE COMMAND ATTITUDE ERROR NEEDLES AND TO CAUSE THE C/M OR S/M REACTION JETS TO FIRE, MANEUVERING THE SPACECRAFT TO NULL THE GENERATED ERROR SIGNAL AND REPOSITIONING THE TOTAL ATTITUDE INDICATORS SO THAT WHEN THE MANEUVER IS COMPLETED, INFORMATION PRESENTED UNDER THE OFFSET AXES INDEX AND ROLL BUG WILL AGREE WITH THE INFORMATION DISPLAYED ON THE CDU DIALS. AS THE MANEUVER IS BEING ACCOMPLISHED, ARS ATTITUDE GYROS SENSE THE CHANGE IN SPACECRAFT ATTITUDE AND WILL CAUSE THE AGCU RESOLVER SHAFTS TO BE REPOSITIONED AND UPDATE THE ATTITUDE REFERENCE SUBSYSTEM.

3.8.6.1 G&N TO SCS MODE CHANGE

IF AN SCS CONTROL MODE IS SELECTED DURING THE G&N MANEUVER, OR AFTER ITS COMPLETION, THE FDAI

ATTITUDE INDICATORS WILL SLEW UNTIL THE INFORMATION DISPLAYED UNDER THE NAV AXES INDEX IS A COMPOSITE OF THE ALIGNED ATTITUDE, PLUS OR MINUS THE MAGNITUDE OF ALL MANEUVERS ACCOMPLISHED DURING THE G&N CONTROL MODE.

3.8.6.2 LIMITATIONS

THE FDAI/AGCU MAY BE ALIGNED TO THE INFORMATION DISPLAYED ON THE ATTITUDE SET DIALS DURING ANY G&N CONTROL MODE BUT THE ATTITUDE INDICATORS WILL NOT INDICATE THE ALIGNMENT PROCESS AND THE ATT SET SWITCH WILL NOT BE FUNCTIONAL. NO MANUAL CONTROL STICK MANEUVERS SHOULD BE ATTEMPTED IN THE G&N AUTOMATIC ENTRY MODE. AUTOMATIC COMMANDS ARE SUBJECT TO THE G&N SYSTEM ACCURACIES AND TO WITHIN THE 0.2 OR 2.0 DEGREE/SECOND RATE AND THE SELECTED ATTITUDE DEADBANDS. MANUAL COMMANDS ARE SUBJECT TO THE ACCURACY TO WHICH THE FDAI MAY BE READ.

3.8.7 G&N DELTA V MODE

THE G&N DELTA V MODE OF OPERATION, AS SHOWN IN FIGURE 3-18, AUTOMATICALLY COMMANDS S/C MOTION BY CONTROLLING SPS ENGINE IGNITION AND GIMBALS, TO CONTROL PITCH, YAW, AND ROLL ATTITUDE, AND MAINTAIN THRUST VECTOR DIRECTION. THE ROLL REACTION JETS ARE USED TO MAINTAIN ROLL ATTITUDE. THE ARS PORTION OF THE SCS WILL PROVIDE BACKUP ATTITUDE ERRORS FROM THE ATTITUDE GYROS AND BACKUP ATTITUDE FROM THE AGCU RESOLVERS. THE FDAI WILL BE DRIVEN BY THE G&N SYSTEM AND WILL INDICATE IMU GIMBAL ANGLES ON THE ATTITUDE DISPLAYS AND THE CDU BODY AXES STEERING COMMANDS ON THE COMMAND ATTITUDE ERROR NEEDLES. ROTATIONAL VELOCITY WILL BE DERIVED FROM THE

ATTITUDE REFERENCE SUBSYSTEM

G&N ΔV

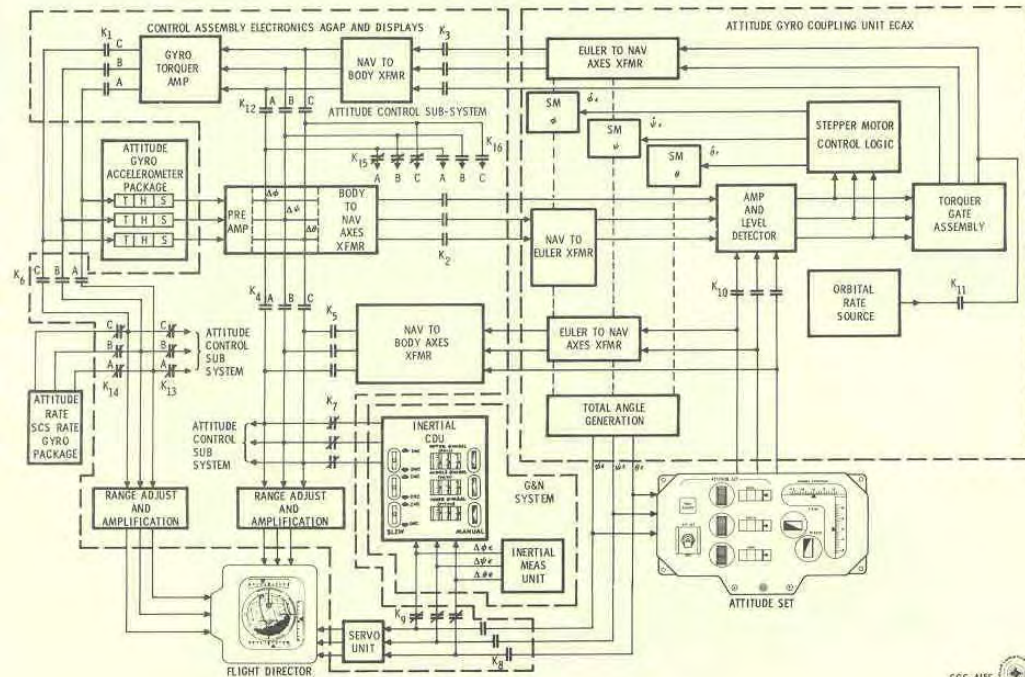


FIGURE 3-18

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-6
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SCS RATE GYRO PACKAGE.

3.8.7.1 OPERATION

DURING A NORMAL OPERATING SEQUENCE, THE VEHICLE WILL CHANGE ATTITUDE AFTER SPS THRUST ON TO CORRECT FOR MOVEMENT OF THE CENTER OF GRAVITY, AND TO ALLOW REALIGNMENT OF THE THRUST VECTOR TO AN INERTIAL THRUSTING PLANE. AS VEHICLE ATTITUDE IS VARIED, THE ATTITUDE AND ATTITUDE ERROR DISPLAYS ON THE FDAI WILL DRIVE TO INDICATE THE MAGNITUDE OF ATTITUDE CHANGE OR ERROR AND THE NEW VEHICLE ATTITUDE. ASSUME THE IMU X AXIS IS ALIGNED IN THE THRUSTING DIRECTION AND ALONG THE X BODY AXIS, AND THE CG IS LOCATED ON THE X AXIS AT THE Y AND Z COORDINATE INTERSECTION. THE ATTITUDE INDICATED BY THE FDAI WOULD BE 0° PITCH, 0° YAW, 0° ROLL (INDICATED AT THE BODY AXES SYMBOL), AND ZERO ATTITUDE ERROR AND ROTATIONAL VELOCITY. THE FOLLOWING SEQUENCE OF EVENTS WOULD OCCUR IF THE CG WERE TO SUDDENTLY MOVE 2° IN THE +Z DIRECTION.

NOTE: THE FOLLOWING EXPLANATION OF THE SEQUENCE ILLUSTRATED IN FIGURE 3-19 IS INTENDED TO PROVIDE A STEP BY STEP ANALOGY OF A TVC OPERATIONAL SEQUENCE IN A SINGLE AXIS.

3.8.7.2 POSITION 1

INITIAL CONDITIONS WILL BE WITH THE THRUST VECTOR THROUGH THE CG AND ALIGNED ON THE X AXIS AND

SELECTED THRUSTING PLANE, AS LISTED BELOW.

INDICATOR	SOURCE	(PITCH)
FDAI ATTITUDE	IMU	0°
FDAI ATTITUDE ERROR	CDU	0°
CDU ANGLE	CDU	0°
GIMBAL POSITION	PITCH GIMBAL	0°

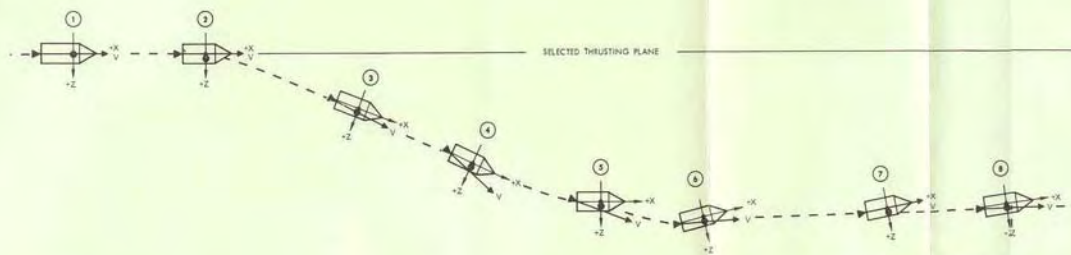
3.8.7.3 POSITION 2

THE CG SHIFTS 2° IN THE +Z DIRECTION AND THE VEHICLE BEGINS A NEGATIVE PITCH ROTATION BECAUSE THE THRUST VECTOR IS NO LONGER THROUGH THE CENTER OF GRAVITY. THE PITCH DISPLAY INDICATIONS WILL BEGIN TO CHANGE, THE PITCH ATTITUDE ERROR NEEDLE WILL DEFLECT UPWARD OPPOSITE THE DIRECTION OF VEHICLE ROTATION, THE PITCH RATE NEEDLE WILL DEFLECT DOWNWARD IN THE DIRECTION OF VEHICLE ROTATION, AND THE PITCH GIMBAL POSITION DISPLAY WILL DEFLECT UPWARDS AS STEERING SIGNALS APPLIED TO THE TVC ELECTRONICS CHANGE THE SPS ENGINE GIMBAL ANGLE IN THE POSITIVE DIRECTION.

3.8.7.4 POSITION 3

THE GIMBAL HAS NOW DEFLECTED SUFFICIENTLY TO BRING THE THRUST VECTOR THROUGH THE CG AND THE VEHICLE STOPS ROTATING AND CONTINUES ACCELERATING IN THE THRUST VECTOR DIRECTION WHICH IS AWAY FROM THE SELECTED THRUSTING PLANE. THE SCS INDICATORS COULD READ AS FOLLOWS:

• CG
 • Y AXIS OUT OF THE PAGE
 — SELECTED THRUSTING PLANE
 - - - FLIGHT PATH
 → THRUST VECTOR



TYPICAL DELTA V MANEUVER

FIGURE 3-19

SCS-801A (3-35)

INDICATOR	SOURCE	(PITCH)
FDAI ATTITUDE	IMU	358°
FDAI ATTITUDE ERROR	CDU	+2° (UP)
CDU ANGLE	CDU	0°
GIMBAL POSITION	ENGINE GIMBAL	+2°

3.8.7.5 POSITION 4

THE IMU SENSES VEHICLE ACCELERATIONS ALONG THE Z AXIS AND PROVIDES THIS DATA TO THE APOLLO GUIDANCE COMPUTER. THE AGC PERFORMS A DOUBLE INTEGRATION ON THE ACCELERATION SIGNAL AND REPOSITIONS THE CDU SHAFTS TO GENERATE ADDITIONAL ATTITUDE ERRORS TO DRIVE THE SPS PITCH GIMBAL FURTHER UP, OR POSITIVE, AND DIRECTS THE THRUST VECTOR BELOW THE NEW CG LOCATION. AT THIS TIME, THE SCS INDICATOR WOULD DISPLAY THE READINGS SHOWN BELOW.

INDICATOR	SOURCE	(PITCH)
FDAI ATTITUDE	IMU	358°
FDAI ATTITUDE ERROR	CDU	3° (UP)
CDU ANGLE	CDU	001°
GIMBAL POSITION	ENGINE GIMBAL	+3°

3.8.7.6 POSITION 5

THE MOMENT ARM CREATED BY DIRECTING THE THRUST VECTOR BELOW THE CG WILL ROTATE THE VEHICLE

TOWARDS THE SELECTED THRUSTING PLANE, CAUSING THE ATTITUDE ERROR NEEDLES TO BEGIN TO NULL AS THE VEHICLE ROTATES AND THE SPS PITCH GIMBAL POSITION INDICATION WILL BEGIN TO MOVE BACK TOWARDS THE CG.

3.8.7.7 POSITION 6

THE VEHICLE WILL CONTINUE TO ROTATE UNTIL THE THRUST VECTOR IS DIRECTED PARALLEL TO THE SELECTED THRUSTING PLANE AND ALIGNED THROUGH THE CG. THE VEHICLE WILL THEN STABILIZE AT THIS ATTITUDE UNTIL THE Z AXIS ACCELERATION HAS BEEN NULLED. IF A COINCIDENCE ANGLE BETWEEN THE THRUST VECTOR AND SELECTED THRUSTING PLANE IS ASSUMED TO BE FOUR DEGREES, THEN THE SCS INDICATORS WILL DISPLAY THE INFORMATION SHOWN BELOW.

INDICATOR	SOURCE	(PITCH)
FDAI ATTITUDE	IMU	6°
FDAI ATTITUDE ERROR	CDU	+2° (UP)
CDU ANGLE	CDU	8°
GIMBAL POSITION	ENGINE GIMBAL	+2°

3.8.7.8 POSITION 7

WHEN THE AGC DETERMINES (USING THE Z ACCELEROMETER) THAT THE VEHICLE IS APPROACHING ZERO Z AXIS VELOCITY, IT WILL REPOSITION THE CDU RESOLVER SHAFTS AND GENERATE ATTITUDE ERROR THAT WILL DRIVE THE SPS GIMBAL TO POSITION THE THRUST VECTOR ABOVE THE CENTER OF GRAVITY AND ROTATE THE VEHICLE DOWNWARD.

THE FDAI BALL WILL DRIVE UP AND THE ATTITUDE ERRORS WILL BE REDUCED TO LESS THAN TWO DEGREES. THE G&N SYSTEM IS NOW ATTEMPTING TO ALIGN THE THRUST VECTOR THROUGH THE CG AND PARALLEL TO THE SELECTED THRUSTING PLANE.

3.8.7.9 POSITION 8

THE VEHICLE IS NOW STABILIZED WITH THE THRUST VECTOR THROUGH THE CG AND PARALLEL TO THE SELECTED THRUSTING PLANE. THE SCS INDICATORS WILL NOW DISPLAY INFORMATION AS SHOWN BELOW.

INDICATOR	SOURCE	(PITCH)
FDAI ATTITUDE	IMU	2°
FDAI ATTITUDE ERROR	CDU	+2°(DN)
CDU ANGLE	CDU	4°
GIMBAL POSITION	ENGINE GIMBAL	+2°

3.8.7.10 SELECTION OF SCS DELTA V MODE

IF AN SCS MODE IS SELECTED DURING A G&N DELTA V MANEUVER, THE ATTITUDE BALL WILL SLEW TO THE ATTITUDE INDICATED ON THE ATTITUDE SET DIALS OF THE AS/GPD. THE ATTITUDE ERROR NEEDLES WILL INDICATE THE MAGNITUDE OF THE DIFFERENTIAL ANGLE BETWEEN THE DESIRED THRUSTING PLANE AND THE BODY X AXIS. THE RATE NEEDLES DISPLAY THE MAGNITUDE OF ROTATION UP TO 5°/SECOND. IF THE SWITCH OVER WERE ACCOMPLISHED WITH THE VEHICLE STABILIZED AS IN PARAGRAPH 3.8.7.7, THE FDAI ATTITUDE ERROR WOULD BE THE SAME MAGNITUDE AS SHOWN, BUT THE POLARITY WOULD BE OPPOSITE.

3.9

SCS ATTITUDE CONTROL, SCS DELTA V, AND SCS ENTRY .05g's (FIGURE 3-20)

DURING THESE MODES, THE INFORMATION LOOP OF THE ARS IS OPERATING. THE ATTITUDE DISPLAY IS FIXED, AND THE ATTITUDE ERROR AND RATE NEEDLES WILL INDICATE CHANGES IN VEHICLE ATTITUDE DUE TO DRIFT, AND THE ANGULAR VELOCITY AT WHICH THE VEHICLE IS DRIFTING. THE OVERALL OPERATION OF THE SYSTEM IS SIMILAR TO COMPARABLE G&N MODES EXCEPT THAT THE ATTITUDE DISPLAY INFORMATION IS DERIVED FROM THE ARS RATHER THAN THE G&N. MINIMUM IMPULSE, CHANNEL DISABLE, ATTITUDE SET, FDAI ALIGN, CONTROL STICK STEERING, AND BACKUP RATE SWITCHES MAY BE USED IN ANY OF THE PRIMARY MODES; HOWEVER, EACH SWITCH WILL ALTER ARS CONFIGURATION TO REFLECT THE SELECTED SUB MODES. ALL OF THE ABOVE SUB MODES, EXCEPT FDAI ALIGN, ATTITUDE SET AND BACKUP RATE ARE DIRECTLY CONNECTED WITH MANEUVERING THE VEHICLE AND WILL CAUSE THE ARS COMMAND OR TORQUING LOOP TO BE ENERGIZED SO THAT THE ARS MAY TRACT VEHICLE MANEUVERS. IN SUMMARY; IF THE COMMAND OR TORQUING LOOP IS ENERGIZED, THE FDAI BALL MOVES TO INDICATE VEHICLE INERTIAL ATTITUDE AND THE ATTITUDE ERROR NEEDLES ARE AT NULL; IF THE COMMAND OR TORQUING LOOP IS NOT ENERGIZED, THE FDAI IS NOT DRIVEN AND THE ATTITUDE ERROR NEEDLES INDICATE THE DIFFERENCE BETWEEN THE INDICATED ATTITUDE AND THE BODY AXES ATTITUDE ERROR OF THE SPACECRAFT. SELECTION OF BACKUP RATE CAUSES CAGEING OF THE APPROPRIATE ATTITUDE GYRO TO

3-37

ATTITUDE REFERENCE SUBSYSTEM

SCS ATTITUDE CONTROL-SCS ΔV-SCS ENTRY <.05g

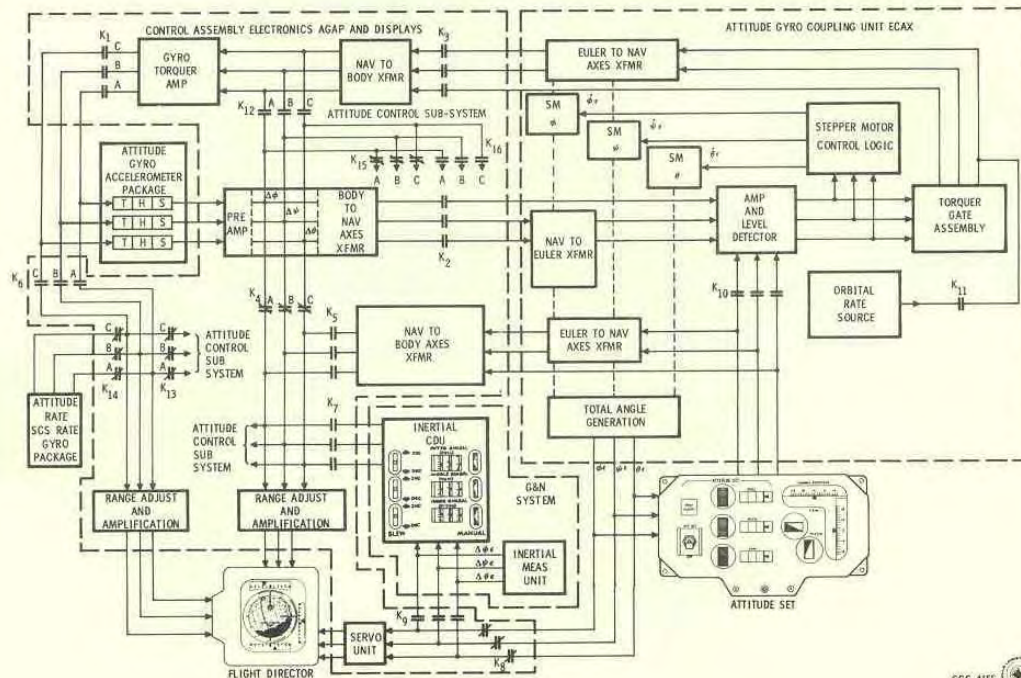


FIGURE 3-20

SCS-415F

-15

3-38

ATTITUDE REFERENCE SUBSYSTEM

SCS ENTRY >.05g

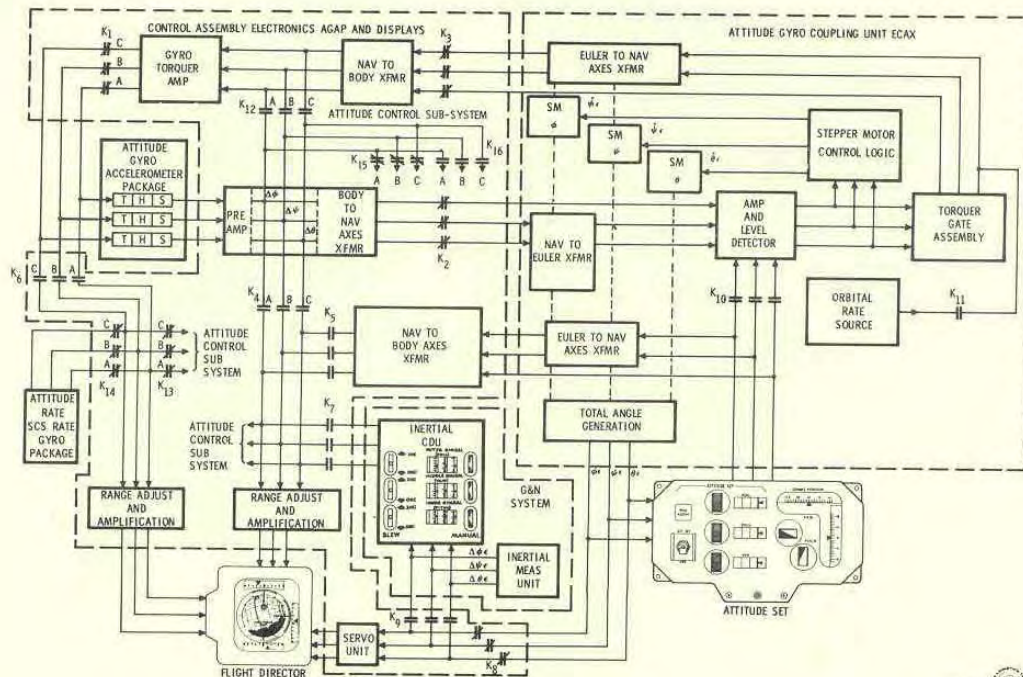


FIGURE 3-21

SCS-415F
-14

3-39

ANGULAR VELOCITY FOR THAT CHANNEL, AND DISABLES THE TORQUING LOOPS OF THE AGCU.

3.10 SCS LOCAL VERTICAL

THIS MODE UTILIZES AN AMPLIFIER AND VOLTAGE DIVIDER WITH A SWITCH FOR SELECTING NOMINAL EARTH ORBIT RATE FOR A CIRCULAR 100 NAUTICAL MILES ORBIT, WHICH IS EQUIVALENT TO A PITCH RATE OF $4.1^\circ/\text{MINUTE}$. ORBIT RATE MAY BE SELECTED PRIOR TO LAUNCH, ACCORDING TO THE MISSION TO BE PERFORMED. THE LOCAL VERTICAL SIGNAL PROVIDES, IN CONJUNCTION WITH THE REVERSE TRANSFORMATION CIRCUIT OF THE AGCU, AN ALL ATTITUDE LOCAL VERTICAL CAPABILITY. FIGURE 3-22 SHOWS SIGNAL FLOW THROUGH THE ARS DURING LOCAL VERTICAL, BEGINNING IN THE AGCU LOCAL VERTICAL SIGNAL SOURCE. THE ERROR SIGNAL IS APPLIED TO THE PITCH GYRO TORQUING CIRCUIT AND TORQUES ONLY THE PITCH ATTITUDE GYRO. IF THE VEHICLE IS MANEUVERED IN ROLL OR YAW, AFTER INITIAL ALIGNMENT, THE SIGNAL PREVIOUSLY APPLIED ONLY TO THE PITCH GYRO WILL BE APPLIED TO ALL THREE GYROS, PROVIDING THEM WITH SUFFICIENT TORQUING CURRENT TO MAINTAIN A SELECTED LOCAL VERTICAL ATTITUDE. IN SHORT, THE TORQUING SIGNAL INDUCES A PRECISION RATE INTO THE GYROS TO COMPENSATE FOR THE APPARENT PRECESSION OF THE ORBITING SPACECRAFT. DISPLAYED ATTITUDE ERROR WILL BE A COMPOSITE OF THE LOCAL VERTICAL SIGNAL AND VEHICLE DRIFT. THESE ERRORS SHOULD NEVER EXCEED THE SELECTED SCS DEADBAND.

3.11 FDAI ATTITUDE BALL POSITIONING LOOP

FIGURE 3-24 ILLUSTRATES THE GIMBAL DRIVE CIRCUITRY FOR A SINGLE CHANNEL OF THE FDAI. IDENTICAL

CIRCUITRY IS USED IN EACH OF THE OTHER TWO CHANNELS. SIMPLY STATED, THE FDAI GIMBALS ARE POSITIONED THROUGH A CLOSED LOOP SERVO SYSTEM WHICH RECEIVES EXCITATION POWER AND CONTROL INPUTS FROM EITHER OF TWO SOURCES, G&N OR SCS. THE LOGIC NETWORKS SHOWN ON THE LEFT OF THE DIAGRAM ARE THE MEANS OF SELECTING THE POWER AND SIGNAL SOURCE. THE LOGIC NETWORKS DEPICTED ON THIS DIAGRAM ARE NOT FULLY MECHANIZED, HOWEVER, THEY ARE FUNCTIONALLY CORRECT.

THE G&N OR GATE AND RELAY DRIVER 1 CONTROL RELAYS 16A3K1, K3, K4, K5, K6, 17A3K1, AND 18A3K1. THOSE RELAYS SELECT THE SIGNAL AND POWER SOURCE FOR THE AMPLIFIER DEMODULATOR, MODULATOR, SERVO MOTOR, AND VELOCITY GENERATOR, AND ARE ENERGIZED ONLY DURING G&N CONTROL MODES. THE EXCITATION FREQUENCY OF THE VELOCITY GENERATOR, AMPLIFIER DEMODULATOR, MODULATOR AND MOTOR IS SELECTED BY CONTACTS OF 19A2K4, K5 AND K6. CONTACTS OF 16A3K1 PROVIDE THE PROPER INPUT SCALING FOR G&N OR AGCU INPUT SIGNALS.

RELAYS 16A3K3 AND K5 CONTROL G&N SIGNALS TO THE FDAI. WHEN THEY ARE ON, G&N SIGNALS DRIVE THE BALL. THE AGCU PROVIDES DIRECTIONAL SINES AND COSINES TO POSITION THE BALL WHEN RELAYS 16A3K4 AND K6 ARE NOT ENERGIZED.

DURING CERTAIN SCS MODES AND SUB MODES THE FDAI IS REPOSITIONED TO FOLLOW SPACECRAFT DRIFT. LOGIC SIGNALS, GENERATED BY MODE SELECTION CAUSE RELAY 22A8K6 TO BE ENERGIZED, CONTACTS OF 22A8K6 CLOSE TO ENERGIZE RELAY 19A2K2. IF SCS ATTITUDE CONTROL OR LOCAL VERTICAL MODES ARE ENERGIZED, RELAYS 19A2K4, 5

3-40

ATTITUDE REFERENCE SUBSYSTEM

SCS LOCAL VERTICAL $\theta = 0^\circ$ $\psi = 0^\circ$ $\phi = 0^\circ$

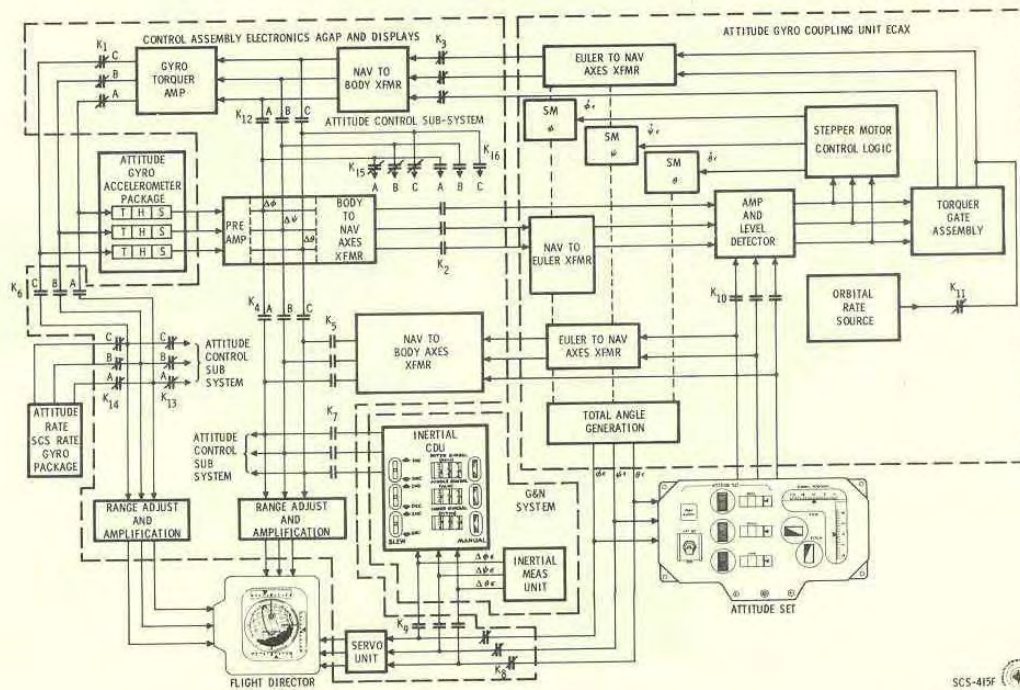


FIGURE 3-22

SCS-415F
-12
-13 3-41

ATTITUDE REFERENCE SUBSYSTEM

SCS LOCAL VERTICAL $\theta = 0^\circ$ $\psi = >0^\circ$ $\phi = >0^\circ$

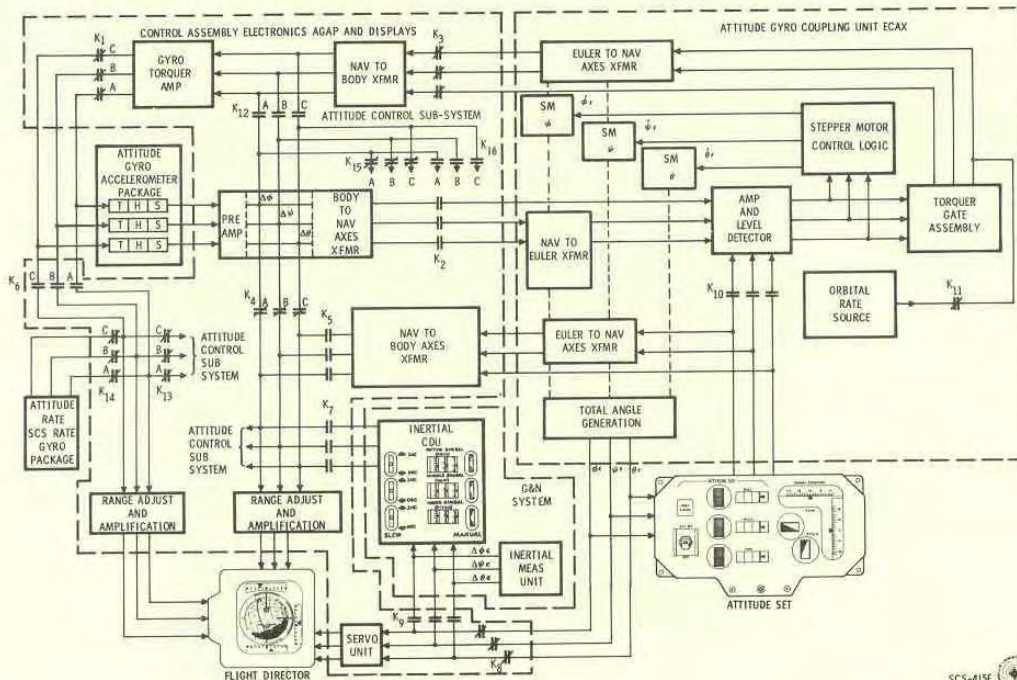


FIGURE 3-23

SCS-415F
-10
-11 3-42

FDAI ATTITUDE ERROR DISPLAY

LOOP DIAGRAM YAW CHANNEL

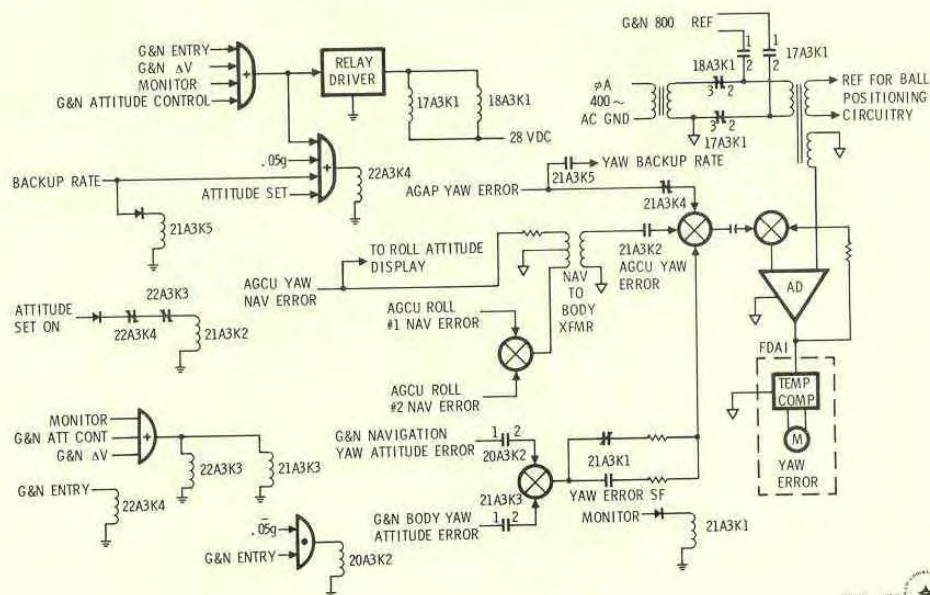


FIGURE 3-25

3-45

WHEN THE BMAG IS SWITCHED TO A RATE BACKUP MODE, THE LOGIC REMOVES THE BMAG INPUT TO THE ERROR NEEDLE AND CONNECTS IT INTO THE RATE DISPLAY BY ENERGIZING RELAYS 21A3K5 AND 21A3K4. THE YAW ATTITUDE ERROR NEEDLE IS INOPERATIVE DURING YAW BACKUP RATE.

3.13 RATE INDICATOR ELECTRONICS

THE RATE INDICATOR IS SUPPLIED WITH RATE INFORMATION BY SIGNALS DERIVED WITHIN THE SCS. FIGURE 3-26 SHOWS THE INPUTS FOR RATE SIGNALS, POWER CIRCUITS, AND THE LOGIC NECESSARY TO PERFORM THE REQUIRED SWITCHING.

POWER REQUIREMENT, OTHER THAN THE DC POWER REQUIRED TO PERFORM LOGIC SWITCHING AND FOR AMPLIFIER OPERATION, IS A 400 CYCLE REFERENCE FREQUENCY USED TO DEMODULATE THE INCOMING RATE SIGNALS. SIGNAL POLARITY IS DETERMINED BY THE PHASE RELATIONSHIP BETWEEN RATE SIGNAL AND THE REFERENCE. THE TWO SOURCES OF REFERENCE FREQUENCY ARE THE RATE GYRO POWER SWITCH AND THE PARTIAL SCS POWER SWITCH. NORMAL OPERATION WILL SELECT THE REFERENCE FREQUENCY FROM THE RATE GYRO POWER SWITCH WITH RELAY K1 DE-ENERGIZED. SELECTION OF ANY ONE OF THE THREE BMAG'S FOR BACKUP RATE OPERATION WILL ENERGIZE RELAY K1, WHICH SELECTS THE REFERENCE FREQUENCY FOR THE DEMODULATORS FROM THE PARTIAL SCS POWER SWITCH. THIS PROVIDES A CAPABILITY OF REMOVING POWER FROM THE RATE GYRO PACKAGE AND USING THE BMAG'S AS RATE GYROS FOR DISPLAY AND CONTROL PURPOSES.

AS SHOWN IN FIGURE 3-26, THERE ARE TWO SOURCES OF RATE SIGNALS. THE ROLL RATE GYRO IS THE PRIMARY

SOURCE AND THE ROLL BMAG THE BACKUP SOURCE. FOR THE ROLL CHANNEL, SELECTION OF THE PRIMARY RATE SIGNAL IS PERFORMED BY THE DE-ENERGIZED CONTACTS OF RELAY K5. THE OPEN CONTACTS OF RELAY K4 PREVENT BMAG SIGNALS FROM ENTERING THE RATE DISPLAY. SELECTING THE ROLL BMAG FOR BACKUP RATE OPERATION WILL ENERGIZE RELAYS K1, K5, AND K4 TO REMOVE THE RATE GYRO SIGNAL INPUT, SUPPLY THE BMAG RATE SIGNAL TO THE ROLL RATE DISPLAY, AND SWITCH THE BMAG PREFERENCE VOLTAGE INTO THE AMPLIFIER DEMODULATOR.

CROSS COUPLING IS REQUIRED BETWEEN THE ROLL AND YAW AXES DURING THE ENTRY PHASE OF THE MISSION, AFTER .05G SENSING, TO PROVIDE NAVIGATION AXES RATE DAMPING FOR CONTROL OF THE C/M DURING ENTRY. THE CROSS COUPLING IS PERFORMED BY ENERGIZING RELAY K2.

RELAY K3 AND K6 ARE USED TO CHANGE AMPLIFIER DEMODULATOR GAIN AND THUS ACHIEVE THE DESIRED SCALE FACTOR ON THE RATE NEEDLES. THE RATE NEEDLES HAVE THREE FULL SCALE DEFLECTION VALUES; $\pm 1^\circ/\text{SECOND}$ WITH K3 DE-ENERGIZED, $\pm 5^\circ/\text{SECOND}$ WITH RELAY K6 ENERGIZED, AND $\pm 25^\circ/\text{SECOND}$ WITH RELAYS K3 AND K6 ENERGIZED.

RELAY K2 IS ENERGIZED AFTER .05G'S TO PROVIDE IMPEDANCE MATCHING FOR ENTRY ROLL TO YAW COUPLING.

The schematic diagram illustrates the Roll Rate Feedback Loop (FDAL). It features two main input paths: the Rate Gyro and the Partial SCS. The Rate Gyro path includes a 'RATE GYRO PACKAGE' and a 'RATE GYRO POWER SWITCH' connected to a '115V 400 CPS' source. The signal passes through a 'SELF TEST' switch and a network of relays (K5, K3, K4) and capacitors (K2, K3). A 'CAGED BMAG' (TA) is also connected to the signal path. The Partial SCS path includes a 'PARTIAL SCS POWER SWITCH' connected to a '115V 400 CPS' source, passing through a 'K1' capacitor and a network of relays (K2, K3, K4) and capacitors (K2, K3). The signals from both paths are combined at a summing junction (represented by a circle with a cross) and then pass through an 'A. D.' (Analog-to-Digital) converter. The output of the A/D converter is connected to a 'ROLL RATE SF' (Roll Rate Signal Filter) and a 'TEMP COMP' (Temperature Compensation) block. The final output is the 'ROLL RATE' signal, which is also connected to an 'FDAL' (Feedback Drive Amplifier) block. The diagram also shows a 'MONITOR' section with inputs for 'G&N ENTRY' and 'SCS ENTRY', and a 'SELF TEST SWITCH CLOSURE' connected to a 'SELF TEST' signal.



3-47

FIGURE 3-26

SECTION IV
ATTITUDE CONTROL SUBSYSTEM

4.1 INTRODUCTION

THE ATTITUDE CONTROL SUBSYSTEM PROVIDES CONTROL OF SPACECRAFT MOTION. REFERRING TO FIGURE 4-1, ONE SEES THAT THIS CONTROL IS ACCOMPLISHED BY MEANS OF THE REACTION JETS ON EITHER THE COMMAND MODULE OR THE SERVICE MODULE. THESE JETS ARE NEITHER GIMBALLED NOR THROTTLEABLE. CONSEQUENTLY, COMMANDS TO THE REACTION CONTROL SYSTEM FROM THE ATTITUDE CONTROL SUBSYSTEM CONSIST SIMPLY OF ON-OFF SIGNALS. THE REACTION JETS ON THE S/M ARE USED FOR CONTROL PRIOR TO C/M-S/M SEPARATION, AND THE C/M REACTION JETS ARE USED AFTER SEPARATION.

THE CONTROL FUNCTIONS OF THE ATTITUDE CONTROL SUBSYSTEM MAY BE DIVIDED INTO FOUR CAPABILITIES:

A. ROTATIONAL MANEUVERS, WHICH ARE REQUIRED FOR NAVIGATION SIGHTINGS, ALIGNMENT OF THE VEHICLE PRIOR TO DELTA V'S, ANTENNA ORIENTATIONS FOR COMMUNICATION PURPOSES, LIFT VECTOR CONTROL DURING RE-ENTRY, ETC.

B. TRANSLATIONAL MANEUVERS, WHICH ARE REQUIRED FOR TRANSPOSITION, DOCKING, AND ULLAGE.

C. ATTITUDE HOLD, WHICH IS REQUIRED IN SITUATIONS SUCH AS NAVIGATION SIGHTINGS, DOCKING,

PREPARATION FOR DELTA V'S, ULLAGE, LIFT VECTOR CONTROL DURING RE-ENTRY, ETC.

D. RATE DAMPING ONLY, AS OPPOSED TO ATTITUDE HOLD. THIS CAPABILITY IS REQUIRED DURING RE-ENTRY AND DURING AN ABORT WHICH OCCURS PRIOR TO LES JETTISON BUT AFTER THE CANARDS ON THE LES HAVE CEASED TO BE EFFECTIVE DUE TO RARIFIED ATMOSPHERE.

4.2 CAPABILITIES OF THE ATTITUDE CONTROL SUBSYSTEM


THE ATTITUDE CONTROL SUBSYSTEM PROVIDES THE ABOVE MENTIONED CAPABILITIES BY UTILIZING INPUTS FROM VARIOUS SOURCES. THE ASTRONAUT HAS MANUAL INPUTS BY MEANS OF THE TRANSLATION AND ROTATION CONTROLS, SWITCHES ON THE CONTROL PANEL, AND THE DIRECT ULLAGE SWITCH ON THE DELTA V DISPLAY PANEL. THESE MANUAL INPUTS ARE USED FOR NORMAL MISSION PROCEDURES AS WELL AS BACKUP FOR NORMALLY AUTOMATIC FUNCTIONS. TWO INERTIAL SENSOR PACKAGES, THE ATTITUDE GYRO ACCELEROMETER PACKAGE (AGAP) AND THE RATE GYRO PACKAGE (RGP), PROVIDE RATE AND ATTITUDE ERROR SIGNAL INPUTS. THESE SIGNALS ARE USED FOR ATTITUDE HOLD, RATE DAMPING, AND MANUAL ROTATIONAL CONTROL. THE MANNER IN WHICH THEY ARE USED FOR THESE FUNCTIONS WILL BE DESCRIBED IN A LATER PART OF THIS SECTION. THE G&N SYSTEM PROVIDES ATTITUDE ERROR SIGNALS FOR ATTITUDE HOLD, AND COMMAND RATE SIGNALS FOR ROTATIONAL MANEUVERS. THE COMMAND RATE SIGNALS FROM THE G&N SYSTEM

4-1

ATTITUDE CONTROL SUBSYSTEM FUNCTIONS

PURPOSE:	CONTROL OF VEHICLE MOTION
MEANS:	1. SM REACTION CONTROL SYSTEM 2. CM REACTION CONTROL SYSTEM
CAPABILITIES:	1. ROTATIONAL MANEUVERS 2. TRANSLATIONAL MANEUVERS 3. ATTITUDE HOLD 4. RATE DAMPING ONLY

FIGURE 4-1

SCS-212 

4-2

CAN BE COMMANDED MANUALLY AS WELL AS AUTOMATICALLY. FINALLY, THE ATTITUDE IMPULSE CONTROLLER ON THE G&N OPTICS CONTROL PANEL PROVIDES MANUAL INPUTS FOR COMMANDING VERY SMALL ANGULAR ACCELERATIONS.

THE ATTITUDE CONTROL ELECTRONICS, WHICH CONSISTS OF THREE ECA'S (PITCH, YAW, AND ROLL), ACCEPTS THESE INPUTS AND GIVES OUTPUT SIGNALS TO THE PROPER REACTION JETS TO TURN THEM ON OR OFF. THE CONFIGURATION OF THE ATTITUDE CONTROL ELECTRONICS IS DEPENDENT UPON VARIOUS MODE AND LOGIC SIGNALS FROM THE CONTROL PANEL, CONTROL STICKS, AND DIRECT ULLAGE SWITCH. THESE SIGNALS CHANGE GAINS AND SIGNAL PATHS WITHIN THE ATTITUDE CONTROL ELECTRONICS TO MODIFY THE CAPABILITIES OF THE VARIOUS CONTROL INPUTS.

A CLOSER LOOK (REF. FIGURE 4-2) WILL NOW BE TAKEN AT THESE INPUTS TO THE ATTITUDE CONTROL SUBSYSTEM, TOGETHER WITH THE MODES DURING WHICH THESE FUNCTIONS ARE AVAILABLE. IN PARAGRAPH 4.3 (MECHANIZATION OF THE ATTITUDE CONTROL SUBSYSTEM), THE SWITCHING AND GAIN CHANGES WHICH TAKE PLACE IN THE ATTITUDE CONTROL ELECTRONICS, AS A RESULT OF THE VARIOUS LOGIC INPUTS, WILL BE COVERED ON A BLOCK DIAGRAM LEVEL.

4.2.1 ROTATIONAL MANEUVERS

ROTATIONAL MANEUVERS CAN BE CLASSIFIED AS MANUAL OR AUTOMATIC. THERE ARE FOUR WAYS FOR COMMANDING ROTATIONS MANUALLY AND ONE AUTOMATICALLY. THE FOUR MANUAL MEANS WILL BE DESCRIBED FIRST, THEN THE ONE

AUTOMATIC CAPABILITY.

4.2.1.1 MANUAL PROPORTIONAL ROTATION

EITHER ONE OF TWO ROTATION CONTROLS CAN BE USED FOR ROTATING THE VEHICLE ABOUT ONE OR MORE OF THE THREE BODY-REFERENCED AXES SIMULTANEOUSLY. THIS CAPABILITY (AS WELL AS DIRECT ROTATION), IS CALLED CONTROL STICK STEERING (CSS). THE ROTATIONAL RATE ACHIEVED IN ANY AXIS WILL BE PROPORTIONAL TO THE MAGNITUDE OF THE STICK DISPLACEMENT IN THAT AXIS. HOWEVER, THE RELATIONSHIP BETWEEN STICK DISPLACEMENT AND VEHICLE RATE IS A NON-LINER PROPORTIONALITY RATHER THAN A DIRECT PROPORTIONALITY. THE PROPORTIONAL CONTROL IS ACHIEVED BY UTILIZING THE RATE OUTPUT OF THE RATE GYROS (OR BMAG'S IN BACKUP RATE) TO CANCEL THE TRANSDUCER OUTPUT OF THE CONTROL STICK. DURING MANUAL PROPORTIONAL ROTATION, THE THREE BMAG'S ARE KEPT CAGED THROUGH THE AGCU AND THE ATTITUDE ERROR INPUTS TO THE SCS ELECTRONICS ARE INHIBITED. WHEN THE CONTROL STICK IS ROTATED APPROXIMATELY 2.5° FROM ITS NEUTRAL POSITION IN ANY AXIS, A CSS BREAKOUT SWITCH IS ACTIVATED, GIVING A CSS LOGIC SIGNAL TO THE ECA'S THAT ACCOMPLISHES THE CAGING AND INHIBITING FUNCTIONS MENTIONED ABOVE.

THE MAXIMUM RATES WHICH CAN BE COMMANDED BY THIS TYPE OF CONTROL ARE APPROXIMATELY:

- A. 17 DEG/SEC DURING ENTRY MODES (ROLL AXIS)
5 DEG/SEC DURING ENTRY MODES (PITCH AND YAW AXES)

4-3

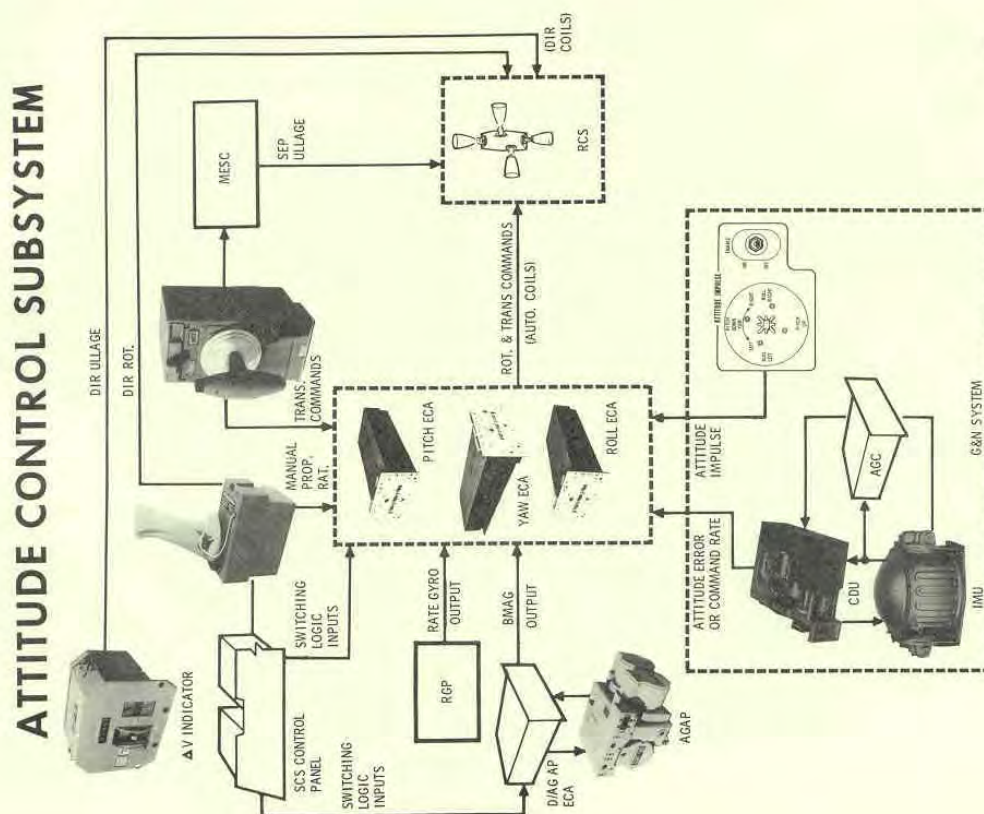


FIGURE 4-2

4-4

8. 0.65 DEG/SEC DURING ALL OTHER MODES
(PITCH, YAW, AND ROLL AXES)
CSS IS AVAILABLE DURING ALL MODES.

4.2.1.2 DIRECT OR EMERGENCY ROTATION

THE SOLENOID VALVES CONTROLLING THE REACTION JETS CONTAIN TWO SETS OF COILS, AUTOMATIC AND DIRECT. ENERGIZING EITHER COIL IN A SOLENOID VALVE WILL OPERATE THE VALVE AND TURN ON THE JET. DIRECT ROTATION, DIRECT ULLAGE, AND SEPARATION ULLAGE USE THE DIRECT COILS. ALL OTHER CONTROL FUNCTIONS USE THE AUTOMATIC COILS.

DIRECT ROTATION CAN BE COMMANDED ABOUT ONE OR MORE AXES SIMULTANEOUSLY BY MOVING THE ROTATION CONTROL ALL THE WAY TO ITS HARD STOPS IN THE APPROPRIATE AXIS. A SWITCH IS CLOSED APPLYING THE DIRECT COMMAND TO THE DIRECT COILS OF THE RCS ABOUT 1° BEFORE THE STICK HITS THE HARD STOPS. THIS CONTROL IS NON-PROPORTIONAL SINCE THE JETS KEEP FIRING AS LONG AS THE DIRECT SWITCHES ARE CLOSED. THERE IS NO RATE FEEDBACK SIGNAL TO CANCEL THIS DIRECT COMMAND. THE THREE BMAG'S ARE ALSO CAGED AND THE ATTITUDE ERROR INPUTS TO THE ECA'S INHIBITED DURING DIRECT ROTATION BY THE SIGNAL FROM THE CSS BREAKOUT SWITCHES.

DIRECT CONTROL IS AVAILABLE AT ANY TIME THROUGHOUT THE MISSION, PROVIDING ONLY THAT THE DIRECT CIRCUIT BREAKERS ARE IN, THE DIRECT MODE SWITCH IS ON, AND THE NECESSARY POWER CIRCUITS AS WELL AS THE DIRECT COILS OF THE RCS ARE FUNCTIONING PROPERLY.

4.2.1.3 ATTITUDE IMPULSE

THE ATTITUDE IMPULSE SWITCH OPERATES IN THREE AXES SIMILAR TO THE ROTATION CONTROL EXCEPT THAT IT GIVES ONLY ONE PULSE TO THE REACTION JETS WHEN IT IS DISPLACED. THIS ENABLES THE ASTRONAUT TO COMMAND VERY LOW ACCELERATIONS, AND CONSEQUENTLY ACHIEVE LOW ANGULAR RATES OF THE VEHICLE.

ATTITUDE IMPULSE CONTROL IS AVAILABLE ONLY IN SCS ATTITUDE CONTROL OR G&N ATTITUDE CONTROL MODE.

4.2.1.4 MANUAL POSITIONING OF THE CDU'S

THIS METHOD WILL NOT BE THE NORMAL WAY FOR COMMANDING ROTATIONS, BUT IT IS INCLUDED SINCE IT IS NEVERTHELESS POSSIBLE. THERE ARE THREE CDU SHAFTS IN THE G&N SYSTEM WHICH CAN BE ROTATED BY HAND OR AUTOMATICALLY BY THE APOLLO GUIDANCE COMPUTER. WHEN ONE OR MORE SHAFTS ARE ROTATED BY HAND, USING EITHER THE THREE SLEW SWITCHES AND THE THUMBWHEELS WHICH ARE PROVIDED ON THE CDU'S, OR THE AGC KEYBOARD, A COMMAND SIGNAL (PROPORTIONAL TO THE DIFFERENCE BETWEEN THE CDU SHAFT ANGLE AND THE CORRESPONDING IMU GIMBAL ANGLE) IS GENERATED WHICH COMMANDS A VEHICLE RATE ABOUT THE PROPER AXES. THE COMMAND SIGNALS FROM THE G&N SYSTEM PASS THROUGH A LIMITER CIRCUIT IN THE SCS WHICH LIMITS THE MAXIMUM RATES WHICH CAN BE COMMANDED BY THE G&N SYSTEM TO THE SAME VALUES FOR MAXIMUM POSSIBLE RATES USING MANUAL PROPORTIONAL ROTATION.

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THIS CONTROL IS AVAILABLE ONLY WHEN THE SCS IS IN G&N ATTITUDE CONTROL MODE, G&N DELTA V MODE, OR G&N ENTRY MODE. THE BMAG'S ARE CAGED THROUGH THE AGCU DURING THESE MODES, EXCEPT FOR G&N DELTA V. CONSEQUENTLY, IF A MANEUVER WERE PERFORMED IN THIS MANNER DURING G&N DELTA V MODE, THE BMAG'S, BEING UNCAGED, COULD HIT THEIR STOPS, RESULTING IN A LOSS OF SPACECRAFT ATTITUDE INFORMATION WITHIN THE AGCU. IT WOULD NOT BE ADVISABLE TO USE THIS TYPE OF CONTROL WHEN THE SPS ENGINE WERE FIRING. THIS CONTROL IS NOT AVAILABLE AFTER .05G DURING ENTRY, EXCEPT IN THE ROLL CHANNEL.

4.2.1.5 AUTOMATIC POSITIONING OF THE CDU'S

THIS CONTROL IS SIMILAR TO MANUAL POSITIONING OF THE CDU'S EXCEPT THAT THE APOLLO GUIDANCE COMPUTER (AGC) ROTATES THE CDU'S AUTOMATICALLY. THIS FUNCTION WOULD BE USED DURING THE G&N ENTRY MODE. THAT IS, THE AGC WOULD HAVE AN ENTRY TRAJECTORY PROGRAMMED INTO IT, AND AT THE PROPER TIMES WOULD AUTOMATICALLY ROTATE THE CDU'S TO PROPERLY CONTROL THE LIFT VECTOR AND HENCE THE PROFILE OF THE RE-ENTRY TRAJECTORY.

4.2.2 TRANSLATION MANEUVERS

THERE ARE THREE WAYS FOR COMMANDING TRANSLATIONS MANUALLY, AND NONE AUTOMATICALLY. THESE ARE DESCRIBED BELOW.

4.2.2.1 NORMAL TRANSLATION USING THE TRANSLATION CONTROL

EITHER ONE OF TWO TRANSLATION CONTROLS CAN BE USED FOR COMMANDING TRANSLATIONAL ACCELERATIONS

ALONG ONE OR MORE OF THE BODY REFERENCED AXES SIMULTANEOUSLY. THE CHANGE IN VELOCITY WHICH IS ACHIEVED IS NON-PROPORTIONAL SINCE THE HAND CONTROL MERELY CLOSSES SWITCHES WHICH TURN ON JETS GIVING A CONSTANT ACCELERATION UNTIL THE HAND CONTROL IS RELEASED OR THE FUEL IS EXPENDED.

THIS CONTROL IS AVAILABLE DURING ALL MODES UNTIL C/M-S/M SEPARATION, AT WHICH TIME IT IS UNAVAILABLE FOR THE REST OF THE MISSION.

4.2.2.2 DIRECT ULLAGE

BY MEANS OF THE DIRECT ULLAGE BUTTON ON THE DELTA V DISPLAY, A POSITIVE X AXIS ACCELERATION CAN BE COMMANDED. THIS COMMAND USES THE DIRECT COILS OF THE RCS AND IS AVAILABLE ANY TIME, PROVIDING THE DIRECT CIRCUIT BREAKERS ARE IN AND THE DIRECT COILS OF THE RCS ARE FUNCTIONING PROPERLY.

4.2.2.3 SEPARATION ULLAGE

A COUNTERCLOCKWISE ROTATION OF THE TRANSLATION CONTROL HANDLE INTO A DETENT POSITION (CLOSING A SWITCH), WHICH COMMANDS EITHER AN SPS ABORT OR SIV-B SEPARATION, WILL ALSO COMMAND AN ULLAGE MANEUVER, USING THE DIRECT COILS OF THE RCS. THIS ULLAGE IS SEMI-AUTOMATIC. IF THE HAND CONTROL IS ROTATED COUNTERCLOCKWISE AND RETURNED TO NEUTRAL, A 2.5 SECOND ULLAGE WILL RESULT. IF THE CONTROLLER IS KEPT TWISTED FOR 2.5 SECONDS OR MORE, THE ULLAGE WILL LAST UNTIL THE CONTROLLER IS RETURNED TO NEUTRAL.

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THIS FUNCTION IS AVAILABLE AFTER THE LES SYSTEM HAS BEEN JETTISONED, THE MASTER EVENT SEQUENCE CONTROLLER (MESC) CIRCUIT BREAKERS ARE IN, AND THE MESC LOGIC ARM SWITCH IS ARMED.

4.2.2.4 ADDITIONAL FUNCTIONS OF THE TRANSLATION CONTROL

IN ADDITION TO COMMANDING TRANSLATIONS, THE TRANSLATION CONTROL HAS A FEW OTHER CAPABILITIES WHICH WILL BE DESCRIBED AT THIS POINT. DURING THE LAUNCH PHASE OF A MISSION, A COUNTERCLOCKWISE TWIST OF THE HAND CONTROL WILL INITIATE ABORT SEQUENCES WHEN THE LAUNCH ESCAPE SYSTEM IS ATTACHED, AND WILL CAUSE SIV-B SEPARATION IF THE LES HAS BEEN JETTISONED.

FURTHERMORE, DURING ANY MODE, IF THE TRANSLATION CONTROL IS ROTATED CLOCKWISE, CLOSING A SWITCH, A CSS LOGIC SIGNAL IS GENERATED WHICH REMOVES THE ATTITUDE ERROR AND COMMAND RATE SIGNALS (FROM EITHER THE G&N OR SCS SYSTEM) FROM THE SCS ELECTRONICS IN ALL THREE AXES, AND ALSO CAGES THE BMAG'S THROUGH THE AGCU. THIS ENABLES THE ASTRONAUT TO MANUALLY CONTROL THE VEHICLE DURING THE G&N ENTRY MODE, WHICH NORMALLY PROVIDES AUTOMATIC ATTITUDE CONTROL (IN THE ROLL AXIS) BY PROVIDING THE SCS WITH A COMMAND RATE SIGNAL. IF THE SCS IS IN EITHER G&N OR SCS DELTA V MODES, THE CLOCKWISE TWIST OF THE TRANSLATION CONTROL ALSO INITIATES MANUAL THRUST VECTOR CONTROL, IN ADDITION TO REMOVING THE ATTITUDE ERROR SIGNALS FROM THE SCS ELECTRONICS AND CAGING THE BMAG'S THROUGH THE BACKUP RATE LOOP. BOTH THE CLOCKWISE AND COUNTERCLOCKWISE ROTATIONS OF THE

TRANSLATION CONTROL HANDLE MOVE THE HANDLE INTO A DETENT POSITION WHICH HOLDS THE HANDLE IN THAT POSITION.

4.2.3 ATTITUDE HOLD

THE SPACECRAFT CAN HOLD A PARTICULAR ORIENTATION IN SPACE ABOUT ALL THREE BODY-REFERENCED AXES. IT WILL OSCILLATE APPROXIMATELY $\pm 5^\circ$ OR $\pm 0.5^\circ$ (DEPENDING ON WHETHER THE SCS IS IN THE MAXIMUM OR MINIMUM DEADBAND CONFIGURATION) IN EACH AXIS ABOUT THE PARTICULAR ORIENTATION WHICH IT IS HOLDING. IF THE SCS IS IN EITHER G&N OR SCS ENTRY MODES, ATTITUDE HOLD WILL USE THE MAXIMUM DEADBAND REGARDLESS OF THE POSITION OF THE DEADBAND SELECT SWITCH. THERE IS NO ATTITUDE HOLD CAPABILITY IN MONITOR MODE.

THE ATTITUDE HOLD CAPABILITY IS MECHANIZED BY USING THE SUM OF ATTITUDE ERROR SIGNALS AND RATE SIGNALS. WHENEVER THE SPACECRAFT ROTATES AWAY FROM ITS REFERENCE POSITION BY AN AMOUNT EXCEEDING THE DEADBAND VALUE, THE SUM OF THE RATE AND ATTITUDE ERROR SIGNALS TURN ON THE PROPER JETS TO ROTATE THE VEHICLE BACK WITHIN ITS DEADBAND.

THE ATTITUDE ERROR SIGNAL FOR A PARTICULAR AXIS IS PROPORTIONAL TO THE MAGNITUDE OF THE ANGULAR DISPLACEMENT OF THE SPACECRAFT (IN THAT AXIS) FROM THE ORIENTATION IN SPACE AT WHICH THE ATTITUDE REFERENCE SYSTEMS ARE NULLED. THE ATTITUDE ERROR SIGNALS ARE GENERATED BY THE THREE BMAG'S IN THE UNCAGED CONFIGURATION, (IN SCS ATTITUDE CONTROL, LOCAL VERTICAL,

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DELTA V, AND ENTRY MODES), OR BY THE DIFFERENCE BETWEEN THE ANGULAR POSITIONS OF THE THREE CDU SHAFTS AND THE THREE GIMBALS OF THE IMU (IN G&N ATTITUDE CONTROL, DELTA V, OR ENTRY MODES) IN THE G&N SYSTEM.

THE RATE SIGNAL, IN A PARTICULAR AXIS, IS PROPORTIONAL TO THE ANGULAR VELOCITY OF THE SPACECRAFT ABOUT THAT AXIS. THE RATE SIGNALS ARE GENERATED BY THE RATE GYROS (OR THE BMAG'S IN A BACKUP RATE CONFIGURATION), WHETHER IN SCS OR G&N CONTROL MODES. THE RATE SIGNALS ARE ADDED TO THE ATTITUDE ERROR SIGNALS TO PROVIDE FOR STABLE OSCILLATIONS ABOUT THE REFERENCE ORIENTATION.

ATTITUDE HOLD ABOUT ALL THREE AXES IS AUTOMATICALLY IN EFFECT DURING ALL MODES EXCEPT:

- MONITOR MODE
- SCS ENTRY MODE AFTER THE .05G SWITCH IS TURNED ON
- G&N ENTRY MODE AFTER THE .05G SWITCH IS TURNED ON; HOWEVER, IN THIS MODE, IT IS STILL IN EFFECT ABOUT THE BODY-OFFSET ROLL AXIS

AN ADDITIONAL COMMENT SHOULD BE MADE CONCERNING ATTITUDE HOLD DURING THE LOCAL VERTICAL MODE IN WHICH THE SPACECRAFT HOLDS APPROXIMATELY A CONSTANT ATTITUDE WITH RESPECT TO THE EARTH. THIS MEANS THAT ITS ACTUAL ATTITUDE WITH RESPECT TO AN INERTIALLY FIXED REFERENCED FRAME MUST BE CONTINUOUSLY CHANGING. THIS

IS ACCOMPLISHED BY TORQUING THE BMAG'S AT A FIXED RATE, SUCH THAT THE INERTIAL ATTITUDE OF THE SPACECRAFT, DEFINED BY THE BMAG'S NULL POSITION, IS KEPT CHANGING IN THE PROPER MANNER.

4.2.4 RATE DAMPING ONLY

IN ADDITION TO THE ABILITY OF THE SCS FOR PROVIDING ATTITUDE HOLD AND MANEUVERING CAPABILITIES, THE SCS CAN ALSO PROVIDE RATE DAMPING ONLY. THAT IS, ALTHOUGH RATE DAMPING IS USED FOR STABILITY OF OSCILLATIONS DURING ATTITUDE HOLD, RATE DAMPING CAN ALSO BE USED TO LIMIT THE ROTATIONAL RATES OF THE SPACECRAFT EVEN WHEN NOT HOLDING A PARTICULAR ATTITUDE. THIS CAPABILITY, AS HAS BEEN PREVIOUSLY INDICATED, WOULD BE USED DURING ABORTS AND RE-ENTRY. THE OUTPUTS OF EITHER THE RATE GYROS OR THE BMAG'S (DURING BACKUP RATE) ARE USED TO MECHANISE THIS CAPABILITY. DURING MONITOR MODE, (WHICH WOULD PROBABLY BE USED FOR ABORTS UTILIZING THE LAUNCH ESCAPE SYSTEM) IF VEHICLE RATES IN ANY AXIS EXCEED .2 DEGREES/SEC., THE OUTPUTS OF THE RATE GYROS WILL TURN ON THE REACTION JETS TO DECREASE VEHICLE RATES BELOW THE .2 DEGREE/SEC. DEADBAND. DURING EITHER SCS OR G&N ENTRY MODES, THE RATE DEADBAND IS 2 DEGREES/SEC.

AT THIS POINT, A FEW WORDS WILL BE SAID ON THE BACKUP RATE FUNCTION. THE THREE BACKUP RATE SWITCHES ON THE CONTROL PANEL CAN CAGE ONE OR MORE BMAG'S, TURNING THEM INTO RATE GYROS, AND APPLYING THEIR OUTPUTS, WHICH WOULD NOW BE PROPORTIONAL TO

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ACTUAL MECHANIZATION OF THESE CAPABILITIES.

- A. THE SCS IS IN MONITOR, LOCAL VERTICAL, G&N ATTITUDE CONTROL, OR G&N ENTRY MODES.
- B. THE SCS IS IN SCS ENTRY MODE AND THE .05G SWITCH IS ON.
- C. THE SCS IS IN SCS ATTITUDE CONTROL MODE AND EITHER THE PITCH, YAW, OR BOTH ROLL CHANNELS HAVE BEEN DISABLED BY MEANS OF THE CHANNEL ENABLE SWITCHES.

RATE DAMPING ONLY IS AVAILABLE IN MONITOR MODE, SCS ENTRY MODE AFTER THE .05G SWITCH IS TURNED ON, G&N ENTRY MODE (PITCH AND YAW CHANNELS) AFTER THE .05G SWITCH IS TURNED ON, AND ANYTIME THE TRANSLATION CONTROL HANDLE IS ROTATED CLOCKWISE, GENERATING A CSS LOGIC SIGNAL.

4.3 MECHANIZATION OF THE ATTITUDE CONTROL SUB-SYSTEM

THE FIRST PART OF THIS SECTION HAS DESCRIBED THE VARIOUS CAPABILITIES OF THE ATTITUDE CONTROL SUB-SYSTEM AND THE MODES DURING WHICH THEY WOULD BE AVAILABLE. THE REMAINDER OF THIS SECTION WILL BE DEVOTED TO DESCRIBING (MOSTLY AT A BLOCK DIAGRAM LEVEL) THE

FIGURES 4-3 AND 4-4 SCHEMATICALLY PRESENT THE GENERAL SIGNAL FLOW AND FUNCTIONS ASSOCIATED WITH THE SCS ATTITUDE CONTROL SYSTEM. IN THE BLOCK DIAGRAMS, THE SIGNAL FLOW SCHEME IS FROM LEFT TO RIGHT. EXCEPT FOR ROLL TO YAW COUPLING AFTER 0.05G IN THE YAW CHANNEL (UPPER LEFT HAND CORNER OF THE DIAGRAM) AND CORRESPONDING JET NUMBERS FOR THE PITCH CHANNEL (JETS 1 THRU 4), THE PITCH AND YAW CHANNELS ARE BASICALLY IDENTICAL. THEREFORE ONE DIAGRAM HAS BEEN ADAPTED TO DESCRIBE THE TYPICAL FUNCTIONING OF EITHER C CHANNEL. SINCE FIGURE 4-3 UTILIZES JETS 5, 6, 7, AND 8, IT REPRESENTS THE ACTION OF THE YAW CHANNEL.

FIGURE 4-4 REPRESENTS THE TYPICAL ROLL CHANNEL. SINCE ITS FUNCTION IS SIMILAR TO PITCH AND YAW ON THE GENERAL SIGNAL FLOW LEVEL, ONLY IMPORTANT DIFFERENCES WILL BE POINTED OUT IN THE DESCRIPTION OF THAT CHANNEL.

MOST OF THE ELECTRONICS WHICH MECHANIZE THE BLOCK DIAGRAMS, GIVEN IN FIGURES 4-3 AND 4-4, FOR THE ATTITUDE CONTROL SUBSYSTEM, ARE CONTAINED WITHIN THE ROLL, PITCH, AND YAW ECA'S. THE INPUTS TO THE CHANNELS BECOME REACTION JET CONTROL SIGNALS (OR SPS PITCH AND YAW GIMBAL CONTROL SIGNALS DURING DELTA V THRUSTING) AT THE OUTPUT. LOGICALLY, THE INPUTS WILL BE COVERED FIRST, WITH A TRANSITION THROUGH THE SIGNAL FLOW AND END IN A DISCUSSION OF THE REACTION JET FUNCTION. MOST OF THE INPUTS TO THE ATTITUDE CONTROL CHANNEL APPEAR

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ATTITUDE CONTROL SUBSYSTEM

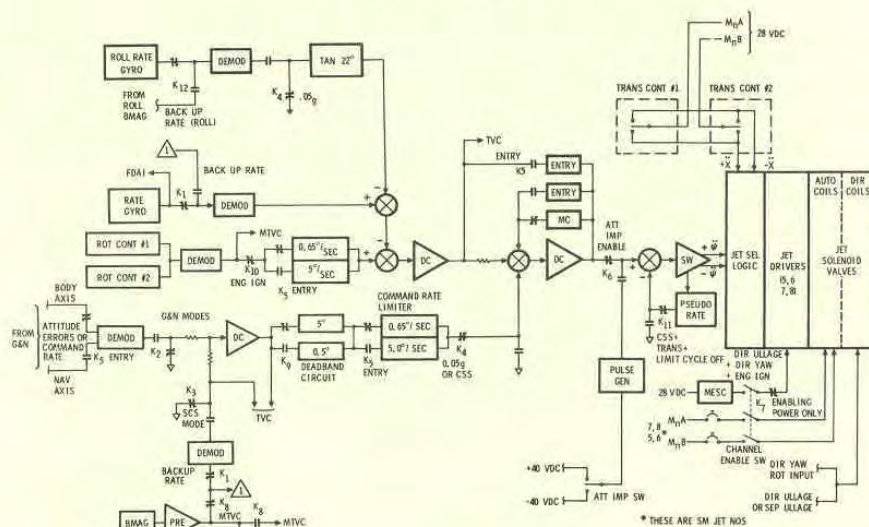


FIGURE 4-3

ATTITUDE CONTROL SUBSYSTEM

(ROLL CHANNEL)

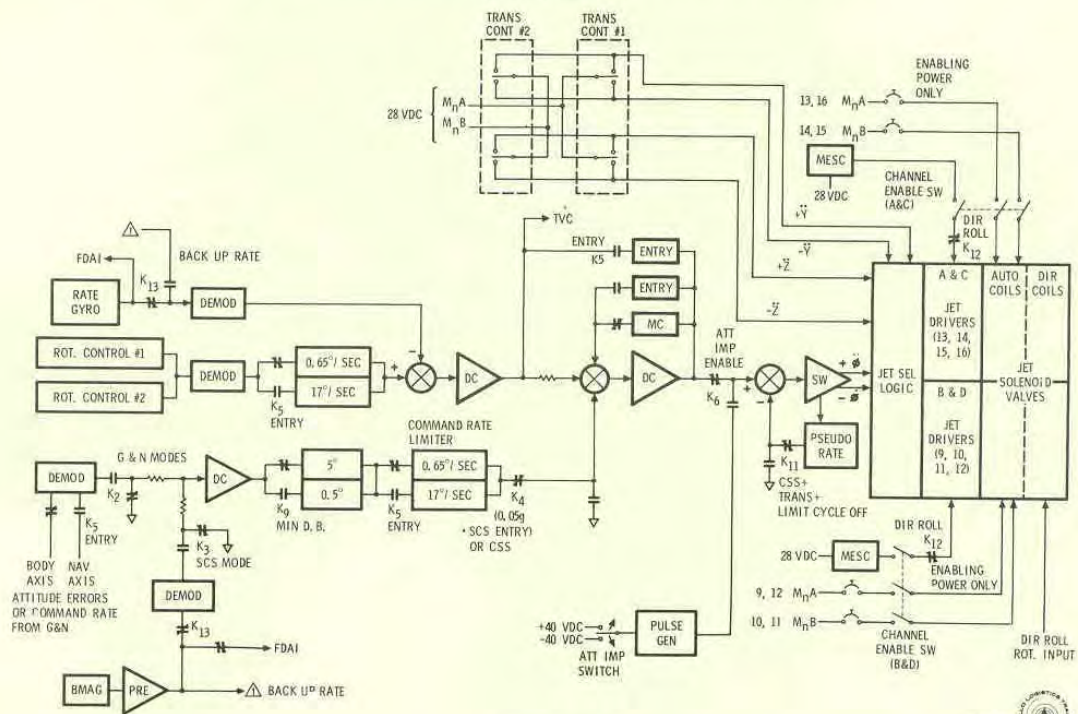


FIGURE 4-4

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ON THE LEFT HAND SIDE OF THE DRAWING. THEY ARE:

- ATTITUDE ERRORS FROM THE UNCAGED AGAP GYROS.
- ATTITUDE ERROR OR RATE COMMANDS FROM THE G&N SYSTEM.
- PROPORTIONAL RATE COMMANDS FROM EITHER OF THE TWO ROTATION CONTROLS.
- VEHICLE BODY RATES FROM THE SCS RATE GYROS OR FROM THE CAGED AGAP GYROS DURING BACKUP RATE.

OTHER COMMAND INPUTS TO THE SIGNAL FLOW ARE:

- ATTITUDE IMPULSE FROM THE ATTITUDE IMPULSE CONTROLLER (LOWER CENTER OF DRAWING).
- TRANSLATION COMMANDS FROM THE TWO TRANSLATION CONTROLS (TOP CENTER OF DRAWING).
- DIRECT COMMANDS FROM THE DIRECT SWITCHES OF THE ROTATION CONTROLS (LOWER RIGHT OF DRAWING).
- SEPARATION ULLAGE FROM THE TWO TRANSLATION CONTROLS VIA THE MISSION SEQUENCER, (WHEN COMMANDING A SERVICE MODULE ABORT OR SIVB SEPARATION) AND DIRECT ULLAGE FROM THE DELTA V DISPLAY (LOWER RIGHT OF DRAWING).

AS WE HAVE SEEN, ALL THESE INPUTS ARE NOT UTILIZED AT THE SAME TIME, AND IN FACT THEIR AVAILABILITY IS A

FUNCTION OF THE SCS MODE SELECTED. A DESCRIPTION OF THE MECHANIZATION FOR THE SCS CAPABILITIES OF ATTITUDE HOLD, ROTATIONAL MANEUVERS, TRANSLATIONAL MANEUVERS, AND RATE DAMPING WILL NOW BE GIVEN FOR THE PITCH AND YAW CHANNELS, FOLLOWED BY A DISCUSSION OF THE ENABLING FUNCTIONS FOR THE REACTION JETS. THIS DISCUSSION WILL IN TURN BE FOLLOWED BY A DESCRIPTION OF THE ROLL CHANNEL IN SO FAR AS IT DIFFERS FROM PITCH AND YAW, A SUMMARY OF THE HAND CONTROL OUTPUTS AND THE G&N SYNC FUNCTION. A DISCUSSION OF THE JET SELECT LOGIC WILL COME AFTER THE ABOVE SUMMARY. FINALLY, THE MECHANIZATION FOR THE DIRECT COMMAND LOOP WILL BE TREATED.

4.3.1 ATTITUDE HOLD

ATTITUDE OF THE SPACECRAFT CAN BE HELD BY THE UNCAGED SCS ATTITUDE GYROS (BMA&G'S) IN THE SCS MODES OR BY G&N INPUTS IN G&N MODES. IN EITHER CASE, THE ATTITUDE ERROR SIGNAL IS APPLIED TO ITS RESPECTIVE DEMODULATOR. THE OUTPUTS OF THE DEMODULATORS (DEM) ARE APPLIED TO A COMMON DC AMPLIFIER VIA RELAYS K2 AND K3, WHICH SELECT G&N ATTITUDE ERRORS IN G&N MODES, AND SCS ATTITUDE ERRORS IN SCS MODES.

AFTER AMPLIFICATION, THE ATTITUDE ERROR SIGNAL IS APPLIED TO THE MINIMUM - MAXIMUM DEADBAND CIRCUIT. EITHER DEADBAND CAN BE SELECTED BY RELAY ACTION USING THE MIN - MAX. POSITION OF THE DEADBAND SWITCH. HOWEVER, IF THE SCS IS IN MONITOR OR ONE OF THE TWO ENTRY MODES, THE MINIMUM DEADBAND CANNOT BE SELECTED. WHEN THE ERROR SIGNAL (G&N OR SCS) IS LARGER THAN THE

DEADBAND SELECTED, THE ERROR IS APPLIED TO THE COMMAND RATE LIMITER. THIS CIRCUIT LIMITS THE APPLIED ATTITUDE ERROR SIGNAL TO AN EQUIVALENT RATE SIGNAL OUTPUT OF APPROXIMATELY $.65^\circ/\text{SEC}$. FOR NON-ENTRY MODES AND APPROXIMATELY $5^\circ/\text{SEC}$. FOR ENTRY MODES. THE OUTPUT FROM THE COMMAND RATE LIMITER IS REMOVED (GROUNDED) BY RELAY K4, WHEN THE $.05g$ SWITCH IS TURNED ON, PROVIDING THE SCS IS IN EITHER SCS OR G&N ENTRY MODES. THUS, AFTER $.05g$ SWITCHING, PITCH AND YAW ATTITUDE CONTROL OF THE S/C ARE REMOVED WHETHER IN A G&N OR SCS ENTRY MODE. HOWEVER, AERODYNAMIC FORCES ENCOUNTERED AFTER $0.05g$ WILL CONTROL THE ATTITUDE OF THE VEHICLE IN PITCH AND YAW, WITH RESPECT TO APPROXIMATELY A 22° OFFSET ORIENTATION OF THE SPACECRAFT (WEATHER-COCKED IN THE AIR STREAM). THE COMMAND RATE LIMITER OUTPUT IS ALSO REMOVED BY A CSS SIGNAL WHICH CAN BE GENERATED EITHER BY CSS ITSELF OR A CLOCKWISE TWIST OF THE TRANSLATION CONTROL HANDLE.

FROM THE COMMAND RATE LIMITER THE ERROR SIGNAL BECOMES AN INPUT TO THE SUMMING POINT FOR THE NEXT DC AMPLIFIER. AT THIS SUMMING POINT, THE ATTITUDE ERROR SIGNAL SUMS WITH THE RATE GYRO OUTPUT (OR $BWAG$ DURING BACKUP RATE WHEN IN A G&N MODE). IF THE VEHICLE IS HOLDING AN ATTITUDE WITHIN THE SELECTED DEADBAND, THERE WILL PROBABLY BE NO APPRECIABLE RATE SIGNAL FROM THE RATE GYROS BECAUSE OF THE LOW VEHICLE DRIFT RATE. WITH RESPECT TO A RATE SIGNAL, RELAY K5 CHANGES THE GAIN OF THIS AMPLIFIER BY A FACTOR OF TEN FOR ENTRY MODES. THE REASON FOR THIS IS THAT THE SWITCHING AMPLIFIER HAS A TRIGGERING THRESHOLD OF 2 VOLTS, WHICH CORRESPONDS TO A RATE INPUT OF $.2^\circ/\text{SEC}$. DURING NON-ENTRY MODES. BY DECREASING THE GAIN OF THE SUMMING

AMPLIFIER BY $1/10$ DURING ENTRY MODES, THE RATE DEADBAND IS INCREASED TO $2^\circ/\text{SEC}$, WHICH RESULTS IN A FUEL SAVING. HOWEVER, WITH RESPECT TO OUR ATTITUDE ERROR SIGNAL, RELAY K5 DECREASES THE GAIN OF THIS AMPLIFIER BY $1/5$ DURING ENTRY MODES, SUCH THAT THE ATTITUDE ERROR DEADBAND IS STILL APPROXIMATELY $\pm 5^\circ$.

THE OUTPUT OF THE SUMMING AMPLIFIER, UPON BEING APPLIED TO THE SWITCHING AMPLIFIER, TURNS IT ON WHEN THE 2 VOLT THRESHOLD IS EXCEEDED. DUE TO POSITIVE FEEDBACK WITHIN THE SWITCHING AMPLIFIER, IT TURNS FULL ON, GIVING AN OUTPUT OF APPROXIMATELY ± 20 VDC. THE SWITCHING AMPLIFIER TRANSFORMS THE INPUT SIGNAL TO A SERIES OF WIDTH AND FREQUENCY MODULATED PULSES DUE TO A PSEUDO-RATE FEEDBACK CIRCUIT. THESE PULSES ARE INPUTS TO THE JET SELECTION LOGIC THAT DETERMINES WHICH JETS ARE TO FIRE TO OBTAIN DESIRED RATE DIRECTION. A COMPREHENSIVE COVERAGE OF THE JET SELECTION LOGIC (WITH OR WITHOUT A TRANSLATION INPUT) IS COVERED IN FIGURE 4-7 AND WILL NOT BE COVERED IN THE GENERAL SIGNAL FLOW DESCRIPTION. THE PSEUDO-RATE SIGNAL GENERATES A VARIABLE JET ON TIME BY VARYING BOTH PULSE WIDTH AND REPETITION RATE AS A FUNCTION OF SIGNAL MAGNITUDE. THUS, FOR A LARGE INPUT SIGNAL THE OUTPUT PULSE (OR PULSES) WILL CAUSE A JET TO FIRE MORE OFTEN AND FOR A LONGER PERIOD OF TIME. AS THE ERROR SIGNAL DECREASES, PULSE WIDTH AND REPETITION RATE DECREASE, THUS CREATING A MINIMUM IMPULSE CONDITION TO BRING THE S/C CLOSE TO A ZERO RATE CONDITION.

THE DIAGRAM SHOWS THAT THE SWITCHING AMPLIFIER HAS TWO MODES OF OPERATION; WITH OR WITHOUT PSEUDO-RATE FEEDBACK. THE PSEUDO-RATE FEEDBACK LOOP IS

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ALWAYS EMPLOYED EXCEPT DURING CSS, TRANSLATION MANEUVERS, OR WHEN THE LIMIT CYCLE SWITCH ON THE CONTROL PANEL IS IN THE OFF POSITION. THIS INHIBITING FUNCTION FOR PSEUDO-RATE IS ACTIVATED BY THE OUTPUT OF THE CSS BREAKOUT SWITCHES ON THE ROTATION CONTROL DURING CSS. DURING TRANSLATIONAL MANEUVERS, IT IS THE OUTPUT OF THE TRANSLATION CONTROL WHICH ACCOMPLISHES THIS FUNCTION. ANALYTICAL STUDIES HAVE INDICATED THAT THE PSEUDO-RATE ACTION OFFERS NO REAL FUEL SAVINGS DURING CSS, TRANSLATION MANEUVERS, OR ENTRY MODES AFTER $.05g$, AND CAN CONSEQUENTLY BE REMOVED DURING THESE TIMES.

WITH PSEUDO-RATE FEEDBACK OPEN, THE SWITCHING AMPLIFIER OUTPUT REMAINS AT APPROXIMATELY ± 20 VDC AS LONG AS THE INPUT IS ABOVE ± 2 VDC.

WITH PSEUDO-RATE IN THE LOOP, THE SWITCHING AMPLIFIER GENERATES A SERIES OF PULSES AS LONG AS THE INPUT SIGNAL IS ABOVE ± 2 VDC. THESE SIGNALS PULSE THE JET SOLENOIDS ON AND OFF. THE DUTY CYCLE OF THE OUTPUT PULSES VARIES WITH THE INPUT SIGNAL. TABLE 4-1 SUMMARIZES THE PSEUDO-RATE OUTPUT OF THE SWITCHING AMPLIFIER.

FROM THE JET SELECTION LOGIC, A ± 28 VDC SIGNAL IS SENT TO THE APPROPRIATE JET DRIVER AMPLIFIERS. WHEN THE JET DRIVER FOR A PARTICULAR SOLENOID COIL IS TURNED ON BY THE 28 VDC SIGNAL FROM THE JET SELECTION LOGIC, A GROUND IS SUPPLIED TO ONE SIDE OF THE SOLENOID COIL (WHICH HAS 28 VDC APPLIED TO THE OTHER SIDE), CAUSING CURRENT TO FLOW IN IT, THUS OPENING THE SOLENOID VALVE AND TURNING ON THE JET. SINCE IT TAKES APPROXIMATELY 7 MILLI-SECONDS FOR A FUEL VALVE AND 9

MILLI-SECONDS FOR AN OXIDIZER VALVE (AND POSSIBLY UP TO ABOUT 12 MILLI-SECONDS FOR THESE VALVES) TO OPEN, THE CURRENT THROUGH THE COIL SHOULD LAST AT LEAST THIS LONG TO ASSURE FIRING OF THE JET. THIS MEANS, CONSEQUENTLY, THAT A LATCHING CIRCUIT IS NEEDED FOR THE JET DRIVER, BECAUSE THE OUTPUT OF THE JET SELECTION LOGIC IS A SERIES OF PULSES WHOSE DURATION COULD BE LESS THAN 10 MILLI-SECONDS FOR SMALL INPUTS TO THE SWITCHING AMPLIFIER. THIS LATCHING CIRCUIT IS CALLED THE MINIMUM IMPULSE FEEDBACK CIRCUIT AND SHOULD NOT BE CONFUSED WITH THE MANUAL ATTITUDE IMPULSE CONTROL LOCATED IN THE G&N SYSTEM. THE LATCHING CIRCUIT KEEPS THE JET DRIVER ON FOR A MINIMUM OF 18 ± 4 MILLI-SECONDS, THUS ASSURING THAT EACH SINGLE PULSE OUTPUT OF THE SWITCHING AMPLIFIER WILL TURN ON THE APPROPRIATE JETS. FURTHERMORE, THIS LATCHING CIRCUIT IS ALWAYS IN EFFECT, WHETHER IN AN ATTITUDE HOLD CONFIGURATION OR NOT.

4.3.2 ROTATIONAL MANEUVERS

ROTATIONAL MANEUVERS CAN BE COMMANDED BY MEANS OF MANUAL PROPORTION CONTROL, ROTATION OF THE CDU'S IN THE G&N SYSTEM, DIRECT ROTATION, OR ATTITUDE IMPULSE.

4.3.2.1 MANUAL PROPORTIONAL ROTATION

FOR MANUAL PROPORTIONAL ROTATION, THE AC OUTPUT OF THE CONTROL STICK TRANSDUCER, WHICH IS PROPORTIONAL IN MAGNITUDE TO THE MAGNITUDE OF THE STICK DISPLACEMENT, IS DEMODULATED TO A POSITIVE OR NEGATIVE DC VOLTAGE, DEPENDING UPON WHETHER A POSITIVE OR NEGATIVE ROTATION IS COMMANDED. THE SIGNAL THEN PASSES

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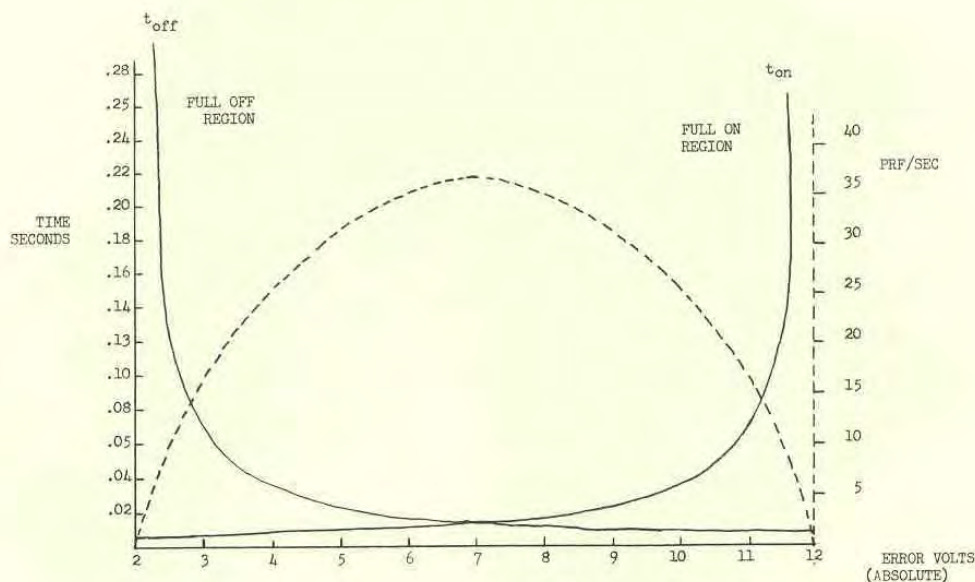


TABLE 4-1

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THROUGH RELAY K10, (WHICH IS CLOSED WHENEVER THE SPS ENGINE IS NOT FIRING) TO A VOLTAGE DIVIDER NETWORK, AFTER WHICH IT IS SUMMED WITH THE RATE SIGNAL. THE VOLTAGE DIVIDER NETWORK CAUSES A VOLTAGE DROP SUCH THAT THE SIGNAL FROM A MAXIMUM STICK DISPLACEMENT IS CANCELLED BY A RATE OUTPUT EQUAL TO ABOUT .65°/SEC. DURING NON-ENTRY MODES, AND 5°/SEC. DURING ENTRY MODES. THE SUM OF THE STICK AND RATE OUTPUTS ARE AMPLIFIED, AND IF GREATER THAN 2 VOLTS AT THE INPUT TO THE SWITCHING AMPLIFIER, TURN IT ON, THUS ACTIVATING THE APPROPRIATE JETS TO CHANGE THE VEHICLE RATE. WHEN THE RATE IS LARGE ENOUGH, THE RATE SIGNAL WILL CANCEL THE CONTROL STICK SIGNAL AND TURN OFF THE JETS, LEAVING THE VEHICLE ROTATING AT THIS RATE. WHEN THE STICK IS MOVED TO ITS NEUTRAL POSITION, THE RATE SIGNAL WILL SLOW THE VEHICLE DOWN WITHIN THE RATE DEADBAND.

4.3.2.2 ROTATION OF THE CDU'S

WHEN THE CDU'S (IN THE G&N SYSTEM) ARE ROTATED, THEY GENERATE SIGNALS PROPORTIONAL TO THE DIFFERENCES BETWEEN THEIR ANGULAR POSITION AND THE ANGULAR POSITIONS OF THE IMU GIMBALS. THESE SIGNALS ARE CONVERTED FROM THE EULER ANGLE REFERENCE TO BODY-AXES COORDINATES AND FED INTO THE SCS WHERE THEY ARE DEMODULATED TO A DC VOLTAGE. IF THE SCS IS IN AN ENTRY MODE, THE SIGNALS ARE CONVERTED FROM AN EULER ANGLE REFERENCE TO THE BODY-OFFSET COORDINATES, AND THEN DEMODULATED. IF THE SCS IS IN A G&N MODE, RELAY K2 THEN ALLOWS THE SIGNAL FOR THE YAW CHANNEL TO BE AMPLIFIED, FED THROUGH THE DEADBAND CIRCUIT AND COMMAND RATE LIMITER, AFTER WHICH IT IS SUMMED WITH THE RATE SIGNAL.

THE COMMAND RATE LIMITER PUTS A MAXIMUM LIMIT ON THE MAGNITUDE OF THE OUTPUT SIGNAL FROM THE DEADBAND CIRCUIT WHICH IS SUMMED WITH THE RATE SIGNAL. FOR NON-ENTRY MODES, THE LIMITING IS SUCH THAT THE MAXIMUM OUTPUT OF THIS CIRCUIT CAN BE CANCELLED BY APPROXIMATELY A .65 DEG/SEC RATE SIGNAL. DURING ENTRY MODES THIS LIMITING IS TO 5 DEG/SEC. THUS, A G&N COMMAND SIGNAL WHICH IS LESS THAN THE MAXIMUM VALUE FOR THE LIMITER WILL COMMAND A PROPORTIONAL VEHICLE RATE IN A SIMILAR FASHION TO MANUAL PROPORTIONAL CONTROL. FOR A G&N COMMAND SIGNAL LARGER THAN THE MAXIMUM OUTPUT OF THE LIMITER CIRCUIT, THE VEHICLE WILL ONLY ACHIEVE THE LIMITING RATES GIVEN ABOVE.

4.3.2.3 DIRECT ROTATION

DIRECT ROTATION CAN BE ACCOMPLISHED ANYTIME THAT THE DIRECT CIRCUIT BREAKERS ARE IN AND THE DIRECT MODE SWITCH ON. BY ROTATING THE ROTATION CONTROL TO WITHIN ABOUT 1 DEGREE OF THE HARD STOP, A SWITCH IS CLOSED APPLYING 28 VDC VIA HARD WIRE CONNECTION TO THE DIRECT COILS OF THE PROPER JET. IN THE ROLL CHANNEL, THERE ARE SOFT STOPS JUST BEFORE THE DIRECT SWITCHES ON THE ROTATION CONTROL. HOWEVER, THE PITCH AND YAW AXES OF THE ROTATION CONTROLS DO NOT HAVE THESE SOFT STOPS.

4.3.2.4 ATTITUDE IMPULSE

THE ATTITUDE IMPULSE CONTROLLER OPERATES IN THREE AXES SIMILAR TO THE ROTATION CONTROL, EXCEPT THAT ITS OUTPUT IS NOT A PROPORTIONAL OUTPUT BUT A PLUS OR

MINUS 40 VDC RESULTING FROM CLOSING A SWITCH IN THE POSITIVE OR NEGATIVE DIRECTION. FURTHERMORE, THIS CLOSING OF THE SWITCH RESULTS IN A SINGLE PULSE TO THE SWITCHING AMPLIFIER DUE TO A PULSE GENERATING CIRCUIT CONSISTING OF A RESISTOR AND TWO CAPACITORS.

IN ORDER FOR ATTITUDE IMPULSE TO BE USED, THE SCS MUST BE IN EITHER THE SCS ATTITUDE CONTROL OR G&N ATTITUDE CONTROL MODES WITH THE ATTITUDE IMPULSE ENABLE SWITCH ON. WHEN THE ATTITUDE IMPULSE ENABLE SWITCH IS ON, RELAY K6 REMOVES THE RATE, ROTATION CONTROL, AND ATTITUDE ERROR INPUTS IN ALL THREE AXES. THERE IS NO ATTITUDE HOLD CAPABILITY WHILE USING ATTITUDE IMPULSE.

4.3.3 TRANSLATIONAL CONTROL

FOR TRANSLATIONAL CONTROL, THE +28 VDC OUTPUT OF THE TRANSLATION CONTROL IS APPLIED DIRECTLY TO THE JET SELECTION LOGIC. THIS SIGNAL ALSO ENERGIZES RELAY K11 TO INHIBIT THE PSEUDO-RATE FEEDBACK.

DIRECT ULLAGE USING THE DELTA V DISPLAY, AND SEPARATION ULLAGE USING THE TRANSLATION CONTROL FOR SIV-B SEPARATION OR ABORT, BOTH APPLY +28 VDC TO THE DIRECT COILS OF THE *X REACTION JETS, USING HARD WIRE CONNECTIONS. ROTATING THE T HANDLE OF THE TRANSLATION CONTROL COUNTERCLOCKWISE (TO COMMAND EITHER AN ABORT OR SIV-B SEPARATION) CLOSES A SWITCH WHICH SENDS A SIGNAL TO THE MASTER EVENT SEQUENCE CONTROLLER. THIS DEVICE (WHICH IS NOT PART OF THE SCS) IN TURN SENDS A 28 VDC SIGNAL TO THE DIRECT COILS OF THE *X REACTION JETS.

4.3.4 RATE DAMPING ONLY

RATE DAMPING ONLY IS ACCOMPLISHED DURING G&N ENTRY (PITCH AND YAW CHANNELS) OR SCS ENTRY (ALL THREE CHANNELS) MODES BY GROUNDING THE ATTITUDE ERROR SIGNAL WITH RELAY K4 WHEN THE .05G SWITCH IS TURNED ON. DURING ANY MODE, ROTATING THE TRANSLATION CONTROL HANDLE CLOCKWISE WILL GENERATE A CSS LOGIC SIGNAL WHICH ALSO GROUND THE ATTITUDE ERROR SIGNAL BY MEANS OF RELAY K4, THUS GIVING RATE DAMPING ONLY. RATE DAMPING ONLY IS ACCOMPLISHED DURING MONITOR MODE BY INHIBITING THE ATTITUDE ERROR SIGNAL, FROM EITHER THE SCS BMAG OR THE G&N SYSTEM, BY MEANS OF RELAYS K2 AND K3. THE RATE SIGNAL CAN COME EITHER FROM THE RATE GYRO OR, IF IN BACKUP RATE, FROM THE CAGED BMAG. AFTER THE .05G SWITCH IS TURNED ON, THE ROLL TO YAW COUPLING CIRCUIT IS USED, BECAUSE AFTER .05G THE S/C WILL EXPERIENCE ROLL MANEUVERS AROUND THE STABILITY ROLL AXIS RATHER THAN THE BODY ROLL AXIS. CONSEQUENTLY, THE BODY AXIS ORIENTED YAW RATE GYRO WILL SENSE A COMPONENT OF THIS ROLL ACTION. THE OUTPUT OF THE YAW RATE GYRO WOULD FIRE YAW JETS IN RESPONSE TO THE SENSED RATE. THUS, BY COUPLING AN OUT-OF-PHASE COMPONENT OF THE BODY ROLL RATE (TANGENT 22°) INTO THE YAW CHANNEL, THE SENSED BODY YAW COMPONENT OF THE STABILITY ROLL MANEUVER IS NULLIFIED TO PREVENT UNDESIRABLE YAW JET FIRING.

4.3.5 RCS ENABLING FUNCTIONS

IT CAN BE SEEN IN FIGURE 4-3 THAT THE JET DRIVERS AND SOLENOID COILS HAVE 28 VDC ENABLING POWER

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INPUTS. THESE INPUTS DO NOT TURN THE JETS ON, BUT ARE NECESSARY FOR ENABLING THE JETS TO BE TURNED ON BY A COMMAND SIGNAL. THE AVAILABILITY OF THE VARIOUS ATTITUDE CONTROL SUBSYSTEM CAPABILITIES (SUCH AS MANUAL PROPORTIONAL ROTATION, ATTITUDE HOLD, ETC.) DURING THE DIFFERENT MODES HAS PREVIOUSLY BEEN MENTIONED. NEVERTHELESS, ALTHOUGH A PARTICULAR CAPABILITY MAY BE PRESENT DURING A GIVEN MODE, ITS AVAILABILITY IS ALSO DEPENDENT UPON WHETHER THE JET DRIVERS AND SOLENOID COILS ARE ENABLED. THE JETS CAN BE DISABLED BY DISABLING EITHER THE COILS THEMSELVES, THE JET DRIVERS, OR BOTH.

CONSIDERING JUST THE COILS, THE MN A CIRCUIT BREAKER FOR THE YAW AXIS MUST BE IN AND THE YAW CHANNEL ENABLE SWITCH ON FOR THE NUMBER 7 AND 8 JETS TO BE ENABLED. THE MN B CIRCUIT BREAKER ENABLES THE NUMBER 5 AND 6 JETS. ACTUALLY, THESE NUMBERS APPLY TO THE SERVICE MODULE ONLY. ON THE COMMAND MODULE, THE MN A CIRCUIT BREAKER ENABLES JETS 5 AND 8, WHEREAS THE MN B CIRCUIT BREAKER ENABLES JETS 6 AND 7. IN THE PITCH AXIS, THERE IS NO DIFFERENCE IN THE NUMBERING FOR THE C/M AND S/M JETS.

CONSIDERING THE JET DRIVERS, THERE ARE SOME RELAYS AND A SWITCH CONTROLLING THE ENABLING OF THE YAW JET DRIVERS. THESE ARE THE RCS LATCHING RELAYS, THE CHANNEL ENABLE SWITCH, AND RELAY K7.

4.3.5.1 RCS LATCHING RELAYS

THE RCS LATCHING RELAYS, WITHIN THE MASTER EVENT SEQUENCE CONTROLLER, MUST BE CLOSED IF THE JETS

ARE TO BE ENABLED. UP UNTIL 42 SECONDS AFTER LAUNCH, THE RCS LATCHING RELAYS CANNOT BE CLOSED. AFTER THIS TIME, THEY CAN BE ACTIVATED IN SEVERAL WAYS.

IF AN ABORT IS COMMANDED PRIOR TO LES JETTISON, THESE RELAYS ARE CLOSED 1 SECOND AFTER COMMANDING THE ABORT. THEY ARE DISABLED 13 SECONDS LATER IF, AT THAT TIME, THE COMMAND MODULE IS AT AN ALTITUDE LESS THAN APPROXIMATELY 24,000 FEET. HOWEVER, IF AT THAT TIME THE COMMAND MODULE IS HIGHER THAN APPROXIMATELY 24,000 FEET, THE RELAYS STAY ENABLED UNTIL THE VEHICLE DESCENDS BELOW 24,000 FEET, AT WHICH TIME THEY ARE DISABLED. ABORT PRIOR TO LES JETTISON CAN BE COMMANDED AUTOMATICALLY BY THE EMERGENCY DETECTION SYSTEM (EDS) OR MANUALLY BY TWISTING THE TRANSLATION CONTROL HANDLE COUNTERCLOCKWISE.

AFTER LES JETTISON, A COUNTERCLOCKWISE TWIST OF THE TRANSLATION CONTROL HANDLE WILL COMMAND SIVB SEPARATION. FOLLOWING A 2.5 SECOND DELAY, THIS COUNTERCLOCKWISE TWIST WILL ALSO-ENABLE THE RCS LATCHING RELAYS. IN THE ABOVE CASES, AS WELL AS THE LES ABORT, THE OX DUMP-RCS CMD (REF. FIGURE 2-12) SWITCH MUST BE IN THE RCS CMD POSITION IN ORDER THAT THE RCS LATCHING RELAYS BE CLOSED EITHER BY THE EDS OR TRANSLATION CONTROL COUNTERCLOCKWISE SWITCH SIGNALS.

PROVIDING THAT 42 SECONDS HAVE ELAPSED FOLLOWING LAUNCH, THE RCS LATCHING RELAYS CAN BE CLOSED IMMEDIATELY AT ANY TIME BY MOMENTARILY PLACING THE RCS CMD SWITCH (DIRECTLY BELOW THE OX DUMP-RCS CMD SWITCH) TO THE ON POSITION. FURTHERMORE, THEY CAN BE DISABLED AT ANY TIME BY PLACING THIS SWITCH IN THE OFF POSITION.

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FINALLY, DURING RE-ENTRY FROM EITHER A SM ABORT OR NORMAL MISSION, THE RCS LATCHING RELAYS ARE OPENED, DISABLING THE JET DRIVERS, AT ABOUT THE 24,000 FOOT ALTITUDE.

4.3.5.1 CHANNEL ENABLE SWITCH AND RELAY K7

IN ORDER THAT THE YAW JET DRIVERS BE ENABLED, THE YAW CHANNEL SWITCH MUST BE ON AND RELAY K7 CLOSED. RELAY K7 IS OPEN, DISABLING THE YAW JETS DURING SPS ENGINE FIRING (ACTUALLY THE DISABLING OCCURS APPROXIMATELY 1 SECOND AFTER ENGINE IGNITION, AND LASTS UNTIL ABOUT 1 SECOND AFTER THE ENGINE OFF SIGNAL IS GIVEN.), DIRECT ULLAGE (OR SEPARATION ULLAGE), OR DIRECT YAW ROTATION.

4.3.6 ROLL CHANNEL SIGNAL FLOW

SINCE THE ROLL SIGNAL FLOW (FIGURE 4-4) IS BASICALLY THE SAME AS THE PREVIOUSLY DESCRIBED PITCH AND YAW CHANNEL, ONLY THE IMPORTANT DIFFERENCES WILL BE LISTED. THEY ARE:

- MAXIMUM MANUAL PROPORTIONAL OR AUTOMATIC ROLL RATE COMMAND IS APPROXIMATELY $.65^{\circ}/\text{SEC}$. FOR NON-ENTRY MODES AND $17^{\circ}/\text{SEC}$ FOR ENTRY MODES.
- THE OUTPUT OF THE ROLL COMMAND LIMITER IS NOT GROUNDED AT $.05G$ UNLESS IN THE SCS ENTRY MODE. IN G&N ENTRY MODE, ROLL ATTITUDE CAN BE AUTOMATICALLY CONTROLLED

FROM THE G&N SYSTEM BY HAVING THE AGC AUTOMATICALLY ROTATE THE CDU'S GENERATING A ROLL RATE COMMAND.

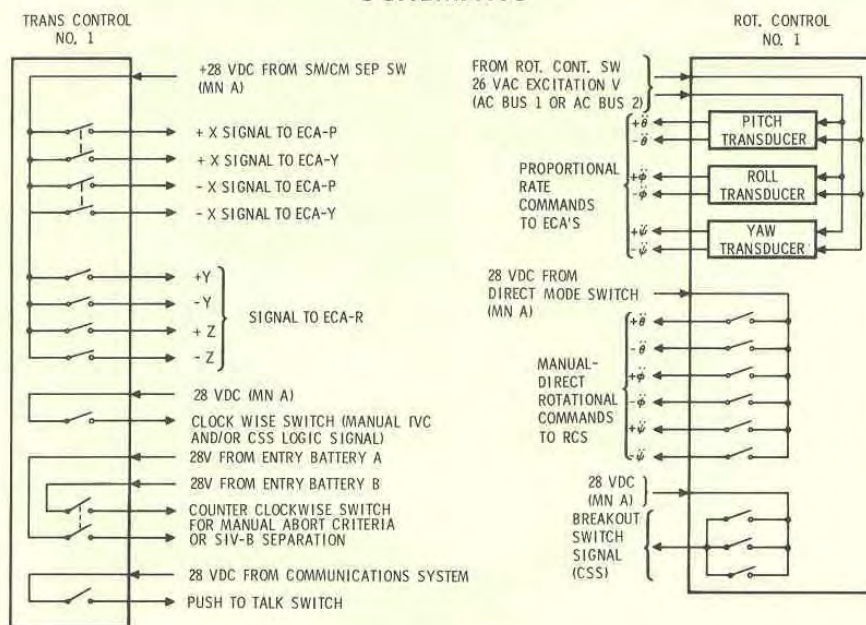
- THE OUTPUT OF THE ROTATION CONTROL IS NOT REMOVED IN THE ROLL CHANNEL DURING SPS ENGINE FIRING.
- THE RCS IS NOT DISABLED IN THE ROLL CHANNEL DURING DIRECT ULLAGE OR SPS ENGINE FIRING.
- FOR ATTITUDE IMPULSE CONTROL IN THE ROLL CHANNEL, EITHER THE A&C OR B&D CHANNEL SHOULD BE DISABLED WITH THE PROPER CHANNEL ENABLE SWITCH. IF THIS WERE NOT DONE, FOUR JETS INSTEAD OF TWO WOULD FIRE FOR A GIVEN ROLL ATTITUDE IMPULSE COMMAND, THUS DECREASING THE ABILITY FOR COMMANDING A SMALL ROTATIONAL ACCELERATION ABOUT THE ROLL AXIS.

4.3.7 TRANSLATION AND ROTATION CONTROL OUTPUTS

FIGURE 4-5 SHOWS THE OUTPUTS OF THE NUMBER 1 ROTATION AND TRANSLATION CONTROLS. THE TRANSDUCERS ON THE ROTATION CONTROL WHICH ARE USED FOR PROPORTIONAL RATE CONTROL RECEIVE AC BUS 1 OR 2 POWER DEPENDING UPON THE POSITION OF THE ROTATION CONTROL SWITCH. THE DIRECT SWITCHES AND THE CSS BREAKOUT SWITCHES ON ROTATION CONTROL NUMBER 1 RECEIVE DC BUS A POWER, WHEREAS ROTATION CONTROL NUMBER 2 RECEIVES DC BUS B POWER. THE DIRECT SWITCHES ARE USED FOR DIRECT ROTATION CONTROL IN ALL THREE BODY AXES OF THE VEHICLE. THE CSS BREAKOUT SIGNAL IS USED FOR CAGING THE BMAG'S, REMOVING

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TRANSLATION & ROTATION CONTROLS SCHEMATIC



SCS-608B

FIGURE 4-5

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FUNCTION IS LABELED, ATTITUDE ERROR SIGNALS. THIS IS THE G&N ATTITUDE ERROR SIGNAL PROCESSED BY THE SCS ELECTRONICS TO CONTROL ATTITUDE DURING G&N MODES. IN A G&N ATTITUDE HOLD CONDITION, THIS OUTPUT SIGNAL REPRESENTS THE DIFFERENCE ANGLE (ATTITUDE ERROR) BETWEEN THE IMU GIMBAL ANGLE AND THE CDU SHAFT ANGLE. WHEN THESE ANGLES ARE EQUAL, A ZERO ATTITUDE ERROR CONDITION EXISTS. WHILE IN AN ATTITUDE HOLD CONDITION, THE SPACECRAFT ROTATES ABOUT THE STABLE PLATFORM (WHICH MAINTAINS A CONSTANT INERTIAL ORIENTATION) CAUSING THE IMU GIMBAL ANGLES TO CHANGE. SINCE THE CDU SHAFT ANGLES REMAIN STATIONARY, AN ERROR SIGNAL IS GENERATED WHICH, WHEN IT EXCEEDS THE SELECTED ATTITUDE DEADBAND, WILL CAUSE THE SCS TO FIRE THE APPROPRIATE REACTION JETS TO ROTATE THE SPACECRAFT AND REDUCE THIS ERROR BELOW THE DEADBAND LIMITS. DURING CSS, WITHOUT A SYNCHRONIZING FUNCTION, AN ATTITUDE ERROR WOULD BE GENERATED AS THE SPACECRAFT WERE MANEUVERED. REACTION JETS WOULD NOT FIRE AS THIS ERROR WERE BUILT UP BECAUSE THE ATTITUDE ERROR SIGNALS ARE INHIBITED IN THE SCS DURING THE CSS MANEUVER. WHEN THE CSS COMMAND IS REMOVED AT THE END OF THE MANEUVER, THE ATTITUDE ERROR WOULD BE PRESENT AND THE SCS WOULD THEN FIRE JETS AS LONG AS THE ATTITUDE ERROR IS GREATER THAN THE SELECTED DEADBAND. ONLY WHEN THE SPACECRAFT IS AGAIN RETURNED TO AN ATTITUDE MATCHING THE INITIAL CDU-IMU CONDITION WOULD THE ERROR SIGNALS BE ELIMINATED.

THE SYNC FUNCTION IS NECESSARY TO PREVENT THE S/C FROM ROTATING BACK TO THE INITIAL ATTITUDE AT THE END OF A CSS MANEUVER WHILE IN G&N ATTITUDE CONTROL MODE. THIS ACTION NORMALLY WOULD OCCUR BECAUSE OF THE ATTITUDE ERROR GENERATED AS THE SPACECRAFT IS MANEUVERED ABOUT THE G&N STABLE PLATFORM (IMU). DURING THE MANEUVER THE FOLLOW-UP ACTION OF THE SYNC FUNCTION HOWEVER, WILL KEEP THIS ATTITUDE ERROR SIGNAL AT ZERO. THE S/C WILL, UPON REMOVAL OF THE CSS FUNCTION, HOLD THE NEW ATTITUDE WITHIN THE LIMITS OF THE SELECTED DEADBANDS.

IN FIGURE 4-6, RELAYS K-1 AND K-4 CONTROL THE SIGNAL FLOW PATHS DURING THE G&N SYNC OPERATION. K-1 IS ENERGIZED BY FULFILLING THE TWO INPUT REQUIREMENTS TO ITS ASSOCIATED AND GATE. THESE TWO CONDITIONS ARE: THE G&N ATT CONT MODE MUST BE SELECTED; AND A

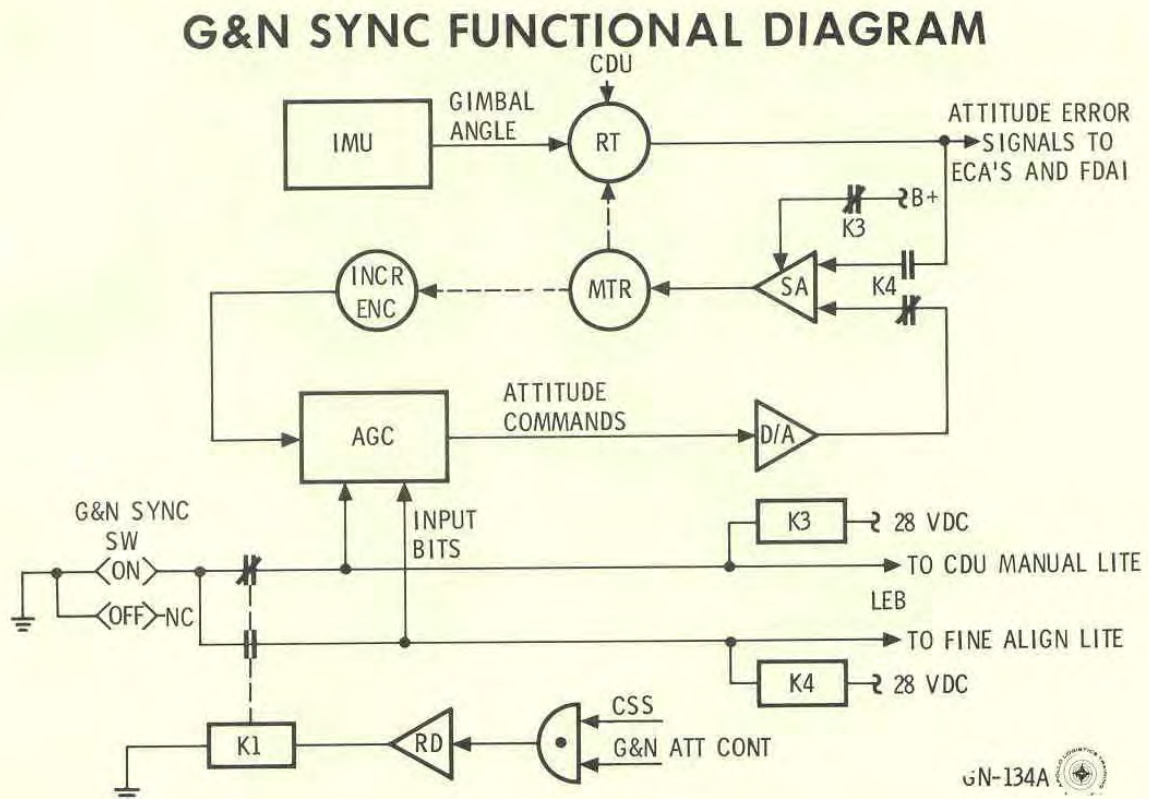


FIGURE 4-6

CSS SIGNAL INITIATED (CSS BREAKOUT SWITCHES CLOSED OR TRANSLATION CONTROL HANDLE ROTATED CLOCKWISE). THEN IF THE G&N SYNC SWITCH IS IN THE ON POSITION, A GROUND IS PROVIDED THROUGH THE ENERGIZED CONTACTS OF K-1 TO ENERGIZE K-4. WITH K-4 ENERGIZED, ANY OUTPUT ERROR SIGNAL PRESENT FROM THE CDU RESOLVERS IS APPLIED TO THE SERVO AMPLIFIER TO DRIVE THE CDU MOTOR AND NULL THE ERROR. THUS, AS AN ERROR IS GENERATED BETWEEN THE IMU GIMBAL ANGLES AND THE CDU SHAFT POSITIONS DURING THE MANEUVER, THIS SAME ERROR WILL DRIVE THE CDU TO KEEP THE ATTITUDE SIGNAL AT ZERO.

WHEN THE CSS SIGNAL IS REMOVED, K-1 IS DE-ENERGIZED OPENING THE CIRCUIT TO DE-ENERGIZE K-4. THE CDU IS CONSEQUENTLY ELECTRICALLY LOCKED (WITH A ZERO ATTITUDE ERROR SIGNAL) AT THE TIME OF CSS REMOVAL. UNDER THESE CONDITIONS, ANY VEHICLE ATTITUDE CHANGE (DRIFT) WOULD AGAIN GENERATE AN ATTITUDE ERROR SIGNAL FROM THE CDU'S TO HOLD THE S/C WITHIN THE SELECTED DEADBANDS AT THE NEW ATTITUDE. THE G&N SYNC FUNCTION IS ONLY POSSIBLE IN THE G&N ATTITUDE CONTROL MODE. CONSEQUENTLY, A CSS MANEUVER IN ANY OTHER G&N MODE WILL RESULT IN THE S/C RETURNING TO THE INITIAL ATTITUDE UPON TERMINATION OF THE CSS SIGNAL.

4.3.9 JET DRIVER CONTROL LOOP

NOW THAT THE CAPABILITIES OF THE ATTITUDE CONTROL SUBSYSTEM HAVE BEEN DESCRIBED, TOGETHER WITH THE MANNER IN WHICH THESE CAPABILITIES ARE MECHANIZED, A MORE DETAILED DESCRIPTION OF THE JET SELECTION LOGIC

AND ITS OUTPUTS TO THE RCS WILL BE GIVEN. THE MECHANIZATION OF THE RCS ENABLING CIRCUITRY WILL ALSO BE SHOWN.

THE SCS JET DRIVER CONTROL LOOP, AS SHOWN IN FIGURE 4-7, CONSISTS OF THE SWITCHING AMPLIFIERS, REACTION JET DRIVERS, LOGIC NETWORKS, CHANNEL ENABLE SWITCHES, C/M - S/M SEPARATION SWITCHES, AND THE AUTOMATIC COILS OF C/M AND S/M RCS SOLENOID VALVES. THE CONTROL LOOP ACCEPTS SIGNALS FROM THE ROTATION CONTROLS, RATE GYROS, BMAG'S, CDU'S (IN THE G&N SYSTEM), AND ATTITUDE IMPULSE CONTROL (THROUGH THE THREE SWITCHING AMPLIFIERS), TOGETHER WITH SIGNALS FROM THE TRANSLATION CONTROLS AS INPUTS TO THE JET SELECTION LOGIC. THE OUTPUTS OF THE CONTROL LOOP ARE CONTROL SIGNALS TO THE AUTOMATIC COILS OF THE PROPER REACTION JET FUEL AND OXIDIZER SOLENOIDS. THE JET DRIVER CONTROL LOOP IS THE NORMAL MEANS OF EXERCISING CONTROL OVER THE SPACECRAFT'S ATTITUDE, RATE OF ROTATION, AND SMALL TRANSLATIONAL MANEUVERS.

THE OUTPUT OF THE SWITCHING AMPLIFIERS IS EITHER A PULSED OR STEADY 20 VDC SIGNAL ON ONE OF TWO LINES; ONE FOR POSITIVE AND THE OTHER FOR NEGATIVE ROTATIONAL COMMANDS. EACH OF THE TWO OUTPUT LINES OF THE SWITCHING AMPLIFIERS IS SPLIT, ONE BRANCH GOING THROUGH AN INVERTER TO GIVE A "NOT ROTATION" LOGIC SIGNAL. THE ROTATION COMMAND OUTPUTS OF THE SWITCHING AMPLIFIERS ARE THEN FED INTO THE SOLID STATE JET SELECTION LOGIC ALONG WITH THE OUTPUTS OF THE TRANSLATION CONTROLS. AFTER C/M - S/M SEPARATION, HOWEVER,

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JET DRIVER CONTROL LOOP

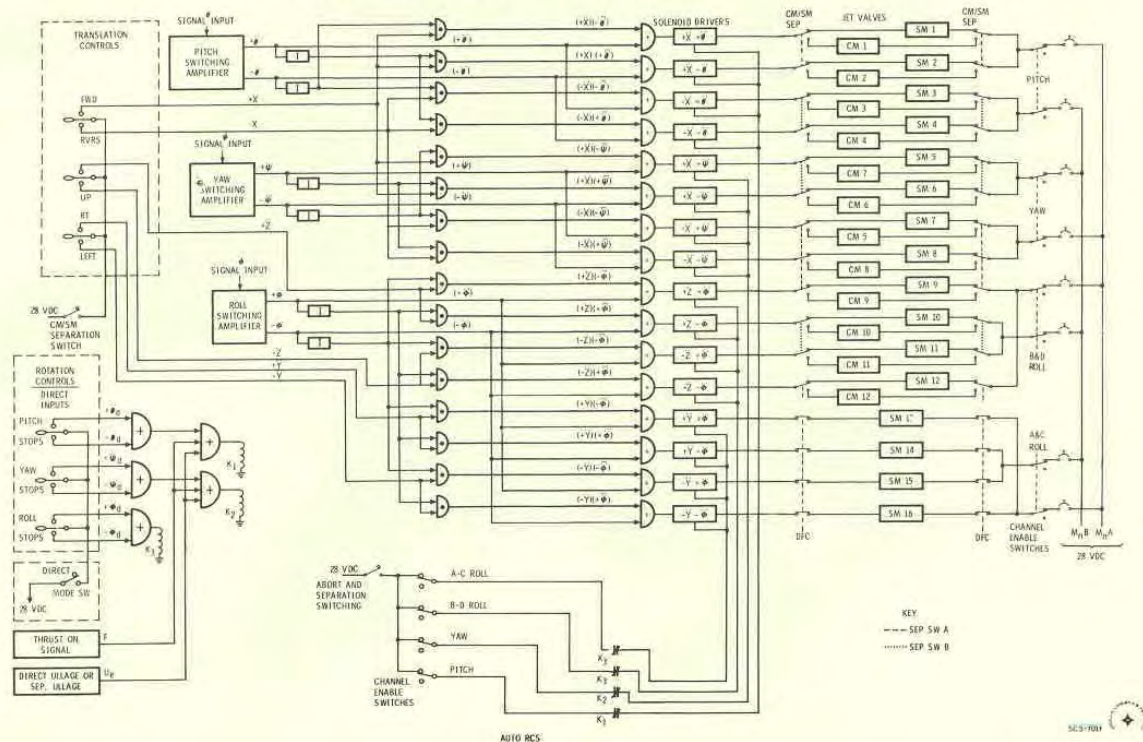


FIGURE 4-7

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THERE CAN NO LONGER BE ANY INPUT SIGNALS TO THE JET SELECTION LOGIC FROM THE TRANSLATION CONTROLS, SINCE THE DC POWER IS REMOVED FROM THE TRANSLATION CONTROLS AT SEPARATION. PRIOR TO SEPARATION, THEREFORE, THE TRANSLATION AND ROTATION COMMANDS ARE APPLIED TO AND GATES AND OR GATES (WITHIN THE JET SELECTION LOGIC) AS NECESSARY TO ENERGIZE THE APPROPRIATE REACTION JET DRIVERS.

SINCE THE TRANSLATION COMMANDS AND THE ROTATION COMMANDS MAY BE APPLIED SIMULTANEOUSLY, IT IS NECESSARY TO ESTABLISH A PRIORITY SYSTEM. TABLE 4-2 PROVIDES THE BASIS FOR THE PRIORITY SYSTEM FOR TWO SIMULTANEOUS COMMANDS ACCORDING TO THE REACTION JET NUMBERING SYSTEM SHOWN IN FIGURE 4-8 FOR THE C/M-S/M. NOTICE THAT FOR TRANSLATION MANEUVERS IN THE Y AND Z DIRECTION, TWO JETS PER AXIS ARE USED. IN THE X DIRECTION, FOUR JETS ARE USED TO PROVIDE ADDITIONAL THRUST FOR ULLAGE. THE JET SELECTION LOGIC PROVIDES A MEANS FOR MAINTAINING ATTITUDE CONTROL DURING TRANSLATION WITHOUT ALLOWING TWO OPPOSING JETS TO BE FIRED. ROTATION MANEUVERS IN YAW AND PITCH REQUIRE TWO JETS TO BE FIRED. ROTATION MANEUVERS IN THE ROLL AXIS REQUIRE EITHER TWO OR FOUR JETS TO BE FIRED DEPENDING UPON WHETHER ALL FOUR OR ONLY TWO S/M CLUSTERS ARE OPERATIVE (A&C OR B&D). THE SELECTION OF THE OPERATIVE CLUSTER PAIRS IS ACCOMPLISHED BY THE CHANNEL ENABLE SWITCHES ON THE CONTROL PANEL, AS SHOWN IN FIGURE 4-4. AFTER THE C/M IS SEPARATED FROM THE S/M, THE SWITCH CONTROLLING A&C HAS NO FUNCTION AND ONLY THE B&D ROLL SWITCH CAN DISABLE THE C/M ROLL JETS.

THE ENABLING FUNCTIONS FOR THE JET DRIVERS ARE INDICATED IN FIGURE 4-7. ALL REACTION JET DRIVER AMPLIFIERS ARE NORMALLY DISABLED BY THE RCS LATCHING RELAYS UNTIL SIV-B SEPARATION, AT WHICH TIME THESE RELAYS ARE CLOSED. THEY ARE OPENED AGAIN DURING RE-ENTRY UPON REACHING THE 24,000 FOOT ALTITUDE. THEY CAN ALSO BE CLOSED DURING LAUNCH IF AN ABORT OCCURS, AS WAS DESCRIBED PREVIOUSLY. THE RCS CMD SWITCH (LOCATED DIRECTLY BELOW THE OX DUMP SWITCH) ON THE CREW SAFETY CONTROL PANEL PROVIDES MANUAL BACKUP CAPABILITY FOR THIS SWITCHING, IF NECESSARY.

DURING THRUSTING OF THE SPS ENGINE, RELAYS K-1 AND K-2 ARE ENERGIZED TO REMOVE POWER FROM THE JET SELECTION LOGIC DRIVER AMPLIFIERS IN THE YAW AND PITCH AXES SINCE CONTROL OF THE SPACECRAFT'S ATTITUDE IS ACCOMPLISHED WITH THE GIMBALED ENGINE. AS HAS BEEN MENTIONED PREVIOUSLY, THESE RELAYS ARE ENERGIZED ABOUT 1 SECOND AFTER ENGINE IGNITION AND DE-ENERGIZED ABOUT 1 SECOND AFTER THE ENGINE OFF SIGNAL IS GIVEN. HOWEVER, ROLL JETS WILL REMAIN OPERABLE THROUGHOUT THE THRUST PERIOD.

RELAYS K-1 AND K-2 ARE ALSO ENERGIZED WITH A DIRECT (OR SEPARATION) ULLAGE SIGNAL (UE) TO DISABLE THE AUTOMATIC PITCH AND YAW RCS. SINCE THE DIRECT ULLAGE COMMAND IS NOT PROCESSED THROUGH THE AUTOMATIC RCS JET SELECTION LOGIC, OPPOSING JETS COULD BE FIRED BY THE AUTOMATIC RCS IF THAT SYSTEM WERE NOT DISABLED.

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JET SELECTION LOGIC

	+X	-X	+Y	-Y	+Z	-Z	+θ	-θ	+ψ	-ψ	+φ	-φ
+X	1 2 3 4		1 2 5 6	1 2 13 14	1 2 3 4	1 2 5 6	1 2 3 4	1 2 5 6	1 2 3 4	1 2 5 6	1 2 3 4	1 2 5 6
-X		2 4 3 6	3 4 7 8	3 4 15 16	3 4 5 6	3 4 7 8	3 4 5 6	3 4 7 8	3 4 5 6	3 4 7 8	3 4 5 6	3 4 7 8
+Y			12 14		9 10 13 14	9 10 13 14	9 10 13 14	9 10 13 14	9 10 13 14	9 10 13 14	9 10 13 14	9 10 13 14
-Y				13 14	9 10 15 16	9 10 15 16	9 10 15 16	9 10 15 16	9 10 15 16	9 10 15 16	9 10 15 16	9 10 15 16
+Z					8 10		1 2 9 10	1 2 9 10	1 2 9 10	1 2 9 10	1 2 9 10	1 2 9 10
-Z						11 12	1 2 11 12	1 2 11 12	1 2 11 12	1 2 11 12	1 2 11 12	1 2 11 12
+θ							1 3		1 3	1 3	1 3	1 3
-θ								2 4		2 4	2 4	2 4
+ψ									5 7		5 7	5 7
-ψ										6 8		6 8
+φ											9 11	
-φ												10 12

CM SM
 # PITCH = 1-4 1-4
 # YAW = 5-8 5-8
 # ROLL = 9-12 9-16

ROLL CLUSTERS:
 JETS 9-12 B & D
 13-16 A&C

ULLAGE (+X) JETS: 1, 2, 5, 6

+X TRANS UTILIZES P&Y JETS
 +Y, +Z TRANS UTILIZES ROLL JETS

— ROTATION PRIORITY LOGIC

SCS-800

TABLE 4-2

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ENGINE LOCATION

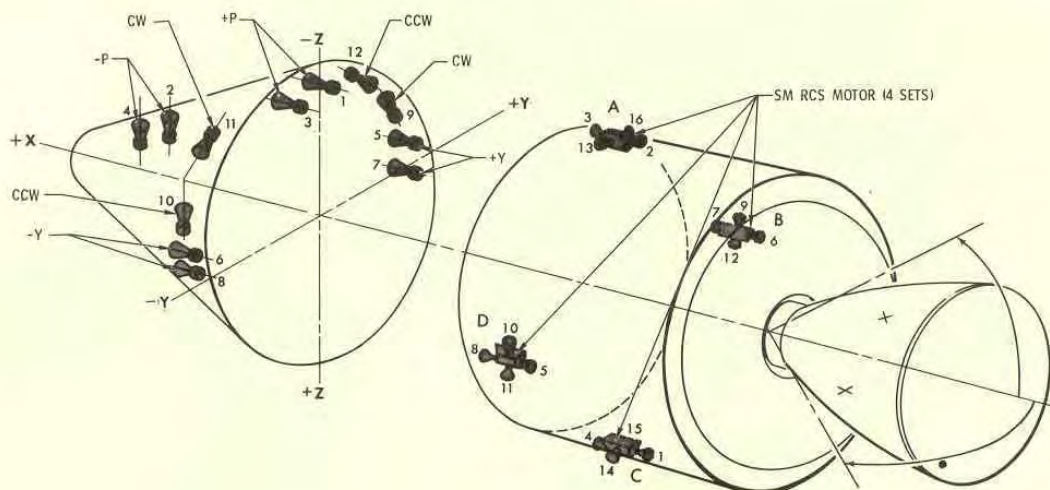


FIGURE 4-8

P-13A
P-13A-1 4-27

IF THE DIRECT REACTION CONTROL SWITCHES ON THE ROTATION CONTROL ARE ACTUATED, RELAYS K-1, K-2, OR K-3 (OR ALL THREE) MAY BE ENERGIZED, AND THE POWER TO THE APPROPRIATE JET DRIVER AMPLIFIERS IS REMOVED BY AXIS, PROVIDED THAT THE DIRECT MODE SWITCH HAS BEEN PLACED IN THE ON POSITION.

AT C/M-S/M SEPARATION, CONTROL OF THE SPACECRAFT IS TRANSFERRED TO THE C/M REACTION JETS BY APPLYING 28 VOLTS DC AND JET SELECTION COMMANDS TO THE C/M JET SOLENOIDS RATHER THAN THE S/M JET SOLENOIDS. THIS TRANSFER IS ACCOMPLISHED BY SEP SW A AND SEP SW B. ROLL JETS 13, 14, 15, AND 16 ARE DEADFACED SINCE THESE ROLL JETS ARE NOT PRESENT ON THE C/M. A DETAILED DISCUSSION OF THE SEPARATION SWITCHES (A AND B) IS DEVELOPED UNDER CONTROL LOOP HEADING.

4.3.10 DIRECT CONTROL LOOP

A GENERAL DESCRIPTION OF THE DIRECT REACTION JET CONTROL HAS ALREADY BEEN GIVEN. A MORE DETAILED DESCRIPTION OF ITS MECHANIZATION WILL NOW BE GIVEN, TOGETHER WITH A DESCRIPTION OF THE C/M-S/M SEPARATION SWITCHING FUNCTIONS AND THE FUEL DUMP AND BURN FUNCTION.

THE DIRECT CONTROL LOOP (FIGURE 4-9) PROVIDES MANUAL DIRECT ROTATIONAL CONTROL BY USING THE DIRECT FUEL AND OXIDIZER SOLENOIDS OF THE C/M AND S/M REACTION JETS. THE DIRECT CONTROL LOOP ALSO PROVIDES THE CAPABILITY TO PERFORM A DIRECT ULLAGE MANEUVER BY USING THE X AXIS DIRECT SOLENOIDS OF THE S/M REACTION JETS. NO

BACKUP TRANSLATION MANEUVER IS PROVIDED THROUGH THE DIRECT CONTROL LOOP EXCEPT IN THE +X AXIS AS NOTED ABOVE.

AFTER ARMING THE DIRECT ROTATION CAPABILITY USING THE DIRECT MODE SWITCH, ANGULAR ACCELERATION COMMANDS MAY BE APPLIED TO THE SPACECRAFT. SINCE THE COMMANDS ARE DIRECT TO THE REACTION JETS WITH NO RATE FEEDBACK AS IN MANUAL PROPORTIONAL ROTATION, THE SPACECRAFT ACCELERATES AS LONG AS THE DIRECT SWITCHES IN THE ROTATION CONTROL ARE CLOSED. AFTER THE CONTROL IS RELEASED AND IT RETURNS TO NEUTRAL, THE SPACECRAFT WILL CONTINUE TO ROTATE UNTIL AN OPPOSITE RATE COMMAND IS APPLIED BY THE ASTRONAUTS. IF THE JET DRIVER CONTROL LOOP WERE ALSO OPERATIVE, THE RATE GYRO WOULD CAUSE THE APPROPRIATE REACTION JETS TO FIRE UNTIL ROTATIONAL RATES WERE WITHIN THE DEADBAND.

DIRECT ULLAGE IS INITIATED BY THE DIRECT ULLAGE PUSHBUTTON ON THE DELTA V DISPLAY. THIS SWITCH BY-PASSES THE ROTATION CONTROL SWITCHES AND APPLIES 28 VOLTS DC DIRECTLY TO THE S/M +X DIRECT SOLENOID COILS. PRESENT SEPARATION SWITCHING ALLOWS THE DIRECT ULLAGE COMMANDS TO BE APPLIED TO C/M JETS 1, 2, 6, AND 7 IF THE DIRECT ULLAGE PUSHBUTTON IS PRESSED AFTER SEPARATION FROM THE S/M. SINCE NO ULLAGE MANEUVER IS POSSIBLE OR NECESSARY AFTER C/M-S/M SEPARATION, THIS CAPABILITY SHOULD CREATE NO APPARENT PROBLEM. SEPARATION ULLAGE CAN BE COMMANDED BY A COUNTERCLOCKWISE ROTATION OF THE TRANSLATION CONTROL HANDLE COMMANDING EITHER SIV-B SEPARATION FOR A SERVICE MODULE ABORT

DIRECT CONTROL LOOP

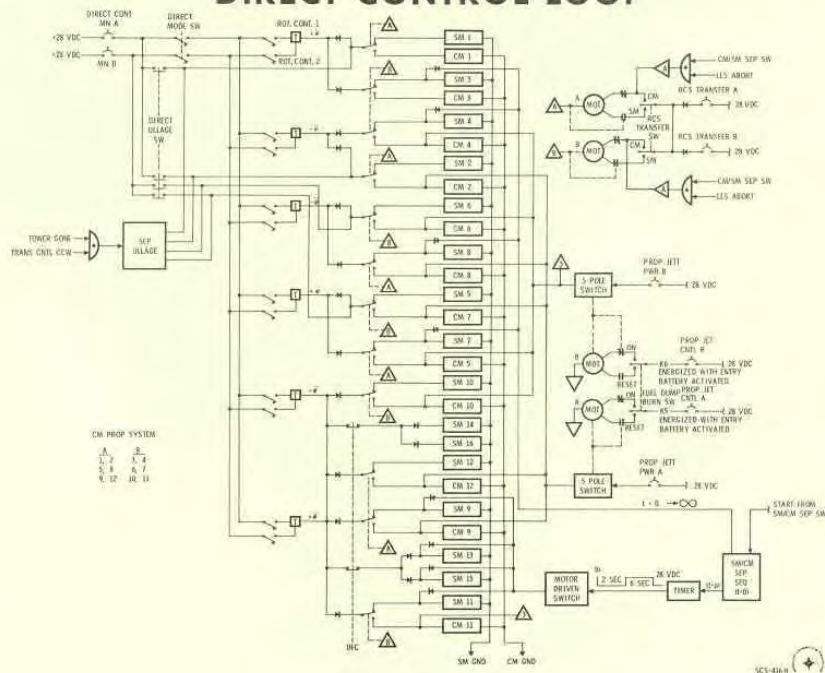


FIGURE 4-9

4-29

(AFTER THE LES TOWER HAS BEEN JETTISONED), OR S-IVB SEPARATION FOLLOWING ORBIT ACQUISITION. THIS ULLAGE IS SEMI-AUTOMATIC IN THAT IT WOULD LAST 2.5 SECONDS IF THE CONTROL HANDLE WERE TWISTED TO THE CCW POSITION AND THEN RETURNED TO THE NEUTRAL POSITION. IF THE CONTROL WERE KEPT ROTATED TO THE CCW POSITION FOR MORE THAN 2.5 SECONDS, THE ULLAGE WOULD LAST UNTIL THE CONTROL IS RETURNED TO NEUTRAL OR UNTIL 12 SECONDS PASSED.

SEPARATION SWITCHING FROM THE S/M TO C/M JETS IS ACCOMPLISHED BY TWO INDEPENDENT MOTOR DRIVEN SWITCHES (A AND B). EACH MOTOR IS DRIVEN BY COMMANDS FROM THE MISSION SEQUENCER OR FROM THE C/M-S/M SEP SWITCH. IF ABORT CRITERIA REQUIRES C/M-S/M SEPARATION, THIS COMMAND WILL CAUSE THE PROPER SEPARATION SEQUENCE TO OCCUR. IF THE C/M IS TO BE SEPARATED FROM THE S/M JUST BEFORE ENTRY DURING A NORMAL MISSION, THE MOTOR DRIVE SIGNAL IS GENERATED BY ACTIVATING THE C/M-S/M SEP SWITCH. A MANUAL BACK-UP CAPABILITY TO BOTH SEPARATION COMMANDS IS PROVIDED BY THE RCS TRANSFER SWITCH. SEPARATION SWITCHING MOTORS A AND B TRANSFER THOSE JETS WHOSE NUMBERS MATCH THE A AND B PROPELLANT SYSTEMS OF THE C/M. THUS, IF ONE MOTOR FAILS TO OPERATE, THE SWITCHING ACTION OF THE SECOND MOTOR WILL ENABLE THE CORRESPONDING PITCH, YAW, AND ROLL JETS. THEREFORE, EVEN THOUGH ONLY HALF OF THE AVAILABLE C/M RCS HAS BEEN TRANSFERRED, AT LEAST ONE POSITIVE AND ONE NEGATIVE PITCH, YAW, AND ROLL JET IS INCLUDED IN THE AVAILABLE GROUP. SIMULTANEOUS SEPARATION SWITCHING OF THE AUTOMATIC COILS OF THE RCS IS ALSO ACCOMPLISHED BY THESE MOTORS WHICH ACTUATE SEP SW A AND SEP SW B IN FIGURE 4-7.

COINCIDENT WITH THE C/M-S/M SEPARATION ASSOCIATED WITH MOTORS A AND B ON THE C/M, IS THE C/M-S/M SEPARATION SIGNAL APPLIED TO THE SEPARATION SEQUENCER UNIT IN THE S/M. UPON RECEIPT OF THE C/M-S/M SEPARATION SIGNAL ($T=0$), THE SEQUENCER APPLIES A CONTINUOUS FIRE SIGNAL TO S/M JETS 3, 4, 7, AND 8. SINCE THESE ARE THE -X TRANSLATION JETS, THEIR ACTION WILL CAUSE THE S/M TO TRANSLATE AWAY FROM THE C/M. THESE JETS CONTINUE TO FIRE AFTER SEPARATION UNTIL THEIR PROPELLANT SUPPLY IS EXHAUSTED OR THE JETS HAVE BURNED OUT. TWO SECONDS AFTER THE -X COMMAND HAS BEEN GENERATED, A SIX SECOND FIRE SIGNAL IS APPLIED TO THE POSITIVE ROLL JETS (9, 11, 13, AND 15) BY THE SEQUENCER.

A FINAL TIE-IN TO THE DIRECT RCS IS THAT OF THE FUEL DUMP BURN FUNCTION. ACTIVATING THE FUEL DUMP SWITCH WILL CAUSE TWO MOTOR DRIVEN SWITCHES TO BE CLOSED. AGAIN THE A AND B MOTORS ARE ASSOCIATED WITH THE SWITCHING ACTION AFFECTING THE A AND B PROPELLANT SYSTEMS OF THE C/M. A DECISION TO RID THE C/M OF EXCESS RCS FUEL AFTER SCS DEACTIVATION, CAUSES THE FUEL TO BE BURNED OUT OF ALL C/M JETS EXCEPT JETS 1 AND 3. SINCE THESE ARE POSITIVE (+) PITCH JETS THAT POINT UPWARD TOWARD THE APEX OF THE C/M, THEIR BURN ENVELOPE COULD ENDANGER THE PARACHUTES AND ASSOCIATED SHROUD LINES.

SECTION V

THRUST VECTOR CONTROL

5.1 INTRODUCTION

SINCE THE MOON AND THE EARTH ARE MOVING IN ORBITS, IT IS NECESSARY TO LAUNCH THE APOLLO SPACECRAFT SO THAT THE SPACECRAFT AND THE MOON ARRIVE AT A PRESELECTED POINT IN SPACE AT THE SAME TIME. IT IS CONCEIVABLE TO OBTAIN ERRORS IN THE TRANSLUNAR INJECTION TRAJECTORY SO THAT THE PRESELECTED POINT COULD BE MISSED. A GROUND-BASED IBM 7090 COMPUTER PRECOMPUTES THE PRECISE TRAJECTORY WHICH SHOULD BE FOLLOWED, BASED ON A FOUR BODY EQUATION OF MOTION THAT TAKES INTO ACCOUNT THE EFFECT OF THE GRAVITATIONAL FIELD OF THE EARTH, MOON, AND SUN ON THE VEHICLE'S MOTION.

THE MIDCOURSE NAVIGATION SYSTEM (G&N) TAKES OVER AFTER THE SPACECRAFT IS INJECTED INTO THE CHOSEN TRAJECTORY. THE G&N COMPUTER CALCULATES THE DEGREE OF DEVIATION FROM THE REFERENCE TRAJECTORY; AND IN DETERMINING THE DEVIATION, THE COMPUTER WILL CALCULATE THE REQUIRED VELOCITY CORRECTION TO ESTABLISH A NEW TRAJECTORY THAT WILL RENDEZVOUS AT A PRESELECTED POINT IN SPACE. SUCCESSFUL ACHIEVEMENT OF THE CALCULATED TRAJECTORY IS DEPENDENT UPON CONTROL OF THE VEHICLE THRUST VECTOR DURING THESE VELOCITY CORRECTION PHASES.

THE APOLLO SPACECRAFT, OPERATING IN A FRICITIONLESS VOID, EXPERIENCES A VARYING CENTER OF GRAVITY

CAUSED BY THE CONSUMPTION OF EXPENDABLES. THE VARYING CENTER OF GRAVITY CAUSES UNDESIRABLE MOMENT ARMS AND SIDE VELOCITIES DURING THE ACCELERATING PHASES; AND IF UNCOMPENSATED, THEY BECOME DETRIMENTAL TO THE SUCCESS OF THE MISSION AND SAFETY OF THE CREW.

5.1.1 THRUST ALIGNMENT

THE THRUST VECTOR CONTROL SUBSYSTEM IS REQUIRED TO POSITION THE GIMBALLED SPS ENGINE. IT MAINTAINS THE ENGINE THRUST THROUGH THE SPACECRAFT CENTER OF GRAVITY, AND HOLDS THE SPACECRAFT ATTITUDE SO THAT THE THRUST VECTOR WILL BE IN THE DESIRED DIRECTION.

POSITIONING THE THRUST VECTOR THROUGH THE CENTER OF GRAVITY IS COMPLICATED BY THE AMOUNT OF EXPENDABLES CONSUMED DURING LARGE THRUSTING MANEUVERS (LUNAR ORBIT INJECTION AND TRANS-EARTH INJECTION). THE TOTAL TRAVEL OF THE SPACECRAFT CENTER OF GRAVITY (FIGURE 5-1 AND 5-2) IS APPROXIMATELY 120 INCHES ALONG THE X AXIS, 12 INCHES ALONG THE Y AXIS AND 7 INCHES ALONG THE Z AXIS. THE SPACECRAFT CENTER OF GRAVITY TRAVEL DURING THE LARGE THRUSTING MANEUVERS CAUSES UNDESIRABLE LATERAL ACCELERATIONS AND RESIDUAL LATERAL VELOCITIES; AND THEY COMBINE WITH INITIAL ALIGNMENT ERRORS OF THE THRUST VECTOR AND POINTING ERRORS IN THE TWO INERTIAL SENSORS (IMU AND SCS ARS) TO DECREASE THE ACCURACY OF THE THRUSTING MANEUVER IN MOST INCIDENTS.

5-1

SERVICE MODULE SECTORS AND CENTER OF MASS SHIFT

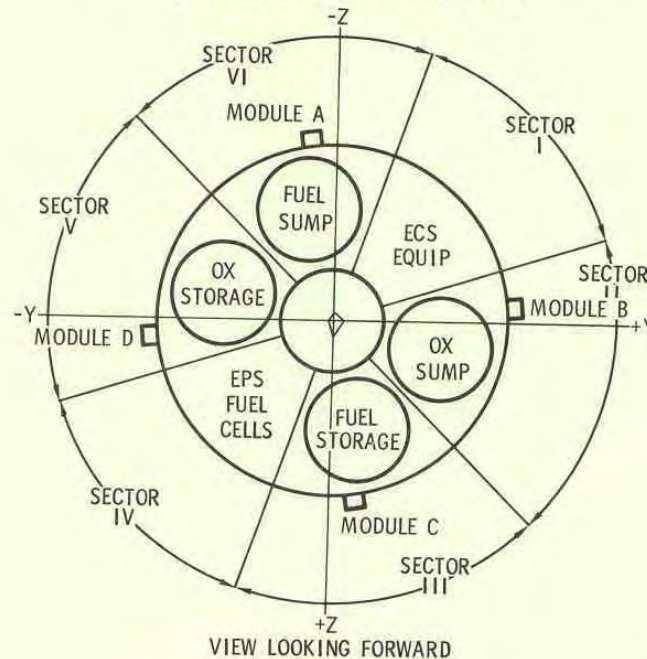


FIGURE 5-1

P-0004A

5-2

CENTER OF MASS SHIFT Y,Z AND X AXIS

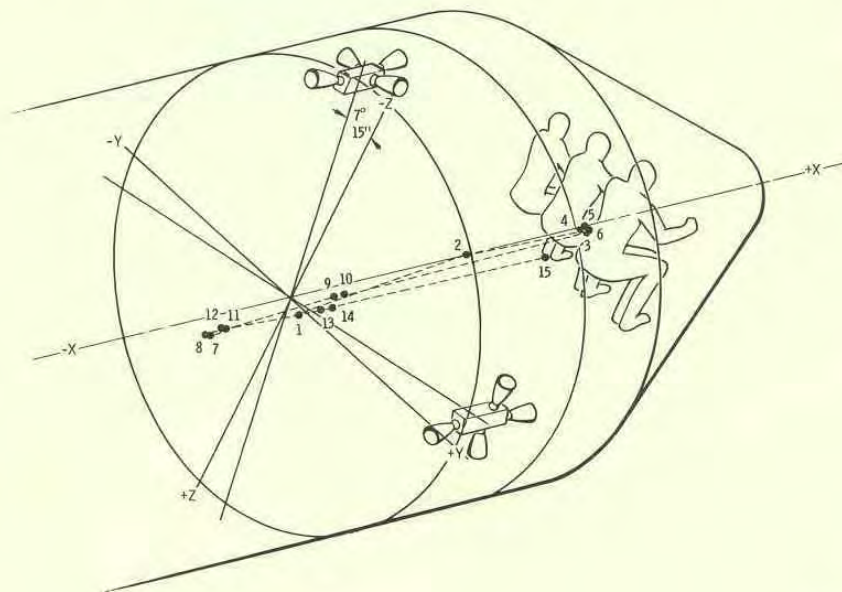


FIGURE 5-2

P-0012
5-3

THE THRUST VECTOR CONTROL SYSTEM CONSISTS OF TWO AXES (PITCH AND YAW) CONTROL OF THE GIMBALLED SPS ENGINE AND ROLL CONTROL PROVIDED BY THE REACTION JETS WHEN ROLL ATTITUDE ERRORS OR ANGULAR RATE EXCEED THE SPECIFIED DEADBAND. THE THRUST VECTOR CONTROL SYSTEMS ABILITY TO COMMAND A MAXIMUM GIMBAL DISPLACEMENT OF $\pm 9.5^\circ$ IN YAW ABOUT A NULL OFFSET OF $\pm 4^\circ$ IN THE SPACECRAFT X-Y PLANE, AND $\pm 9.5^\circ$ ABOUT ZERO IN THE SPACECRAFT X-Z PLANE, ALLOWS THE SPACECRAFT TO THRUST THROUGH THE CENTER OF GRAVITY AND IN THE DESIRED DIRECTION.

THE MECHANICAL TRAVEL OF EACH ACTUATOR IS LESS THAN THE MAXIMUM COMMANDABLE BY THE TVC SUBSYSTEM. THE YAW AXIS IS A NOMINAL $\pm 7^\circ \pm \frac{1}{2}^\circ - 0$ WITH AN ADDITIONAL 1° FOR SNUBBING AND THE PITCH AXIS IS A NOMINAL $\pm 6^\circ \pm \frac{1}{2}^\circ - 0$ WITH AN ADDITIONAL 1° FOR SNUBBING. THE SPACECRAFT AND GIMBAL ELASTICITY SHOULD ABSORB THE EXTREME TRAVEL CONDITIONS THAT PERMIT STABILITY FOR LARGE ERROR SIGNALS THAT COULD OCCUR IN ABORTS. THE NORMAL TVC COMMANDED GIMBAL ANGLES SHOULD BE SLIGHTLY LESS THAN THE NOMINAL GIMBAL TRAVEL IN EACH AXIS.

5.1.2 PRIMARY DELTA V MODE

THE PRIMARY DELTA V MODE (THRUSTING) WILL BE THE G&N DELTA V MODE WHICH PROVIDES THE MOST ACCURATE TRAJECTORY CORRECTIONS. THE IMU IN THE G&N SYSTEM HAS THREE ACCELEROMETERS WHICH PERMIT CONTINUOUS TRAJECTORY CORRECTIONS WHILE THRUSTING TO COMPENSATE FOR ANY LATERAL ACCELERATIONS OR RESIDUAL LATERAL VELOCITIES. THE G&N COMPUTER INTEGRATES THE LATERAL ACCELERATIONS AND

PROVIDES STEERING COMMANDS TO THE GIMBALLED SPS ENGINE FOR TRAJECTORY CORRECTIONS. WHEN CALCULATING THE VELOCITY REQUIRED TO CORRECT THE TRAJECTORY, THE G&N COMPUTER CONSIDERS THE GRAVITATIONAL ACCELERATIONS EFFECTING THE SPACECRAFT; THEREFORE, THE ACTUAL THRUSTING VELOCITY WILL BE OF A DIFFERENT MAGNITUDE THAN THE REQUIRED VELOCITY CHANGE AND RESULT IN A CURVED TRAJECTORY.

5.1.3 BACKUP DELTA V MODE

THE BACKUP DELTA V MODE WILL BE THE SCS DELTA V MODE WHICH HAS THE ABILITY TO PERFORM INERTIALLY ORIENTED THRUSTING MANEUVERS BY CONTROLLING THE SPS THRUST VECTOR. THE NORMAL ACTION FOR A MALFUNCTION IN THE DELTA V MODE WOULD BE TO TERMINATE THRUST - - INVESTIGATE AND RE-ALIGN TO COMPLETE THE DELTA V MANEUVER. HOWEVER, THERE ARE LIMITATIONS AND RESTRICTIONS THAT REQUIRE INDIVIDUAL CONSIDERATION. THE BACKUP MODE CAN BE SELECTED TO COMPLETE THE DELTA V MANEUVER WHERE IT PROVIDES GREATEST CREW SAFETY TO INSURE SAFE RETURN WHEN SUFFICIENT INFORMATION IS AVAILABLE.

5.1.4 MANUAL DELTA V MODE

THE MANUAL THRUST VECTOR CONTROL OPERATING MODE PROVIDES A SECONDARY BACKUP CONTROL OF THE GIMBALLED SPS ENGINE. THE ASTRONAUT WILL PROVIDE COMMAND INPUTS FROM THE ROTATION CONTROL TO POSITION THE GIMBALLED SPS ENGINE FOR THIS OPERATING MODE. FOR BLOCK I MISSIONS, MANUAL THRUST VECTOR CONTROL WILL BE USED

PRIMARYLY TO RECOVER FROM A MALFUNCTION IN THE OTHER TWO DELTA V MODES THAT HAS CAUSED EXCESSIVE ANGULAR BODY RATES. AFTER THE ASTRONAUT HAS MANUALLY, WITH THE ASSISTANCE OF THE RATE CAGED BMAG'S, STABILIZED THE S/C WITH THE SPS ENGINE THRUSTING, THE DELTA V MANEUVER WOULD BE TERMINATED. EXCESSIVE ANGULAR RATES AT TERMINATION OF SPS ENGINE THRUSTING WOULD USE EXCESSIVE, IF NOT MORE THAN AVAILABLE, RCS FUEL AND OXIDIZER TO ARREST THE TUMBLING CREATED BY THE MALFUNCTION.

MANUAL THRUST VECTOR CONTROL WILL INSERT COMMAND INPUTS INTO THE NUMBER 2 REDUNDANT SERVO POSITIONING LOOP WHERE IT IS SUMMED WITH RATE SIGNALS FROM THE RATE CAGED BMAG'S FOR POSITIONING THE GIMBALLED SPS ENGINE. THE ROTATION CONTROL MUST BE CONTINUALLY DISPLACED TO COMMAND A POSITION OTHER THAN THE POSITION SET BY THE GIMBAL POSITION TRIM KNOBS. ALL POWER REQUIRED FOR MANUAL TVC WILL BE ROUTED THROUGH GROUP 2 CIRCUIT BREAKER AND POWER SWITCHES.

5.1.5 DYNAMIC RESPONSE

THE DYNAMIC RESPONSE OF THE THRUST VECTOR CONTROL SYSTEM IS SUCH THAT NO SYMPATHETIC HARMONIES ARE CREATED BETWEEN THE ACTUATOR, SPACECRAFT, AND INERTIAL SENSORS WHEN COUPLED BY A SERVO LOOP. THE PRIMARY AND BACKUP METHODS OF PERFORMING A DELTA V MANEUVER HAVE BEEN INVESTIGATED TO INSURE COMPLIANCE WITH THE DYNAMIC REQUIREMENTS.

5.2 THRUST VECTOR CONTROL

THE THRUST VECTOR CONTROL FUNCTIONAL DIAGRAM (FIGURE 5-3) ILLUSTRATES THE FUNCTIONAL CAPABILITIES OF THE G&N DELTA V MODE, SCS DELTA V MODE, AND THE MANUAL THRUST VECTOR CONTROL MODE.

5.2.1 G&N DELTA V MODE

FOR THE G&N DELTA V MODE, THE INPUTS FROM THE G&N SYSTEM POSITION THE FDAI ATTITUDE BALL AND ATTITUDE ERRORS FOR DISPLAY THROUGH RELAY K1. RELAY K8 WILL ALSO BE CLOSED TO PROVIDE COMMAND INPUTS FOR THE ATTITUDE CONTROL ELECTRONICS AND THE THRUST VECTOR CONTROL ELECTRONICS. PRIOR TO THRUST ON, THE INPUTS WILL BE USED TO HOLD THE S/C IN ALL THREE AXES OF ATTITUDE CONTROL. AFTER THRUST ON IS COMMANDED, ROLL ATTITUDE ERROR ONLY WILL BE RECOGNIZED AND ACTED UPON BY THE JET SELECTION LOGIC IN THE ATTITUDE CONTROL ELECTRONICS FOR HOLDING THE SELECTED ROLL ATTITUDE. RELAY K11 WILL CLOSE FOR THRUST ON TO SUPPLY PITCH AND YAW RATE AND ATTITUDE ERROR SIGNALS INTO THE GIMBAL POSITIONING ELECTRONICS TO POSITION THE GIMBALLED SPS ENGINE FOR CONTROL OF THE SPS THRUST VECTOR. RELAY K10 WILL OPEN, REMOVING ALL PROPORTIONAL RATE INPUTS FROM THE ATTITUDE CONTROL ELECTRONICS FOR PITCH AND YAW. THE ATTITUDE ERROR INPUT FROM THE G&N SYSTEM WILL PROVIDE THE REQUIRED CHANGE IN THE SPS GIMBAL POSITION WHICH WILL ROTATE THE SPACECRAFT TO COMPENSATE FOR THE

5-5

THRUST VECTOR CONTROL FUNCTIONAL DIAGRAM

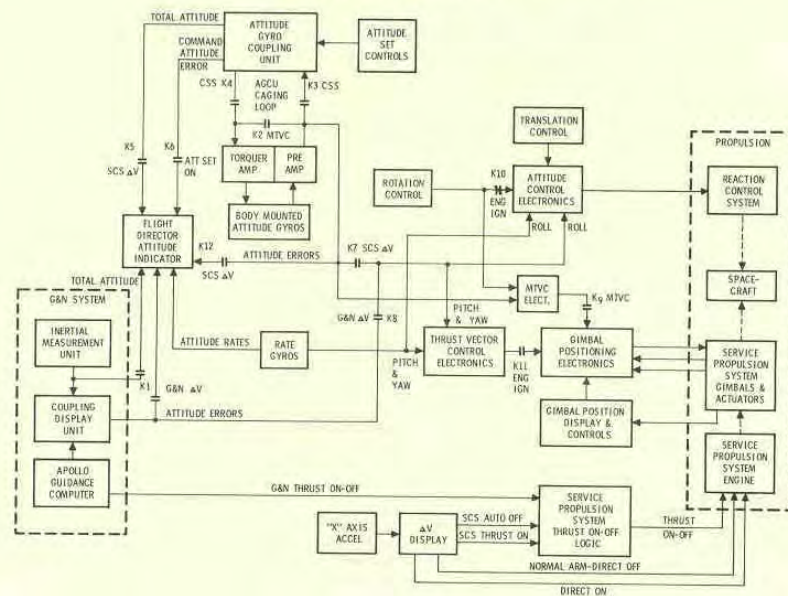


FIGURE 5-3

5-6

CENTER OF GRAVITY TRAVEL WHILE THRUSTING. WHEN THIS ATTITUDE ERROR IS USED TO "FLY" A CURVED TRAJECTORY, THE ATTITUDE ERROR INPUTS WILL REFLECT A STEERING COMMAND IN ADDITION TO THE ATTITUDE ERROR REQUIRED TO COMPENSATE FOR THE CENTER OF GRAVITY TRAVEL. THEREFORE, THE G&N SYSTEM WILL BE REQUIRED TO PERFORM THE CURVED SPS THRUSTING MANEUVER.

THE GIMBAL POSITIONING ELECTRONICS AND GIMBAL ACTUATORS PROVIDE A CLOSED LOOP SERVO THAT WILL BE TRIMMED PRIOR TO ALL THRUSTING PHASES. THE GIMBAL POSITION DISPLAY AND CONTROL KNOBS WILL BE USED TO TRIM THE CLOSED SERVO LOOP FOR THRUSTING THROUGH THE CENTER OF GRAVITY AT THRUST INITIATION. ALL INPUTS FROM THE G&N SYSTEM WILL MOVE THE ACTUATOR ABOUT THE INITIAL TRIM POINT. INITIAL TRIM CONDITIONS ARE ALWAYS MANUALLY SET BY THE ASTRONAUTS FOR ALL OPERATING MODES. THE SPS ENGINE GIMBALS ARE ALIGNED TO THE S/C BODY AXIS FOR THE ASCENT PHASE.

THE G&N DELTA V MODE AFFECTS THE BODY MOUNTED ATTITUDE GYROS TO COMPLETE THE SCS BACKUP CAPABILITY. THE GYROS WILL BE UNCAGED UPON SELECTION OF THE G&N DELTA V MODE SO THE G&N AND SCS WILL HAVE THE SAME INERTIAL REFERENCE NULL FOR A MINIMUM TRANSIENT SWITCH OVER IF REQUIRED WHILE THRUSTING.

5.2.2 SCS DELTA V MODE

IN THE SCS DELTA V MODE, THE FDAI ATTITUDE BALL WILL BE POSITIONED FROM THE ATTITUDE GYRO COUPLING UNIT THROUGH RELAY K5 IF A MANUAL MANEUVER IS COMMANDED PRIOR TO ENGINE IGNITION. THE ATTITUDE ERRORS WILL BE

SUPPLIED BY THE BODY MOUNTED ATTITUDE GYROS THROUGH RELAY K12 WITH THE ATTITUDE SET SWITCH IN THE OFF POSITION. RELAY K6 WOULD BE CLOSED AND K12 OPEN WHEN MANEUVERING TO THE THRUSTING ATTITUDE USING THE COMMAND ATTITUDE ERROR OUTPUT OF THE ATTITUDE GYRO COUPLING UNIT. THE ATTITUDE SET SWITCH WOULD BE IN THE ATT SET POSITION TO UTILIZE THIS CAPABILITY BUT IT WOULD BE PLACED TO THE OFF POSITION PRIOR TO THRUST INITIATION.

THE ATTITUDE RATE AND ERROR SIGNALS WOULD BE PROVIDED TO THE THRUST VECTOR CONTROL ELECTRONICS THROUGH RELAY K7. THE THRUST VECTOR CONTROL ELECTRONICS WILL BE CONFIGURED SUCH THAT THE THRUST VECTOR WILL REMAIN INERTIALLY ORIENTATED FOR A DELTA V MANEUVER BECAUSE OF THE ATTITUDE ERROR INPUT SIGNAL AND THE INTEGRATION PERFORMED ON THE ATTITUDE ERROR AND POSITION FEEDBACK SIGNALS IN THE THRUST VECTOR CONTROL ELECTRONICS.

THE SAME SWITCHING FOR RELAYS K11 AND K10 WILL OCCUR AT THRUST INITIATION IN THE SCS DELTA V MODE AS OCCURRED IN THE G&N DELTA V MODE. ATTITUDE HOLD WILL REVERT TO ROLL ONLY, AS BEFORE WITH SIGNALS PROVIDED TO THE JET SELECTION LOGIC IN THE ATTITUDE CONTROL ELECTRONICS.

5.2.3 MANUAL THRUST VECTOR CONTROL MODE

THE MANUAL THRUST VECTOR CONTROL (MTVC) MODE IS NOT A SELECTABLE MODE FROM THE SCS CONTROL PANEL. IT CAN BE ENTERED ONLY IF THE CONTROL PANEL HAS A DELTA V MODE SELECTED. WITH A DELTA V MODE SELECTED, THE CLOCKWISE SWITCH ON THE TRANSLATION CONTROL WILL

5-7

ENERGIZE RELAYS K2 AND K9 AND OPEN K11. RELAY K2 CAGES THE BMAG TO A RATE CONFIGURATION TO PROVIDE RATE DAMPING FOR THE MTVC OPERATING MODE. RELAY K9 INSERTS THE RATE AND ROTATION CONTROL SIGNALS INTO THE GIMBAL POSITIONING ELECTRONICS. RELAY K11 REMOVES ALL NORMAL SIGNAL INPUTS FROM THE GIMBAL POSITION ELECTRONICS THAT ARE USED FOR THE G&N OR SCS DELTA V MODES TO PREVENT OPPOSITION TO THE MTVC COMMANDS.

THE ROTATION CONTROL MUST BE HELD AT A GIVEN DISPLACEMENT TO HOLD THE SPS ENGINE GIMBALS DISPLACED FROM THE NEUTRAL TRIM POSITION ORIGINALLY SET IN WITH THE GIMBAL POSITION TRIM CONTROL KNOBS. THE GIMBAL POSITION DISPLAY PROVIDES THE ONLY INDICATION OF SPS GIMBAL ANGLES WITH RESPECT TO THE SPACECRAFT BODY AXES.

5.3 THRUST CONTROL

THRUST CONTROL MEASURES AND CONTROLS THE MAGNITUDE OF VELOCITY IMPARTED TO THE S/C BY THE SERVICE PROPULSION SYSTEM. WITH PROPER SEQUENCE, THRUST FROM THE SERVICE PROPULSION SYSTEM CAN BE APPLIED OR REMOVED IN THREE METHODS AS SHOWN IN THE LOWER SECTION OF FIGURE 5-3.

5.3.1 G&N THRUST ON-OFF

THE APOLLO GUIDANCE COMPUTER, AFTER PROPER SEQUENCES AND PROGRAMS, CAN SUPPLY A THRUST ON COMMAND TO THE SERVICE PROPULSION SYSTEM THRUST ON-OFF ELECTRONICS. THE THRUST ON-OFF LOGIC WILL ACCEPT A G&N THRUST

ON COMMAND IF THE LOGIC NETWORK HAS BEEN PROPERLY ENABLED. ON RECEIPT OF THE G&N THRUST ON COMMAND, THE SCS ELECTRONICS WILL CAUSE THE SPS ENGINE SOLENOID VALVES TO ENERGIZE, THUS INITIATING A VELOCITY CHANGE MANEUVER. AFTER THE DESIRED VELOCITY HAS BEEN OBTAINED, THE GUIDANCE COMPUTER WILL REMOVE THE THRUST ON COMMAND WHICH WILL BE INTERPRETED BY THE THRUST ON-OFF LOGIC AS A THRUST OFF COMMAND. THEREFORE, IF THE PROPER CREW PROCEDURES ARE FOLLOWED, THE G&N SYSTEM CAN AUTOMATICALLY TURN THE SPS ENGINE ON AND OFF.

5.3.2 SCS THRUST ON-OFF

THE SCS NORMALLY PROVIDES BACKUP CONTROLS AND DISPLAYS TO MONITOR OR REPLACE, IF NECESSARY, G&N THRUST ON-OFF COMMANDS TO THE SPS ENGINE. THE MONITORING FUNCTION IS ACCOMPLISHED BY THE DELTA V REMAINING INDICATOR AND ILLUMINATION OF THE THRUST ON BUTTON. THE COMMAND WILL BE ACCEPTED BY THE SPS THRUST ON-OFF LOGIC. IF THE PROPER SEQUENCE OF EVENTS HAVE OCCURRED, THE SPS ENGINE SOLENOIDS WILL BE ENERGIZED TO START A THRUSTING MANEUVER. WHEN THE DESIRED AMOUNT OF VELOCITY HAS BEEN IMPARTED TO THE S/C, THE DELTA V REMAINING INDICATOR WILL READ ZERO AND INITIATE AN AUTOMATIC THRUST OFF COMMAND. THE SPS ENGINE SOLENOIDS CAN NOT DISTINGUISH BETWEEN THE SYSTEMS ORIGINATING THE THRUST ON COMMAND, BUT THE THRUST CONTROL SWITCH MUST BE IN THE NORMAL POSITION BEFORE THE SOLENOIDS CAN BE ENERGIZED BY THE SPS THRUST CONTROL LOGIC. THE NORMAL AND DIRECT-ON SIGNAL PATH PROVIDES 28 VDC FOR ARMING THE SPS ENGINE

5-8

SOLENOIDS FROM THE THRUST CONTROL SWITCH. THE DIRECT ON POSITION ALSO PROVIDES A GROUND TO ENERGIZE THE SOLENOIDS. THE DIRECT OFF POSITION PROVIDES A BACKUP THRUST OFF COMMAND CAPABILITY TO BOTH AUTOMATIC THRUST OFF COMMANDS AND IS THE NORMAL OFF FOR THE DIRECT ON POSITION.

5.3.3 DIRECT THRUST ON-OFF

THE DIRECT THRUST ON-OFF FUNCTION PROVIDES A PATH TO ENERGIZE THE SPS ENGINE SOLENOIDS WITH NO ELECTRONICS. IT REQUIRES MANUAL ACTION TO UNLOCK THE SWITCH AND PROVIDE THE DIRECT THRUST ON COMMAND, AND MANUAL ACTION TO PERFORM THE THRUST OFF COMMAND. THE DIRECT ON WILL PROVIDE THE POWER AND GROUND CONNECTION REQUIRED TO ENERGIZE THE SPS ENGINE SOLENOIDS.

5.4 THRUST VECTOR CONTROL OPERATION

A TYPICAL THRUST VECTOR CONTROL CHANNEL IS SHOWN IN FIGURE 5-4. IT IS DRAWN FOR THE YAW CHANNEL. THE PITCH CHANNEL WOULD BE THE SAME.

5.4.1 SERVO POSITIONING

THE SERVO POSITIONING LOOP CONSISTS OF VELOCITY POSITION FEEDBACK LOOPS TO CONTROL RATE AND DISPLACEMENT OF THE ACTUATOR. THE SERVO POSITIONING IS A CLOSED SERVO LOOP WITH AN EXTERNAL OPEN LOOP TRIM. THE OPEN LOOP TRIM IS COMPOSED OF A MANUAL GIMBAL POSITION CONTROL AND GIMBAL POSITION DISPLAY. MANUAL CREW ACTION PROVIDES LOOP CLOSURE FOR THE INITIAL SP3 ENGINE GIMBAL ALIGNMENT. THE SERVO POSITIONING LOOP MUST BE

ACTIVE TO HOLD THE SPS ENGINE GIMBAL STATIONARY AND PREVENT EXTERNAL MOMENTS FROM INFLICTION MOTION. THE MECHANICAL ACTION WILL WITHSTAND SMALL FORCES, BUT THE MAGNETIC CLUTCHES PROVIDE THE REQUIRED HOLDING FORCES. THE MAGNETIC CLUTCHES WILL HAVE A QUIESCENT CURRENT OUTPUT OF EQUAL LEVEL FOR CW AND CCW ROTATIONS OF THE GEAR TRAINS IN THE STATIC CONDITIONS. FOR INPUT POSITIONING COMMANDS, A DIFFERENTIAL CURRENT OUTPUT WILL BE GENERATED TO PRODUCE CORRECT GIMBAL DRIVE FOR THE GIMBAL ACTIVATORS. TORQUE OUTPUT FROM THE GIMBAL ACTUATION WILL BE PROPORTIONAL TO THE DIFFERENTIAL CURRENT LEVEL.

MANUAL CREW ACTION IS ALWAYS REQUIRED TO POSITION THE SPS ENGINE GIMBAL PRIOR TO EACH THRUSTING OF THE SPS ENGINE. THE CLOSED LOOP SERVO POSITIONING ACTUALLY PROVIDES THE INITIAL STABILITY FOR THRUST BUILDUP.

THE ACTUATOR ASSEMBLY USED BY THE SERVO POSITIONING LOOP, FIGURES 5-5 AND 5-6, CONSISTS OF TWO DC MOTORS, FOUR ELECTRO-MAGNETIC CLUTCHES, TWO RATE GENERATORS, AND FOUR LINEAR POSITION TRANSDUCERS FOR INTERFACING WITH THE TVC SUBSYSTEM. THE ACTUATOR ASSEMBLY ALSO CONTAINS ALL THE MECHANICAL GEARING AND LINKAGE REQUIRED TO POSITION THE SPS ENGINE GIMBAL.

THE UPPER SECTION OF FIGURE 5-6 CONTAINS ONE MOTOR, TWO CLUTCHES, AND A RATE GENERATOR WHICH ARE IDENTIFIED AS SYSTEM 1. THE LOWER SECTION CONTAINS AN IDENTICAL SET THAT IS IDENTIFIED AS SYSTEM 2 WITHIN THE ACTUATOR. SYSTEM 2 IS POSITIONED BY THE REDUNDANT SERVO POSITIONING ELECTRONICS.

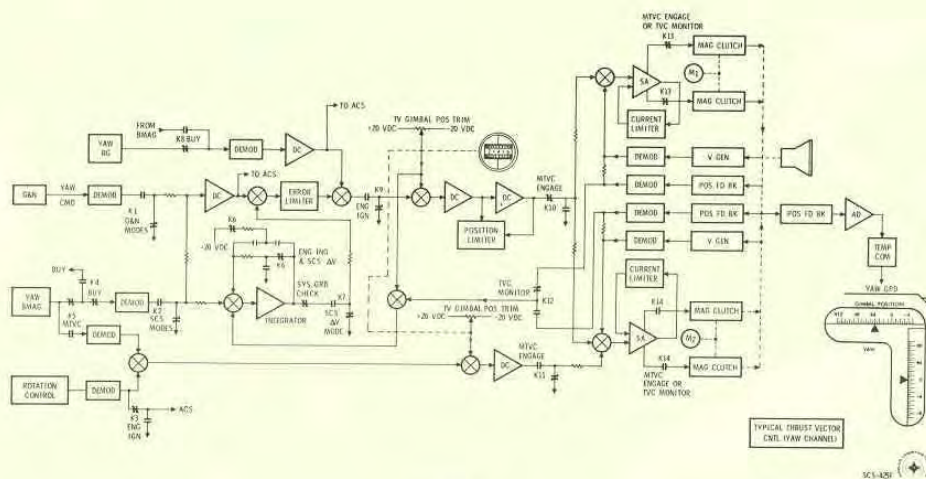
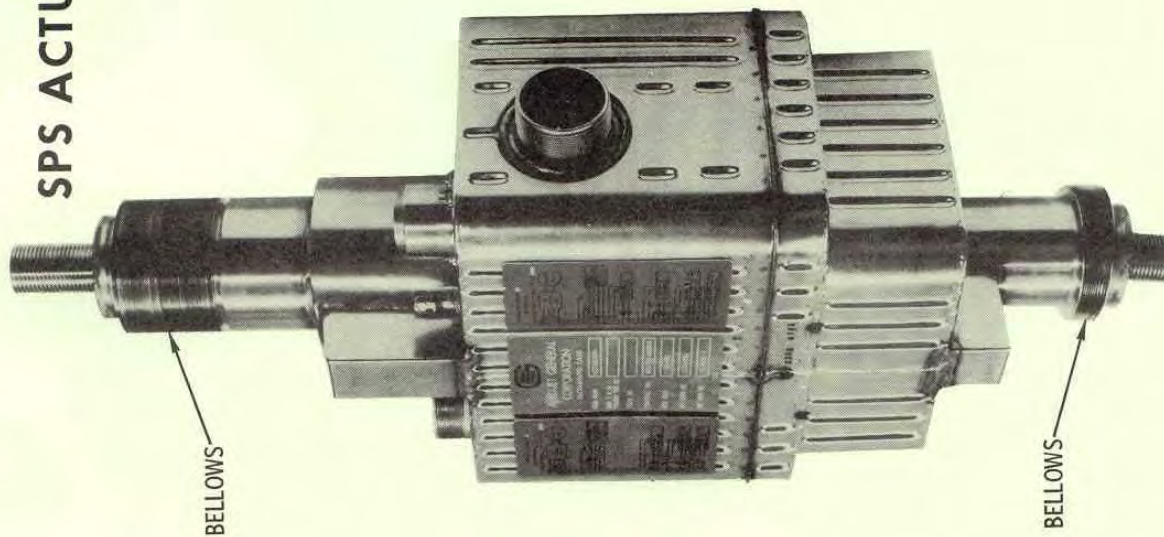


FIGURE 5-4

SPS ACTUATOR

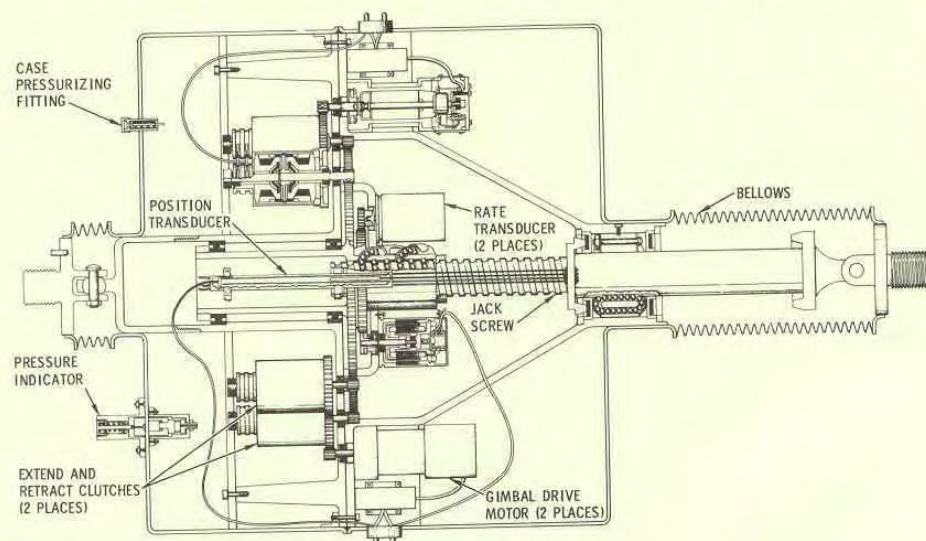


P-1066

FIGURE 5-5

5-11

SPS ELECTRICAL GIMBAL ACTUATOR



P-1017A

FIGURE 5-6

5-12

THE CLUTCH HOUSING ROTATES AS A FUNCTION OF MOTOR SPEED AND THE TVC SUBSYSTEM ENERGIZES THE ELECTROMAGNETIC CLUTCHES TO TRANSMIT REQUIRED TORQUE TO THE CENTER SHAFT BY ACTION OF THE MAGNETIC PARTICLES IN THE CLUTCH. THE RATE GENERATOR AND POSITION TRANSDUCER PROVIDES THE ELECTRICAL FEEDBACK FOR THE CLOSED SERVO LOOP. TABLE 5-1 DEFINES GIMBAL DISPLAY, THRUST VECTOR POINTING, AND ACTUATOR MOVEMENT AS RELATED TO TRIM COMMAND INPUT.

5.4.1.1 REDUNDANT SERVO POSITIONING

EACH CHANNEL OF THE THRUST VECTOR CONTROL HAS REDUNDANT SERVO POSITIONING ELECTRONICS AND MOTORS. THE PRIMARY ELECTRONICS AND MOTOR WILL NORMALLY BE USED TO POSITION THE SPS ENGINE GIMBALS. POWER DISTRIBUTION TO THE MOTORS AND ELECTRONICS ARE DESIGNED TO AVOID SINGLE POINT FAILURES IN POWER DISTRIBUTION FROM DISABLING THE SERVO POSITIONING LOOP.

THERE ARE THREE METHODS OF PLACING THE REDUNDANT ELECTRONICS AND MOTOR (M2) INTO OPERATION. FIRST, WITH BOTH M1 AND M2 OPERATING, THERE IS AN AUTOMATIC SWITCH OVER FROM M1 TO M2 SHOULD MOTOR CURRENT EXCEED THE HIGH OR LOW SPECIFIED TOLERANCES. SECOND, IF M1 IS NOT ACTIVATED, THE SWITCH OVER WILL OCCUR AND M2 WILL GENERATE THE CONTROLLING TORQUES. THIRD, THE MANUAL THRUST VECTOR CONTROL OPERATING MODE WILL AUTOMATICALLY SELECT M2 AND THE REDUNDANT ELECTRONICS TO GENERATE THE CONTROLLING TORQUES. IT IS ASSUMED THAT SCS POWER SWITCHES FOR TVC 1 AND 2 ARE

PROCEDURALLY TURNED ON AND CONNECTED TO DIFFERENT BUSES FOR TVC OPERATIONS.

THE TVC MONITOR SIGNAL IS GENERATED BY THE OVER-UNDER CURRENT SENSING CIRCUIT SHOWN IN FIGURE 5-7 TO PROVIDE THE AUTOMATIC SWITCH-OVER FOR ACTUATOR CURRENT DRAIN MALFUNCTIONS. THE MOTOR CONTROL SWITCH IS ACTIVATED BY THE ACTUATOR MOTOR SWITCH ON PANEL 3. WHEN THE SWITCH IS PLACED TO THE START POSITION, THE MOTOR SWITCH WILL BE DRIVEN TO THE ENERGIZED POSITION FOR THE DC ACTUATOR MOTOR. THE MOTOR SWITCH CONTACT OPENS AND WILL NOT SEND A FAIL SENSE SIGNAL TO THE SCS. WHEN THE PANEL SWITCH IS RELEASED, IT WILL DROP TO THE ON POSITION AND APPLY POWER TO THE OVER-UNDER CURRENT SENSING CIRCUIT. IF AN OVER OR UNDER CURRENT CONDITION SHOULD OCCUR, ONE SCR WILL ILLUMINATE THE YAW GIMBAL DRIVE FAIL MASTER CAUTION LIGHT AND THE OTHER WILL START THE MOTOR SWITCH TO REMOVE THE DC ACTUATOR MOTOR FROM ITS DC BUS. WHEN THE MOTOR SWITCH IS POSITIONED TO FULL OFF, THE SWITCH CONTACT CLOSING PROVIDES 28 VOLTS TO THE SCS FOR A TVC MONITOR SIGNAL, WHICH AUTOMATICALLY CAUSES THE SCS TO SELECT THE REDUNDANT GIMBAL POSITIONING LOOP. THE MASTER CAUTION LIGHT WILL REMAIN ILLUMINATED UNTIL THE PANEL SWITCH IS POSITIONED TO OFF.

MOTOR NO. 2 HAS AN IDENTICAL OVER-UNDER CURRENT SENSING CIRCUIT TO PROTECT THE DC BUS. IT HAS NO SIGNAL OUTPUTS TO THE SCS OR MASTER CAUTION LIGHTS IN EVENT OF A OVER OR UNDER CURRENT MALFUNCTION; THEREFORE, NO SWITCHING OR WARNING CIRCUITS ARE PROVIDED.

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GIMBALLING OF THE SERVICE PROPULSION ENGINE


S/C MOTION DESIRED BY THE CREW	THUMB WHEEL POSITIONED ON PANEL ASSEMBLY 6 TO A	ENGINE NOZZLE MOVES TOWARDS THE	THE THRUST VECTOR OF THE ENGINE MOVES TOWARDS THE	GIMBAL POSITION INDICATOR ON PANEL ASSEMBLY 6 MOVES TO A	ACTUATOR RAM
S/C NOSE DOWN (PITCH)	+ NUMERAL (UP)	+ Z AXIS OF THE S/C	- Z AXIS OF THE S/C	+ NUMERAL	PITCH EXTENDS
S/C NOSE UP (PITCH)	- NUMERAL (DOWN)	- Z AXIS OF THE S/C	+ Z AXIS OF THE S/C	- NUMERAL	PITCH RETRACTS
S/C RIGHT (YAW)	- NUMERAL (RIGHT)	+ Y AXIS OF THE S/C	- Y AXIS OF THE S/C	- NUMERAL	YAW RETRACTS
S/C LEFT (YAW)	+ NUMERAL (LEFT)	- Y AXIS OF THE S/C	+ Y AXIS OF THE S/C	+ NUMERAL	YAW EXTENDS

THE ACTUATOR NULL POSITION IN YAW IS 4° OFFSET FROM THE S/C X AXIS DUE TO THE ENGINE MOUNTING PADS IN THE SERVICE MODULE BEING CANTED (BLOCK 1 VEHICLES). THE THRUST VECTOR IS 4° TO THE +Y AXIS OF THE S/C AND THE ENGINE NOZZLE IS 4° TO THE -Y AXIS OF THE S/C. AS A RESULT THE GIMBAL POSITION INDICATOR ON PANEL ASSEMBLY 6 WILL INDICATE A +4° WHEN THE ACTUATORS ARE IN THE NULL POSITION. TO PARALLEL THE THRUST VECTOR AND THE ENGINE NOZZLE WITH THE X AXIS OF THE S/C, THE YAW THUMB WHEEL ON PANEL ASSEMBLY 6 MUST BE POSITIONED TO 0° AND AS A RESULT THE YAW POSITION INDICATOR ON PANEL ASSEMBLY 6 WILL INDICATE 0°.

IN THIS CASE, THE YAW ACTUATOR IS NO LONGER IN ITS NULL POSITION IN RESPECT TO THE GIMBAL RING. THE THRUST VECTOR AND THE ENGINE NOZZLE ARE NOW PARALLEL TO THE X AXIS OF THE S/C.

THE ACTUATOR NULL POSITION IN PITCH IS 0° (BLOCK 1 VEHICLES).

TABLE 5-1

P-1073A 

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TYPICAL PRIMARY SPS GIMBAL MOTOR CONTROL CIRCUIT

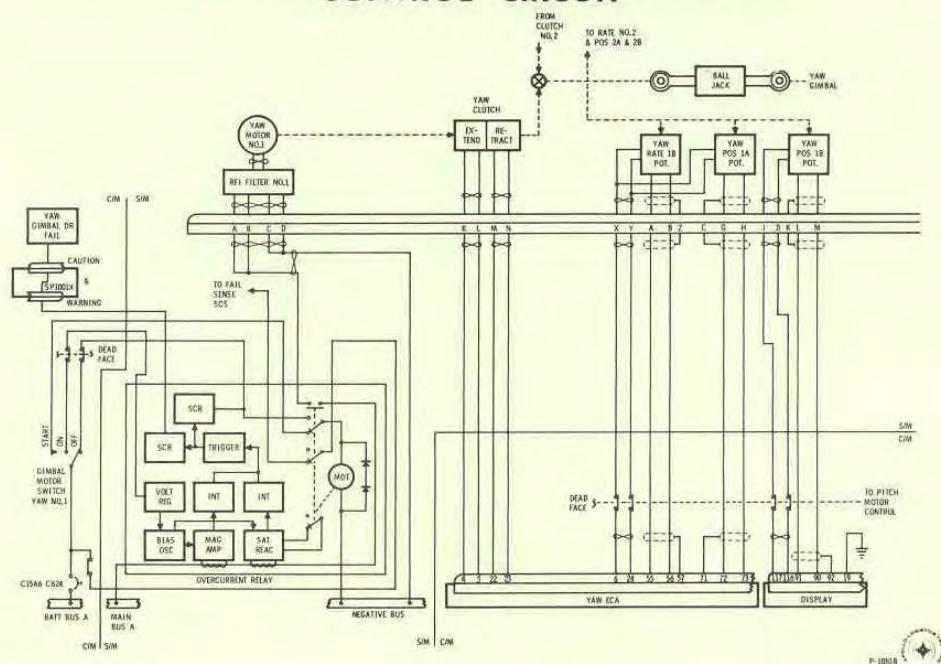


FIGURE 5-7

5-15

5.4.1.2 SERVO AMPLIFIER LIMITING

CURRENT LIMITERS ARE INCORPORATED AROUND THE SERVO AMPLIFIER FOR PROTECTION OF THE AMPLIFIERS. THE CURRENT LIMITER PERMITS A LINEAR OUTPUT UP TO 640 MA AND THEN CHANGES THE OUTPUT SLOPE BY GAIN CONTROL UNTIL A MAXIMUM OUTPUT OF 900 MA IS REACHED. THE OUTPUT SLOPE BECOMES ZERO AND WILL HAVE NO CHANGE IN THE OUTPUT CURRENT FOR AN INCREASED COMMAND SIGNAL INPUT.

5.4.1.3 RELAY SWITCHING

OPERATION OF THE PRIMARY GIMBAL POSITION LOOP REQUIRES NO RELAY SWITCHING. ALL RELAYS ARE DRAWN IN THE NORMALLY DE-ENERGIZED STATE WITH THE FUNCTION REQUIRED TO ENERGIZE A RELAY ADJACENT TO THAT RELAY. THE GIMBAL POSITION LOOP REQUIRES THE PRIMARY GIMBAL ACTUATOR MOTOR BE ON TO GENERATE CONTROLLING TORQUES AND THE TVC 1 POWER SWITCH BE ON TO PROVIDE AMPLIFIER OPERATION BEFORE THE SPS GIMBAL CAN BE HELD STATIONARY. THE REDUNDANT ACTUATOR MOTOR AND TVC ELECTRONICS MUST BE ON TO PROVIDE REDUNDANT SPS GIMBAL HOLD ABILITY.

5.4.2 GIMBAL POSITION TRIM

THE GIMBAL POSITION TRIM INPUT IS FOR MANUALLY POSITIONING THE SPS ENGINE GIMBALS PRIOR TO EACH DELTA V MANEUVER. IT IS PROCESSED THROUGH TWO DC AMPLIFIERS BEFORE BIASING THE GIMBAL POSITIONING LOOP. THE GIMBAL POSITION DISPLAY PROVIDES A READOUT OF THE SPS ENGINE GIMBAL FOR VERIFICATION OF THE TRIM POSITION.

THERE ARE TWO THRUST VECTOR GIMBAL POSITION TRIM POTS CONNECTED TO THE CONTROL KNOB. ONE SUPPLIES

THE NORMAL TVC TRIM REQUIREMENTS AND THE SECOND PROVIDES A TRIM CONTROL FOR THE MANUAL THRUST VECTOR CONTROL MODE. THE GIMBAL POSITION TRIM CONTROL BIASES THE SERVO POSITIONING LOOP FOR THE DESIRED DISPLACEMENT AT ENGINE IGNITION. INPUTS FROM THE INERTIAL SENSORS IN THE SCS OR G&N DELTA V MODE AND FROM THE ROTATION CONTROL IN THE MANUAL THRUST VECTOR CONTROL MODE WILL POSITION THE SPS ENGINE GIMBAL ABOUT THE TRIM POSITION. THE POSITION LIMITER WILL CONTROL THE MAGNITUDE OF THE TOTAL GIMBAL COMMAND INPUT TO THE SERVO AMPLIFIER.

5.4.3 COMMAND SIGNAL INPUTS

THERE ARE THREE INERTIAL SENSORS THAT CAN PROVIDE COMMAND SIGNALS INTO THE SERVO POSITIONING LOOP FOR NORMAL DELTA V MANEUVERS. THE ROTATION CONTROL INPUTS WILL BE USED AS COMMAND INPUTS ONLY FOR THE MANUAL THRUST VECTOR CONTROL MODE. THE INERTIAL SENSOR INPUTS WILL NOT BECOME ACTIVE INPUTS UNTIL THE THRUST ON COMMAND IS GENERATED FROM THE SPS THRUST CONTROL LOGIC TO ENERGIZE RELAY K9. EXCEPT FOR MANUAL THRUST VECTOR CONTROL, THE ONLY COMMAND INPUT ACTIVE BEFORE THE THRUST ON (ENGINE IGNITION) SIGNAL IS GENERATED WILL BE THE GIMBAL POSITION TRIM.

5.4.3.1 RATE GYRO INPUT

FOR THE G&N AND SCS DELTA V MODE, THE YAW RATE GYRO WILL PROVIDE THE REQUIRED STABILITY TO OPPOSE ANY SUDDEN ANGULAR MOTION. THE RATE GYRO SIGNAL IS PROCESSED THROUGH BODY BENDING FILTERS TO PROVIDE RATE STABILITY, BUT AN ATTITUDE ERROR OR STEERING COMMAND INPUT IS REQUIRED TO CORRECT FOR THE CENTER OF GRAVITY

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TRAVEL AND THRUST VECTOR MISALIGNMENT WITH RESPECT TO THE CENTER OF GRAVITY. AN ALTERNATE SOURCE OF RATE CAN BE OBTAINED FROM THE BMAG IF IT IS PLACED IN A BACKUP RATE CONDITION (BUY) AND ENERGIZES RELAYS K4 AND K8. LOSS OF THE ATTITUDE ERROR OUTPUT CAPABILITY FROM THE BMAG WOULD ALSO REMOVE THE CAPABILITIES OF THE SCS DELTA V MODE.

5.4.3.2 G&N INPUT COMMANDS

THE G&N INPUTS REPRESENT ATTITUDE ERROR INPUTS TO THE THRUST VECTOR CONTROL ELECTRONICS. HOWEVER, THE INPUTS WILL BE A COMPOSITE OF STEERING COMMANDS FOR TRAJECTORY CORRECTIONS AND ATTITUDE CHANGES REQUIRED TO COMPENSATE FOR CG TRAVEL. THE INPUT COMMANDS FROM THE G&N SYSTEM WILL CAUSE THE SPS GIMBAL TO BE DISPLACED, CREATING THE NECESSARY LEVER ARMS AND MOMENTS FOR CHANGES IN THE S/C ATTITUDE. THE STEERING COMMANDS PERMIT THE G&N SYSTEM TO PERFORM CURVED TRAJECTORIES.

THE G&N INPUT IS ACTIVATED THROUGH RELAY K1 WHEN THE G&N DELTA V MODE IS SELECTED. THEREFORE, AFTER THE THRUST ON COMMAND BY THE SPS THRUST ON-OFF ELECTRONICS, RELAY K9 WILL CLOSE, INSERTING RATE AND ATTITUDE SIGNALS INTO THE TVC ELECTRONICS. THE ATTITUDE ERROR LIMITER PREVENTS THE G&N OR SCS COMMAND INPUTS FROM EXCEEDING $\pm 8^\circ$ IN THE PITCH AND YAW AXES. THE INTEGRATOR IS NOT USED WITH THE G&N DELTA V MODE SELECTED.

COMMANDED BY THE SPS THRUST ON-OFF LOGIC WHICH ENERGIZES RELAY K6 IF THE SCS DELTA V MODE IS SELECTED. RELAY K6 CONVERTS THE AMPLIFIER TO AN INTEGRATOR AT ENGINE IGNITION TO PREVENT UNDERSIRABLE INTEGRATED OUTPUTS UPON INSERTION INTO THE THRUST VECTOR CONTROL ELECTRONICS WHEN THE SPS THRUST ON COMMAND CLOSING RELAY K10. THE INTEGRATOR OUTPUT IS THE FIRST INTEGRAL OF THE SIGNAL INPUT. ALL AMPLIFIERS IN THE THRUST VECTOR CONTROL SUBSYSTEM INVERT THE POLARITY OF THE DC SIGNAL LEVEL.

5.4.3.5 MANUAL THRUST VECTOR CONTROL INPUTS

SELECTING THE MTVC MODE REMOVES ALL NORMAL G&N OR SCS INPUTS TO THE SERVO AMPLIFIERS. RELAYS K10, K11, K13, K14, AND K5 WILL BE ENERGIZED. RELAY K10 REMOVES THE NORMAL INPUTS FROM THE G&N AND SCS. RELAY K11 INSERTS THE MTVC COMMANDS INTO THE GIMBAL POSITION ELECTRONICS. RELAY K13 REMOVES THE SERVO DRIVE AMPLIFIERS OUTPUT FROM THE MAGNETIC CLUTCHES IN THE PRIMARY GIMBAL POSITIONING LOOP. RELAY K14 CONNECTS THE OUTPUT OF THE REDUNDANT SERVO DRIVE AMPLIFIER TO THE REDUNDANT MAGNETIC CLUTCHES. RELAY K5 INSERTS THE RATE CAGED BMAG OUTPUT INTO THE MTVC ELECTRONICS TO PROVIDE THE REQUIRED RATE DAMPING FOR MTVC OPERATION.

THE MTVC MODE WILL BE USED PRIMARILY TO ATTENUATE RATES CREATED BY MALFUNCTIONS IN THE SCS OR G&N DELTA V MODES. THE THRUSTING MANEUVER WOULD BE TERMINATED AFTER THE RATES ARE REDUCED AND THE RCS WOULD COMPLETELY STABILIZE THE S/C WITH THE SPS ENGINE OFF. IT WOULD REQUIRE EXCESSIVE RCS PROPELLANTS TO

5.4.3.3 SCS INPUT COMMANDS

THE YAW BMAG INPUT REPRESENTS ATTITUDE CHANGES EXPERIENCED BY THE SPACECRAFT. FOR THE INSTANTANEOUS CONDITION OF THRUSTING, THE BMAG OUTPUT WILL BE EQUIVALENT TO THE SPACECRAFT RE-ORIENTATION REQUIRED TO MAINTAIN AN INERTIALLY ORIENTED THRUSTING FRAME. THE BMAG CAN CONTROL ONLY THE INERTIALLY ORIENTED THRUSTING MANEUVERS WHEN OPERATED IN CONJUNCTION WITH THE THRUST VECTOR CONTROL INTEGRATOR. THE BMAG'S ARE USED TO PROVIDE ATTITUDE ERROR REFERENCE INPUTS IN THE SCS DELTA V MODE WHICH IS A BACKUP TO THE G&N DELTA V MODE. THE BMAG INPUT IS ACTIVATED BY RELAY K2. IT IS ENERGIZED BY SELECTING THE SCS DELTA V MODE PROVIDING BACKUP RATE OR MTVC ARE NOT SELECTED.

5.4.3.4 THRUST VECTOR CONTROL INTEGRATOR

THE THRUST VECTOR CONTROL INTEGRATOR IS INCORPORATED TO CONTROL CROSS AXIS ACCELERATIONS AND VELOCITIES IN THE SCS DELTA V MODE; HOWEVER, IT DOES NOT REMOVE ALL CROSS AXIS VELOCITIES. WITHOUT THE INTEGRATOR, THE SCS DELTA V MODE WOULD EXCEED THE LATERAL DISPLACEMENT ALLOWABLE WHILE PERFORMING A DELTA V MANEUVER.

THE INTEGRATOR OUTPUT IS ENABLED BY SELECTION OF THE SCS DELTA V MODE WHICH ENERGIZES RELAY K7. INTEGRATION WILL NOT START UNTIL THE SPS THRUST ON IS

STABILIZE THE S/C WITH EXCESSIVE ANGULAR VELOCITIES CREATED BY THE SPS ENGINE.

5.4.4 G&N AND SCS DELTA V MODES

IN THE G&N DELTA V MODE OF OPERATION, THE ASTRONAUT WILL USE THE GIMBAL POSITION TRIM CONTROLS TO POSITION THE SPS GIMBALLED ENGINE SUCH THAT THE THRUST VECTOR WILL BE THROUGH THE CG IN THE THRUSTING DIRECTION. AT SPS ENGINE IGNITION THE RATE GYRO AND ATTITUDE ERROR SIGNAL WILL BECOME ACTIVE INPUTS TO CONTROL THE SPS THRUST VECTOR. THE ATTITUDE ERROR INPUTS ARE PROCESSED THROUGH THE ERROR LIMITER WHICH CONTROLS THE MAGNITUDE OF ATTITUDE ERROR INPUT. THE ERROR LIMITER RESTRICTS THE COMMAND ATTITUDE ERROR INPUT TO APPROXIMATELY $\pm 8^\circ$. IN THE G&N DELTA V MODE, THE TOTAL SPACECRAFT ATTITUDE CHANGE CAN BE GREATER BUT THE OUTER STEERING WILL ALWAYS SEND ATTITUDE ERRORS OF $\pm 8^\circ$ OR LESS TO ACCOMPLISH THE ATTITUDE CHANGE. FOR THE INSTANTANEOUS CONDITION, THE ATTITUDE ERROR WILL REFLECT THE ATTITUDE CHANGE REQUIRED BECAUSE OF CG TRAVEL WHILE THRUSTING.

THE SCS DELTA V MODE WILL USE THE GIMBAL POSITION TRIM CONTROLS TO PERFORM THE INITIAL ALIGNMENT, AS IN THE G&N DELTA V MODE. THE YAW BMAG AND THRUST VECTOR CONTROL INTEGRATOR WILL APPROXIMATE INSTANTANEOUS FIXED ANGLE THRUST VECTOR CONTROL. ASSUME ZERO INITIAL ERROR AND THEN AN ATTITUDE ERROR IS DETECTED BY THE BMAG AS A RESULT OF CG TRAVEL. THE ATTITUDE ERROR SIGNAL INPUT WILL INITIATE CORRECTIVE MOTION OF THE SPS ENGINE GIMBAL. THE POSITION FEEDBACK

WILL BE OF THE SAME POLARITY AT THE BMAG INPUT. THEREFORE, THE INTEGRATOR WILL HAVE AN INPUT GREATER THAN THE BMAG SIGNAL. THE OUTPUT IS INVERTED WITH RESPECT TO THE INPUT AND SUMMED WITH THE INVERTED ATTITUDE ERROR SIGNAL PRIOR TO THE ERROR LIMITER. THE INCREASED SIGNAL LEVEL CAUSES THE SPS ENGINE GIMBAL TO DRIVE PAST THE DESIRED ANGLE TO INDUCE OPPOSITE ROTATIONS INTO THE SPACECRAFT. THIS WILL TERMINATE LATERAL ACCELERATION AND REDUCE THE LATERAL VELOCITIES. SOME LATERAL VELOCITY MAY REMAIN BUT THEY SHOULD BE SMALL WHEN COMPARED TO THE VELOCITY ACHIEVED IN THE DESIRED THRUSTING DIRECTION. AFTER OSCILLATIONS HAVE STOPPED, THE STEADY STATE SIGNAL OUTPUT FROM THE BMAG WILL BE EQUAL AND OPPOSITE TO THE POSITION FEEDBACK SIGNAL AT THE INPUT SUMMING JUNCTION FOR THE TVC INTEGRATOR. THE INVERTED OUTPUT OF THE BMAG WILL BE ALGEBRAICALLY SUMMED WITH THE OUTPUT OF THE TVC INTEGRATOR AT THE SUMMING JUNCTION FOR THE ERROR LIMITER. THE SIGNALS WILL BE OF OPPOSITE POLARITY, BUT THE TVC INTEGRATOR WILL HAVE THE LARGEST SIGNAL LEVEL. THEREFORE, THE RESULTING SIGNAL, WHEN PROCESSED THROUGH THE NEXT TWO AMPLIFIERS, WILL BE EQUAL AND OPPOSITE TO THE POSITION FEEDBACK AT THE SUMMING JUNCTION FOR THE SERVO DRIVE AMPLIFIER. IN THIS HYPOTHETICAL CONDITION, NO EFFECTIVE DRIVE SIGNAL WOULD BE SENSED BY THE SERVO DRIVE AMPLIFIER AND THE THRUST VECTOR WOULD BE THROUGH THE CG WITH AN INERTIALLY ORIENTED ATTITUDE.

THE G&N DELTA V MODE DOES NOT REQUIRE AN INTEGRATOR SIMILAR TO THE SCS BECAUSE THE THREE ACCELEROMETERS ON THE INERTIAL MEASUREMENT UNIT IN THE G&N

SYSTEM PROVIDE DATA TO THE APOLLO GUIDANCE COMPUTER SO THAT SOLUTIONS TO STEERING EQUATIONS WILL INCORPORATE THE REQUIRED CORRECTIONS. THERE SHOULD BE NO RESIDUAL LATERAL ACCELERATIONS OR VELOCITIES IN THE G&N DELTA V MODE. HOWEVER, THE ACCELEROMETER SENSITIVITY WILL BE A CONTRIBUTING FACTOR.

5.5 SPS THRUST CONTROL LOGIC

THE SPS THRUST CONTROL LOGIC, FIGURE 5-8, PROVIDES THE NECESSARY ON-OFF CONTROL FOR THE SPS ENGINE. ITS PRIMARY FUNCTION IS TO ACTIVATE THE TWO SETS OF FUEL AND OXIDIZER SOLENOID VALVES AND INDICATE VISUALLY THAT THRUST IS IN PROGRESS. THE LOGIC OPERATION IS DEPENDENT UPON EXTERNAL INPUTS AND SWITCHES TO GENERATE THE THRUST ON-OFF COMMANDS AND DISPLAY SIGNALS.

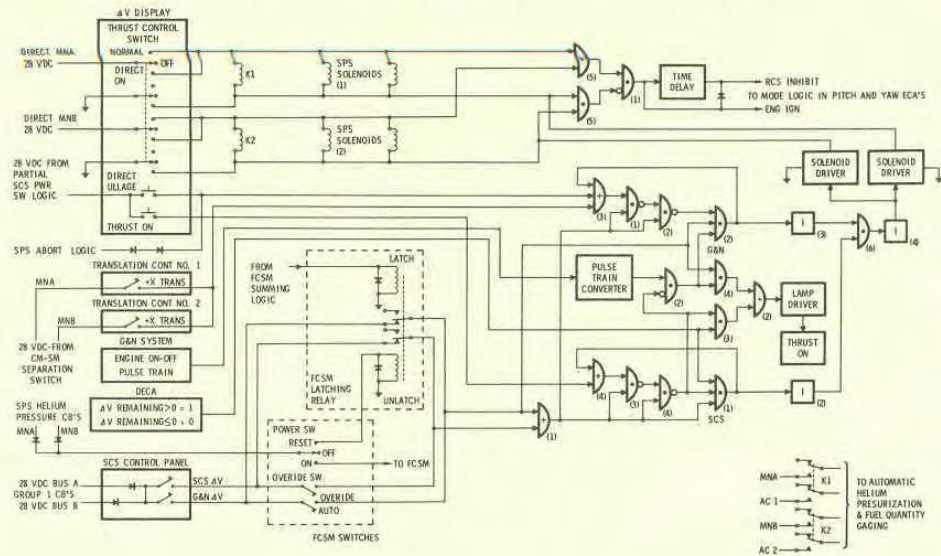
5.5.1 LOGIC INPUTS

THE INPUTS ARE DERIVED FROM THE DELTA V DISPLAY, TRANSLATION CONTROLS, DISPLAY SECTION OF THE DISPLAY/AGAP ECA, APOLLO GUIDANCE COMPUTER AND THE SCS CONTROL PANEL. EACH UNIT HAS ONE OR MORE DISCRETE INPUTS TO THE SPS THRUST CONTROL LOGIC.

5.5.1.1 DELTA V DISPLAY

THE DELTA V DISPLAY PROVIDES THREE SWITCHING INPUTS. THE SWITCHES ARE THRUST CONTROL SWITCH, THRUST ON SWITCH, AND DIRECT ULLAGE SWITCH. THE THRUST

SPS THRUST CONTROL LOGIC



SCS-7000

FIGURE 5-8

CONTROL SWITCH HAS THREE POSITIONS. FROM TOP TO BOTTOM THEY ARE; NORMAL, OFF, AND DIRECT ON. THE NORMAL POSITION PROVIDES THE NORMAL ARMING OF THE SPS ENGINE SOLENOID VALVES TO PERMIT A G&N AUTOMATIC OR SCS MANUAL THRUST ON COMMAND TO ACTIVATE THE SOLENOIDS. THE AUTOMATIC OFF COMMANDS WILL BE GENERATED FROM THE APOLLO GUIDANCE COMPUTER OR THE SCS WHEN THE DESIRED AMOUNT OF VELOCITY IS OBTAINED. THE OFF POSITION WILL REMOVE ELECTRICAL POWER FROM THE SPS ENGINE SOLENOID VALVES AND PROVIDE A BACKUP DIRECT THRUST OFF COMMAND TO TERMINATE OR PREVENT INITIATING OF THRUSTING WITH THE SPS ENGINE AT ANY TIME DURING THE MISSION. THE DIRECT ON POSITION OF THE THRUST CONTROL SWITCH PERMITS ENERGIZING THE SPS ENGINE SOLENOID VALVES IN THE EVENT OF A MALFUNCTION IN THE SPS THRUST CONTROL LOGIC. THIS POSITION OF THE THRUST CONTROL SWITCH REQUIRES MANUAL USE OF THE DIRECT THRUST OFF TO TERMINATE THE THRUSTING MANEUVER WITH THE SPS ENGINE. IT WILL BE USED IN EVENT OF MALFUNCTIONS ONLY.

THE THRUST CONTROL SWITCH PROVIDES POWER FROM THE DC BUSES THROUGH THE DIRECT CIRCUIT BREAKERS. SPS SOLENOID SET 1 WILL BE CONNECTED TO MN BUS A AND SET 2 WILL BE CONNECTED TO MN BUS B WHEN THE THRUST CONTROL SWITCH IS IN THE NORMAL OR DIRECT ON POSITION. THE NORMAL POSITION SWITCHES HIGH SIDE POWER ONLY AND THE DIRECT ON POSITION SWITCHES HIGH AND LOW SIDES OF THE POWER AS SHOWN IN FIGURE 5-8.

THE THRUST ON SWITCH IS A MOMENTARY CONTACT SWITCH FOR MANUALLY INITIATING SPS ENGINE IGNITION IN

THE SCS DELTA V MODE. THE SWITCH HAS A TALK BACK LIGHT THAT WILL BE ILLUMINATED AT ALL TIMES WHEN THE G&N COMPUTER OR THE THRUST ON SWITCH IS USED TO ENERGIZE THE SPS ENGINE SOLENOID VALVES. WHEN THE THRUST ON SWITCH IS USED TO INITIATE SPS ENGINE THRUST, THE AUTOMATIC OFF COMMAND WILL BE DERIVED FROM WITHIN THE SCS.

THE DIRECT ULLAGE SWITCH IS A BACKUP METHOD OF PERFORMING AN ULLAGE PRIOR TO IGNITION OF THE SPS ENGINE. IT INHIBITS PITCH AND YAW ATTITUDE HOLD; THEREFORE, THE INITIAL THRUSTING ATTITUDE IS DEGRADED. IT WOULD BE USED ONLY IF MALFUNCTIONS PREVENTED USE OF THE +X TRANSLATION CAPABILITY OF THE TRANSLATION CONTROLS. THE DIRECT ULLAGE SWITCH WILL ALSO PROVIDE THE LOGIC INPUT WHICH ENABLES THE G&N SYSTEM TO AUTOMATICALLY IGNITE THE SPS ENGINE. THE INPUT IS RECEIVED AT OR GATE 3.

5.5.1.2 TRANSLATION CONTROLS

THE TRANSLATION CONTROLS ARE THE PRIMARY METHOD OF PERFORMING THE REQUIRED MANUAL ULLAGE PRIOR TO IGNITION OF THE SPS ENGINE. THEY PROVIDE THE ULLAGE AT A VARYING LEVEL BECAUSE OF INTERRUPTIONS THAT MAY OCCUR FOR MAINTAINING PITCH AND YAW ATTITUDE HOLD. THIS ACTION REDUCES INITIAL ERROR INPUT TO THE THRUST VECTOR CONTROL ELECTRONICS UPON IGNITION OF THE SPS ENGINE. THE LOGIC INPUT IS PROVIDED INTO OR GATE 3 TO PERMIT AUTOMATIC IGNITION OF THE SPS ENGINE.

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5.5.1.3 DISPLAY/AGAP ECA

THE INPUT FROM THE DECA IS GENERATED IN THE DISPLAY SECTION OF THE DISPLAY/AGAP ECA. THE GENERATION OF THIS SIGNAL IS A DIRECT FUNCTION OF THE DELTA V REMAINING DISPLAY. IF THE DISPLAY IS READING A VALUE GREATER THAN ZERO, A LOGIC ONE WILL PROVIDE AN ENABLING LOGIC SIGNAL TO AND GATES 1 AND 3 IN THE SPS THRUST CONTROL LOGIC. WHEN THE DELTA V REMAINING DISPLAY READS ZERO OR LESS, A LOGIC ZERO WILL PROVIDE A LOGIC INHIBIT INTO AND GATES 1 AND 3. THEREFORE, TO GENERATE AN SPS ENGINE IGNITION FROM THE SCS, THE LOGIC ONE MUST BE RECEIVED FROM THE DECA AND ABSENCE OF THIS LOGIC ONE WILL INHIBIT OR TERMINATE THRUSTING OF THE SPS ENGINE.

5.5.1.4 G&N SYSTEM

THE G&N SYSTEM PROVIDES A THRUST ON-OFF COMMAND FROM THE APOLLO GUIDANCE COMPUTER. THE THRUST ON COMMAND IS REPRESENTED BY THE PRESENCE OF A 102.4 KC SIGNAL. THE ABSENCE OF THE 102.4 KC SIGNAL REPRESENTS A THRUST OFF COMMAND. THE SPS THRUST CONTROL LOGIC HAS A PULSE TRAIN CONVERTER TO CONVERT THE 102.4 KC SIGNAL INTO A LOGIC SWITCHING SIGNAL. THE OUTPUT OF THE PULSE TRAIN CONVERTER WILL BE INHIBITED AT INHIBIT AND GATE 2 IF THE THRUST ON SWITCH, ON THE DELTA V DISPLAY, IS USED TO GENERATE THE SPS ENGINE IGNITION SIGNAL. THE LOGIC INPUT FROM THE PULSE TRAIN CONVERTER WILL BE PASSED THROUGH INHIBIT AND GATE 2 IF SCS HAS NOT COMMANDED A THRUST ON AND ENABLE AND GATES 2 AND 4.

5.5.1.5 SCS CONTROL PANEL

THE MODE SELECT INPUTS FROM THE SCS CONTROL PANEL ARE PROVIDED TO THE THRUST CONTROL LOGIC THROUGH THE FLIGHT COMBUSTION STABILITY MONITOR (FCSM). AFTER THE LOGIC SIGNALS ARE PASSED THROUGH THE FCSM, THEY PROVIDE ENABLING SIGNALS TO THE THRUST CONTROL LOGIC. THE G&N DELTA V LOGIC SIGNAL PROVIDES AN INPUT TO OR GATE 1 AND AND GATES 2 AND 4. THE SCS DELTA V LOGIC SIGNAL IS PROVIDED TO OR GATE 1 ONLY. THE OUTPUT FROM OR GATE 1 PROVIDES INPUTS TO NAND GATES 1 THROUGH 4, AND AND GATE 1. TO PERFORM A NORMAL THRUSTING MANEUVER WITH THE SPS ENGINE, ONE OF THE DELTA V MODES MUST BE SELECTED TO ENABLE INPUTS TO THE THRUST CONTROL LOGIC.

5.5.1.6 FLIGHT COMBUSTION STABILITY MONITOR

THE FCSM PROVIDES AN AUTOMATIC LOGIC THRUST OFF COMMAND FOR ROUGH COMPUTATION OF THE SPS ENGINE. ROUGH COMBUSTION WOULD BE A FUNCTION OF SPS OPERATION, BUT THE INTERFACE WITH SCS IS REQUIRED, FOR PROPER THRUST OFF TO INSURE THRUST WILL NOT BE COMMANDED ON AGAIN WITHOUT COMPLETE SHUTDOWN. THE FCSM LATCHING RELAY OPENS THE MODE SELECT LOGIC INPUT SO THAT ALL LOGIC HOLDING CIRCUITS WILL DROP OUT. A FULL THRUST ON LOGIC SEQUENCE MUST BE FOLLOWED BEFORE THE SPS ENGINE IS TURNED ON AGAIN. TO RESET THE FCSM RELAYS, THE POWER SWITCH ON PANEL 2 MUST BE PLACED TO THE RESET POSITION WHICH ENERGIZES THE UNLATCH COILS AND ENABLES THE LOGIC PATH.

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SHOULD THE FCSM FAIL, OR FOR THE CREW'S SAFETY, AN OVERRIDE SWITCH IS PROVIDED. THE OVERRIDE SWITCH IS LOCATED ON PANEL 2. IT HAS TWO POSITIONS, AUTO AND OVERRIDE. THE AUTO POSITION IS OFF AND NO SIGNALS WILL BE PASSED. THE OVERRIDE POSITION BY-PASSES AND PREVENTS THE FCSM FROM CONTROLLING THE MODE SELECT LOGIC SIGNAL TO THE SPS THRUST CONTROL LOGIC.

5.5.2 SPS THRUST CONTROL LOGIC OPERATION

THE OPERATION OF THE SPS THRUST CONTROL LOGIC IS DIVIDED INTO FOUR CATEGORIES, G&N DELTA V, SCS DELTA V, HYBRID, AND DIRECT.

5.5.2.1 G&N DELTA V MODE

THE G&N DELTA V MODE OF OPERATION WILL REQUIRE AND GATE 2 TO BE COMPLETELY ENABLED. ITS REQUIRED INPUTS WILL BE ULLAGE MANEUVER FROM OR GATE 3 AND THE HOLDING INPUT AFTER AND GATE 2 IS ENABLED, WHICH IS ALL PROCESSED THROUGH NAND GATES 1 AND 2, G&N DELTA V MODE SELECTED FROM THE SCS CONTROL PANEL, AND THE PULSE TRAIN CONVERTER OUTPUT OF LOGIC ONE TO INHIBIT AND GATE 2. IF THE SCS THRUST ON COMMAND HAS NOT BEEN COMMANDED ON, THE GATE WILL NOT BE INHIBITED AND A LOGIC ONE OUTPUT IS GENERATED FOR AND GATE 2. THE THREE INPUTS WILL ENABLE AND GATE 2 AND PROVIDE THE LOGIC ONE INPUT TO INVERTER 3 WHICH DISABLES AND GATE 6. INVERTER 4 WILL PROVIDE A LOGIC ONE SIGNAL TO THE SOLENOID DRIVERS AT THE TWO SETS OF SPS FUEL AND OXIDIZER SOLENOIDS. THE OUTPUT OF THE PULSE TRAIN CONVERTER WILL BE REMOVED AND DISABLE AND GATE 2 TO TERMINATE A G&N DELTA V MANEUVER.

5.5.2.2 SCS DELTA V MODE

THE SCS DELTA V MODE REQUIRES ENABLING AND GATE 1 TO INITIATE THRUSTING WITH THE SPS ENGINE. AND GATE 1 HAS THREE ENABLING INPUTS: THE INPUT FROM OR GATE 1 INDICATING A DELTA V MODE SELECTED, THE OUTPUT FROM THE DECA INDICATING A VALUE GREATER THAN ZERO SETTING ON THE DELTA V REMAINING DISPLAY, AND THE INPUT FROM THE THRUST ON SWITCH DESIRING THRUST TO BE INITIATED AFTER IT IS PROCESSED THROUGH NAND GATES 3 AND 4, INSURING A DELTA V MODE SELECTED. THE OUTPUT FROM AND GATE 1 IS INVERTED BY INVERTER 2 AND DISABLES AND GATE 6, WHICH IS INVERTED BY INVERTER 4 TO ENABLE THE SOLENOID DRIVERS. TERMINATION OF THE SCS DELTA V MANEUVER WILL BE A LOGIC ZERO FROM THE DECA INDICATING ZERO VELOCITY TO BE GAINED ON THE DELTA V REMAINING DISPLAY WHICH DISABLES AND GATE 1. THE OUTPUT FROM AND GATE 1 OPERATES INTO INVERTER 2, WHICH ENABLES AND GATE 6, AND THE SIGNAL IS INVERTED BY INVERTER 4 TO DE-ENERGIZE THE SOLENOID DRIVERS AND TERMINATE THRUSTING.

5.5.2.3 HYBRID MODE

THE HYBRID MODE IS A SPECIAL CASE WHERE THE OUTPUT OF OR GATE 1 ENABLES THE DELTA V MODE INPUT TO AND GATE 1, AND WITH THE REQUIREMENT OF SETTING THE DELTA V REMAINING DISPLAY FOR MONITORING ALL G&N DELTA V MANEUVERS, THE LOGIC OUTPUT FROM THE DECA WILL PROVIDE AN ENABLE INPUT FOR AND GATE 1. IF THE AUTOMATIC THRUST ON COMMAND DOES NOT ARRIVE FROM THE APOLLO GUIDANCE COMPUTER, THE THRUST ON SWITCH CAN BE DEPRESSED AND INITIATE THE ENGINE IGNITION COMMAND. THEREFORE, THE G&N WILL CONTROL THE TRAJECTORY AND THE SCS TOTAL

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VELOCITY IMPARTED BY THRUSTING. AT PRESENT, IT IS UNKNOWN IF THIS WILL BE DESIRABLE UNLESS THE COMPLETE STATUS OF THE G&N SYSTEM IS KNOWN.

5.5.2.4 DIRECT MODE

THE DIRECT OPERATING MODE BY-PASSES ALL ELECTRONICS AND SUPPLIES 28 VDC AND GROUND CIRCUITS DIRECT FROM THE THRUST CONTROL SWITCH. THE DIRECT OPERATION ALSO REQUIRED MANUAL CREW ACTION TO INITIATE AND TERMINATE THRUST FROM THE SPS ENGINES.

5.5.2.5 BACKUP THRUST OFF

IF THE AUTOMATIC THRUST OFF COMMAND FAILS FOR THE G&N, SCS, OR HYBRID MODES, THE THRUST CONTROL SWITCH WILL BE USED TO TERMINATE THE THRUSTING MANEUVER. THE BACKUP THRUST OFF OPERATION WILL TERMINATE A THRUSTING MANEUVER AT ALL TIMES. IT REMOVES THE 28 VDC FROM THE SOLENOIDS REGARDLESS OF THE SPS THRUST CONTROL LOGIC CONDITIONS.

5.5.2.6 THRUST IN PROGRESS INDICATION

IN ADDITION TO THE OPERATING CONDITIONS DISCUSSED, THE SPS THRUST CONTROL LOGIC WILL PROVIDE ILLUMINATION OF THE TALKBACK LIGHT IN THE THRUST ON SWITCH. TO ILLUMINATE THE LIGHT IN A G&N DELTA V MODE, AND GATE 4 MUST BE ENABLED. IT HAS TWO INPUTS WHICH ARE G&N DELTA V MODE SELECTED AND THE PRESENCE OF A LOGIC ONE OUTPUT FROM INHIBIT AND GATE 2. WITH AND

GATE 4 ENABLED, OR GATE 2 WILL TRIGGER THE LAMP DRIVER AND ILLUMINATE THE THRUST ON LIGHT. TO ILLUMINATE THE LIGHT IN THE SCS DELTA V MODE, AND GATE 3 MUST BE ENABLED. THE TWO ENABLING SIGNALS TO AND GATE 3 ARE FROM THE THRUST ON SWITCH AND DECA. WHEN AND GATE 3 IS ENABLED, IT WILL ALSO SATISFY OR GATE 2 AND TRIGGER THE LAMP DRIVER. THE SPS THRUST CONTROL LOGIC IS INTERLOCKED SO THAT AND GATES 3 AND 4 WILL NEVER BE ENABLED SIMULTANEOUSLY BECAUSE OF THE THRUST ON SWITCH INHIBITED TO THE PULSE TRAIN CONVERTER. THEREFORE, THE THRUST ON LIGHT WILL BE ILLUMINATED AT ALL TIMES WHEN THE THRUST IS ON FOR NORMAL OPERATION. IF THE DIRECT FUNCTION IS USED TO INITIATE THRUSTING, IT WILL BY-PASS ALL ELECTRONICS AND NOT ILLUMINATE THE THRUST ON LIGHT.

5.5.3 SPS THRUST CONTROL LOGIC OUTPUTS

THE OUTPUT FROM THE SPS THRUST CONTROL LOGIC PERFORMS A FUNCTION OTHER THAN ENERGIZE THE SPS SOLENOID VALVES AND RELAYS K1 AND K2. IT PROVIDES THE LOGIC SWITCHES REQUIRED TO RECONFIGURE THE SCS RELAYS FOR PROPER THRUST VECTOR CONTROL. THE THRUST CONTROL SWITCH PROVIDES BOTH INPUTS TO OR GATE 5 IF BOTH DC BUSES ARE OPERATIONAL. EITHER DC BUS WILL ENABLE OR GATE 5 TO PROVIDE THE UPPER INPUT TO INHIBIT AND GATE 1. AND GATE 5 PROVIDES THE CONTROLLING INPUT TO THE INHIBIT AND GATE 1. WHEN THE SOLENOID DRIVERS ARE NOT ENERGIZED AND THE THRUST CONTROL SWITCH IS IN NORMAL, BOTH INPUTS TO AND GATE 5 ARE TRUE. THE TRUE INPUT WILL MAINTAIN A LOGIC FALSE OUTPUT FROM THE

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INHIBIT AND GATE 1 BECAUSE OF THE INVERSION ON THE INPUT OF THE GATE. WHEN EITHER SPS SOLENOID SET IS ACTIVATED BY A SOLENOID DRIVER OR BY THE GROUND CONTACTS OF THE DIRECT ON SWITCH, AND GATE 5 WILL BE DISABLED BY THE GROUND OR FALSE INPUT. THE OUTPUT WILL BE INVERTED BY THE INHIBIT AND GATE 1 INPUT TO ENABLE AN OUTPUT TO THE TIME DELAY. THE TIME DELAY IS REQUIRED TO PERMIT THRUST BUILD UP FROM THE SPS ENGINE BEFORE THE ULLAGE MANEUVER IS TERMINATED; HOWEVER, THE PITCH AND YAW ATTITUDE ERROR INPUTS ARE INSERTED INTO THE TVC ELECTRONICS IMMEDIATELY. THIS ACTION ASSURES POSITIVE G FORCES THROUGHOUT THRUST INITIATION OF THE SPS ENGINE AND GIMBALLING CONTROL OF THE SPS ENGINE FOR THE ENTIRE THRUST BUILD UP. THE TIME DELAY IS ALSO ACTIVE AFTER INHIBIT AND GATE 1 IS DISABLED BY ENABLING AND GATE 5. AND GATE 5 IS ENABLED WHEN BOTH SETS OF SPS SOLENOID VALVES ARE DE-ENERGIZED. THE TIME DELAY IS ACTIVE FOR BOTH OUTPUTS WHEN THE SIGNAL IS REMOVED TO PERMIT CONTINUED SPS ENGINE GIMBAL CONTROL WHILE THE RESIDUAL THRUST IS PRESENT AND INHIBIT RCS OPERATION IN PITCH AND YAW UNTIL RESIDUAL THRUST IS REDUCED. THIS REDUCES THE TUMBLING INDUCED AT THRUST TERMINATION. THE TIME DELAY IS APPROXIMATELY ONE SECOND FOR APPLICATION AND REMOVAL OF THE ENGINE IGNITION SIGNAL.

RELAYS K1 AND K2 ARE TO AUTOMATICALLY ENABLE FUNCTIONS IN THE SPS COMMENSURATE WITH A THRUST ON COMMAND. THE POWER INPUTS TO THE FUEL QUANTITY GAGING SYSTEM IS THE CONTROLLING INPUT WITH NO MANUAL OVERRIDE FOR POWER INPUTS. THE HELIUM PRESSURIZATION IS INTERFACED WITH ENABLING SWITCHES IN THE SPS AND REQUIRES THEY BE POSITION CORRECTLY TO COMPLETE AUTOMATIC

PRESSURIZATION. THERE ARE MANUAL OVERRIDE SWITCHES TO PERFORM HELIUM PRESSURIZATION IF REQUIRED FOR A SPS THRUSTING OR AS REQUIRED FOR OTHER SPS OPERATIONS.

5.6 DELTA V DISPLAY

THE DELTA V DISPLAY PROVIDES VISUAL INDICATIONS AND CONTROL DIRECTLY ASSOCIATED WITH THRUST VECTOR CONTROL. FIGURE 5-9 IS DIRECTLY ASSOCIATED WITH MEASURING THE ACTUAL VELOCITY IMPARTED TO THE SPACECRAFT THAT WILL MODIFY THE S/C TRAJECTORY.

5.6.1 OUTPUTS

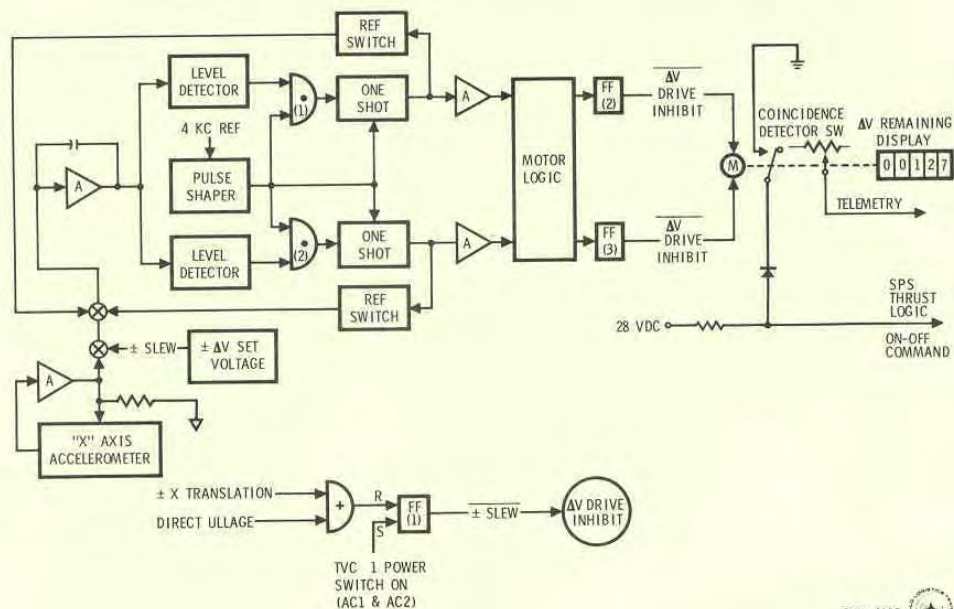
THERE ARE THREE OUTPUTS ASSOCIATED WITH CONTROLLING THE DELTA V. THEY ARE; (1) SPS THRUST LOGIC ON-OFF COMMAND, (2) DELTA V REMAINING DISPLAY READOUT, AND (3) DELTA V TELEMETRY OUTPUT.

5.6.1.1 THRUST OFF COMMAND

THE SPS THRUST CONTROL LOGIC ON-OFF COMMAND TERMINATES THE THRUSTING FROM THE SPS ENGINE WHEN THE VELOCITY TO BE GAINED IS ZERO. THIS FUNCTION WILL HAVE A VALID INPUT TO THE SPS THRUST CONTROL LOGIC IN THE AUXILIARY ECA FOR THE SCS DELTA V MODE WHEN THE THRUST CONTROL SWITCH, ON THE DELTA V DISPLAY, IS IN THE NORMAL POSITION.

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ΔV DISPLAY BLOCK DIAGRAM



SCS-408C

FIGURE 5-9

5-26

5.6.1.2 DELTA V REMAINING DISPLAY

THE DELTA V REMAINING DISPLAY PROVIDES A VISUAL INDICATION TO THE CREW OF THE INSTANTANEOUS DELTA V REMAINING. IT ALSO PROVIDES A COMPARISON FOR THE THRUST TERMINATION POINT AT ZERO SO THE CREW CAN PROVIDE A MANUAL BACKUP TO THE G&N AND SCS AUTOMATIC OFF COMMANDS PREVIOUSLY DISCUSSED IN THE SPS THRUST CONTROL LOGIC DISCUSSION. THE DELTA V REMAINING DISPLAY ALSO MEASURES THE TAIL-OFF VELOCITY IMPARTED BY THE SPS ENGINE SO THAT IT CAN BE INSERTED WHERE REQUIRED IN COMPUTATIONS.

5.6.1.3 TELEMETRY

THE DELTA V TELEMETRY OUTPUT PROVIDES GROUND BASED MONITORS WITH A GROSS INDICATION OF THE VELOCITY IMPARTED TO THE SPACECRAFT FOR THE DELTA V MANEUVER. IT HAS NO CREW VISIBILITY IN THE SPACECRAFT.

5.6.2 DELTA V DISPLAY OPERATION

TO OPERATE OR PERFORM INITIAL SET OF THE DELTA V REMAINING DISPLAY, THE TVC 1 POWER SWITCH MUST BE PLACED ON. THE APPLICATION OF POWER WILL SET FF #1 AND INHIBIT OPERATION OF THE COUNTER IN THE DELTA V REMAINING DISPLAY WHEN THE BOOLEAN NOTATION \pm SLEW IS TRUE. THE BOOLEAN NOTATION WILL BE FALSE WHEN THE DELTA V SET SWITCH IS DISPLACED FROM NEUTRAL. THIS PERMITS SETTING THE DELTA V COUNTER TO ANY DESIRED READING WITHIN ITS DISPLAY CAPABILITY. THE \pm DELTA V

SET VOLTAGE WILL PASS THROUGH THE BOOLEAN NOTATION \pm SLEW WHEN IT BECOMES TRUE BY DISPLACING THE DELTA V SET SWITCH FROM NEUTRAL. THE FUNCTION OF INHIBITING THE DRIVE FOR THE DELTA V COUNTER PREVENTS ANY STRAY SIGNALS FROM CHANGING THE DELTA V COUNTER PRIOR TO STARTING THE THRUSTING WITH THE ULLAGE MANEUVER. THE ULLAGE MANEUVERS INITIATED BY THE TRANSLATION CONTROLS OR DIRECT ULLAGE BUTTON WILL PASS THROUGH THE OR GATE AND RESET FF #1 AND ENABLE THE DELTA V COUNTER DRIVE FOR MONITORING THE CHANGES IN VELOCITY. TO INHIBIT THE DELTA V COUNTER AGAIN, THE POWER SWITCH MUST BE TURNED OFF, THEN ON TO SET FF #1.

THE ACCELEROMETER OUTPUT TO DRIVE THE DELTA V COUNTER WILL BE A VOLTAGE LEVEL PROPORTIONAL TO THE INSTANTANEOUS ACCELERATION DETECTED BY THE ACCELEROMETER. THE VOLTAGE LEVEL INPUT WILL BE AMPLIFIED AND PASSED TO THE LEVEL DETECTORS TO DETERMINE FORWARD OR REVERSE ROTATION FOR THE DELTA V COUNTER MOTOR. THE SIGNAL WILL THEN BE GATED THROUGH THE AND GATES WITH THE 4 KC REFERENCE FREQUENCY FOR SYNCHRONIZATION. THE PULSE SHAPER WILL HAVE A FREE RUNNING 4 KC OUTPUT IF THE CLOCK INPUT FAILS, BUT IT WILL NOT HAVE THE ACCURACY OF THE CLOCK REFERENCE FREQUENCY. THE OUTPUT FROM AND GATES 1 AND 2 WILL TRIGGER THE CORRECT "ONE SHOT" AND GENERATE A STEPPING SIGNAL TO THE DELTA V COUNTER MOTOR LOGIC AND PROVIDE THE NECESSARY FEEDBACK TO THE AMPLIFIER. FLIP FLOPS 2 AND 3 WILL BE USED TO STEP THE DELTA V COUNTER MOTOR AS DIRECTED BY THE MOTOR LOGIC. AS THE DELTA V COUNTER COUNTS TO ZERO WHILE THRUSTING, THE COINCIDENCE DETECTOR SWITCH WILL CLOSE, INITIATING THE THRUST OFF SEQUENCE FOR THE SCS DELTA V MODE.

SECTION VI
SCS POWER DISTRIBUTION

6.1 INTRODUCTION

THE ELECTRICAL POWER SYSTEM SUPPLIES THE SCS WITH 28 VDC FROM TWO SEPARATE BUSES; MAIN BUS A AND MAIN BUS B. IN ADDITION, IT SUPPLIES 115 VOLT, 3 PHASE, 400 CPS POWER FROM A Y-CONNECTED, 4 WIRE SOURCE WHICH ALSO USES TWO SEPARATE BUSES; BUS 1 AND BUS 2. THE TWO BUSES FOR AC AND DC POWER DISTRIBUTION PROVIDE REDUNDANCY FOR CRITICAL SCS FUNCTIONS IN CASE OF PARTIAL POWER FAILURE, SHORTS, ETC. IN THE FOLLOWING SECTIONS, THE TWO DC BUSES WILL BE REFERRED TO SIMPLY AS MN A AND MN B. THE TWO AC BUSES WILL BE CALLED AC 1 AND AC 2.

CONSIDERING FIGURE 6-1, IT CAN BE SEEN THAT THIS POWER IS SUPPLIED TO THE SCS THROUGH 18 CIRCUIT BREAKERS LOCATED ON THE LEFT HAND CIRCUIT BREAKER PANEL. FROM THESE CIRCUIT BREAKERS, THE POWER IS DISTRIBUTED TO THE SCS COMPONENTS THROUGH SIX POWER SWITCHES ON THE SEQUENCE CONTROLLER AND SCS POWER PANEL. THESE SIX SWITCHES ARE SUBDIVIDED INTO TWO GROUPS OF THREE SWITCHES EACH, CALLED GROUP 1 AND GROUP 2. THE GROUP 2 POWER SWITCHES SUPPLY POWER TO THOSE SCS COMPONENTS WHICH PROVIDE THE BACKUP (MANUAL TVC) CAPABILITY FOR CONTROLLING THE SPACECRAFT DURING THE CRITICAL PERIODS WHEN THE SPS ENGINE IS FIRING. THE GROUP 1 POWER SWITCHES SUPPLY POWER TO THE REST OF THE SCS.

ALL SIX POWER SWITCHES ACT INDEPENDENTLY OF EACH OTHER AND INDIVIDUALLY SELECT EITHER DC POWER FROM MN A AND AC POWER FROM AC 1, DC POWER FROM MN B AND AC POWER FROM AC 2, OR CAN SIMPLY BE OFF. THAT IS, A SINGLE POWER SWITCH SELECTS EITHER:

- A. MN A AND AC 1
- B. MN B AND AC 2
- C. OFF

SOME OF THE 28 VDC POWER IS DISTRIBUTED TO THE SCS DIRECTLY FROM THE CIRCUIT BREAKERS WITHOUT BEING ROUTED THROUGH ANY OF THE SIX SCS POWER SWITCHES. THE POWER DISTRIBUTION WILL BE SUBDIVIDED INTO THE FOLLOWING THREE SECTIONS:

- A. 28 VDC POWER WHICH DOES NOT GO THROUGH ANY OF THE POWER SWITCHES ON THE SEQUENCE CONTROLLER AND SCS POWER PANEL.
- B. 28 VDC AND 115 VAC POWER WHICH GOES THROUGH THE THREE GROUP 1 SCS POWER SWITCHES ON THE ABOVE MENTIONED PANEL.
- C. 28 VDC AND 115 VAC POWER GOING THROUGH THE THREE GROUP 2 POWER SWITCHES.

6-1

SCS POWER DISTRIBUTION FUNCTIONAL DIAGRAM

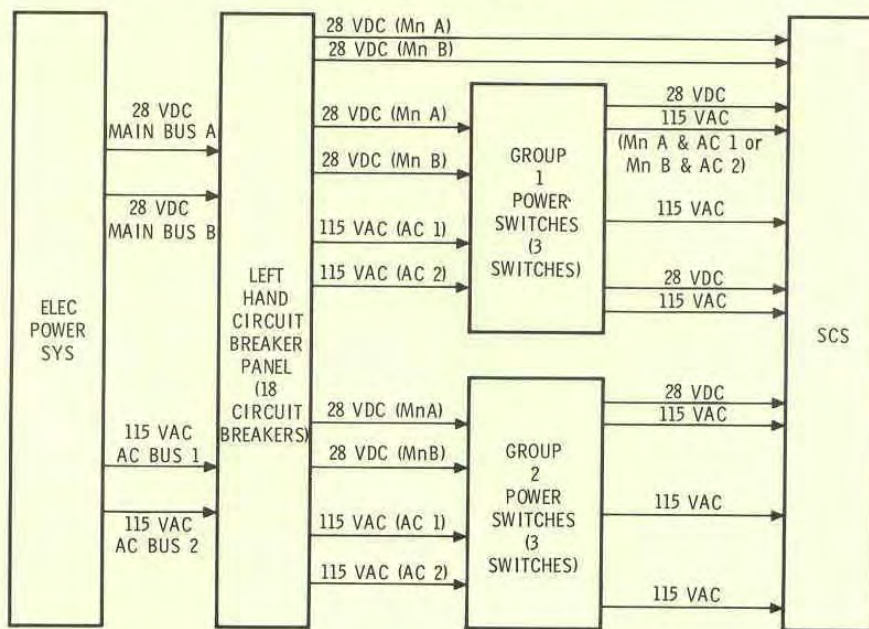


FIGURE 6-1

SCS-422B



6-2

A MORE DETAILED DISCUSSION WILL NOW BE GIVEN OF THE POWER DISTRIBUTION TO THE SCS, IN WHICH EACH OF THE ABOVE THREE CATEGORIES WILL BE TREATED SEPARATELY.

6.2 28 VDC NON-SWITCHED POWER

REFERRING TO FIGURE 6-2, IT CAN BE SEEN THAT THE 28 VDC NON-SWITCHED POWER IS DISTRIBUTED TO THE SCS THROUGH 14 OF THE 18 CIRCUIT BREAKERS ON THE LEFT HAND CIRCUIT BREAKER PANEL. THESE 14 CIRCUIT BREAKERS ARE LABELED; YAW, PITCH, A&C ROLL, B&D ROLL, GROUP 1, DIRECT CONT, AND GROUP 2. THIS POWER IS CALLED NON-SWITCHED POWER SINCE ITS AVAILABILITY TO THE SCS IS INDEPENDENT OF THE STATE OF THE SIX SCS POWER SWITCHES. THE POWER DISTRIBUTION FROM THESE CIRCUIT BREAKERS WILL NOW BE CONSIDERED ACCORDING TO THEIR FUNCTIONS.

6.2.1 REACTION JET CIRCUIT BREAKERS

THE YAW, PITCH, A&C ROLL, AND B&D ROLL CIRCUIT BREAKERS APPLY 28 VOLTS TO THE HIGH SIDE OF THE AUTOMATIC COILS FOR THE INDICATED JETS IN THE REACTION CONTROL SYSTEM. THE JETS CAN BE ACTIVATED BY THE SCS JET DRIVERS, WHICH SUPPLY A GROUND WHEN THE JET SHOULD BE ON. THE POWER FROM THE CIRCUIT BREAKERS GOES THROUGH THE CHANNEL ENABLE SWITCHES ON THE CONTROL PANEL, WHICH ARE LABELED YAW, PITCH, A&C ROLL, AND B&D ROLL. ANY OF THE FOUR CHANNELS CAN BE ENABLED SEPARATELY BY MEANS OF THESE SWITCHES.

6.2.2 GROUP 1 CIRCUIT BREAKERS

THE TWO GROUP 1 DC CIRCUIT BREAKERS SUPPLY 28 VOLTS TO THE REACTION JET DRIVERS, TRANSLATION CONTROLLERS, AND CONTROL PANEL. THEY ALSO SUPPLY DC POWER THROUGH TWO OF THE SCS POWER SWITCHES.

THE POWER TO THE REACTION JET DRIVERS GOES THROUGH A SET OF RELAYS IN THE TWO MASTER EVENT SEQUENCE CONTROLLERS (WHICH ARE NOT PART OF THE SCS), THROUGH THE CHANNEL ENABLE SWITCHES ON THE CONTROL PANEL, THROUGH A SET OF RELAYS IN THE SCS, AND FINALLY TO THE JET DRIVERS. THIS POWER DOES NOT TURN ON THE DRIVERS. IT IS MERELY AN ENABLE SIGNAL. THUS, IT CAN BE SEEN THAT THE CHANNEL ENABLE SWITCHES ON THE CONTROL PANEL DISABLE A GIVEN CHANNEL BOTH BY REMOVING THE POWER FROM THE HIGH SIDE OF THE COILS, AND ALSO BY DISABLING THE JET DRIVERS FOR THAT PARTICULAR CHANNEL. NOTICE THAT IN ANY GIVEN CHANNEL, HALF THE JETS GET THEIR POWER FROM BUS A AND HALF FROM BUS B. THIS MEANS THAT IF POWER ON ONE BUS IS LOST, DISABLING HALF THE JETS, THE REST OF THE JETS ON THE REMAINING BUS ARE SUFFICIENT TO PROVIDE POSITIVE OR NEGATIVE ROTATION IN ALL THREE AXES.

THE POWER, WHICH IS USED FOR COMMANDING NORMAL TRANSLATION MANEUVERS BY MEANS OF THE TRANSLATION CONTROLS, IS ROUTED THROUGH THE C/M-S/M SEPARATION SWITCH, SO THAT TRANSLATION CONTROL IS DEACTIVATED AFTER C/M-S/M SEPARATION. PRIOR TO THIS SEPARATION, HOWEVER,

6-3

NON-SWITCHED 28VDC POWER DISTRIBUTION

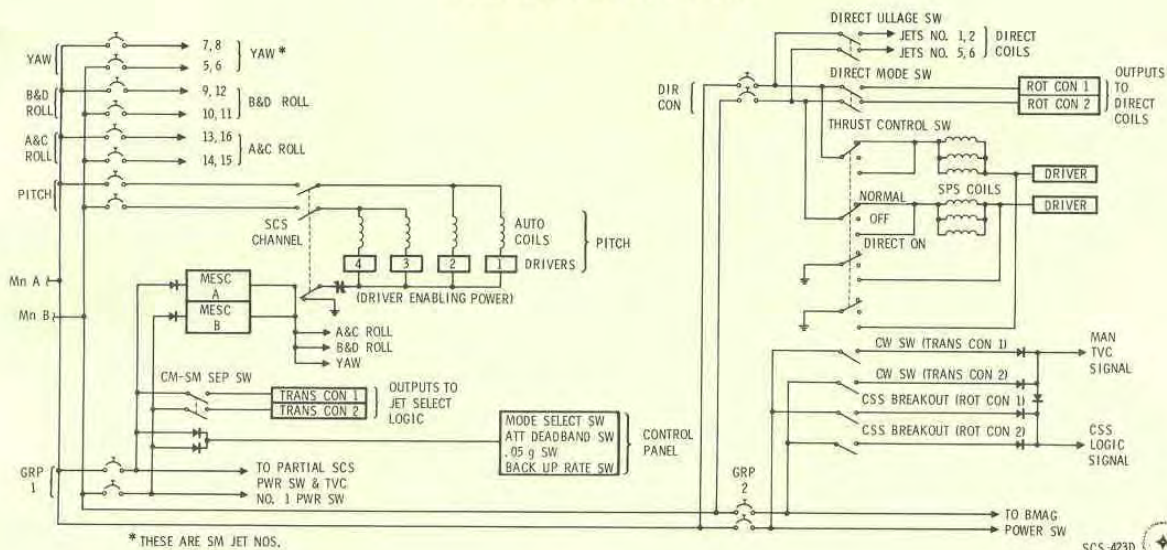


FIGURE 6-2

6-4

THE OUTPUTS OF THE TWO CONTROLLERS ARE ROUTED TO THE JET SELECT LOGIC TO PROVIDE 3 AXIS TRANSLATION CAPABILITY. AGAIN, THE TWO POWER BUSES, EACH FEEDING ONE TRANSLATION CONTROL, PROVIDE REDUNDANT POWER FOR TRANSLATIONAL MANEUVERS IN CASE OF A POWER FAILURE ON ONE BUS.

TWO ISOLATION DIODES FEED THE POWER FROM BOTH GROUP 1 DC BUSES TO THE INDICATED SWITCHES ON THE CONTROL PANEL. A MORE DETAILED DRAWING OF THE CONTROL PANEL IS SHOWN IN FIGURE 2-2.

FINALLY, IT CAN BE SEEN THAT DC POWER FROM THE GROUP 1 CIRCUIT BREAKERS IS ALSO ROUTED TO THE SCS POWER SWITCHES. THE DISTRIBUTION FROM THESE SWITCHES WILL BE COVERED UNDER THE SECTION DEALING WITH THE GROUP 1 POWER SWITCHES.

6.2.3 GROUP 2 CIRCUIT BREAKERS

IN REFERENCE TO FIGURE 6-2, IT CAN BE SEEN THAT THE TWO GROUP 2 DC CIRCUIT BREAKERS SUPPLY POWER TO THE CLOCKWISE SWITCHES ON THE TWO TRANSLATION CONTROLS, TO THE BREAKOUT SWITCHES ON THE ROTATION CONTROLS, AND TO THE BMAG POWER SWITCH. THE DISTRIBUTION FROM THE BMAG POWER SWITCH WILL BE COVERED IN THE SECTION DEALING WITH THE GROUP 2 POWER SWITCHES.

6.2.4 DIRECT CONTROL CIRCUIT BREAKERS

THE DIRECT CONTROL CIRCUIT BREAKERS ARE USED TO PROVIDE TWO REDUNDANT SOURCES OF POWER FOR DIRECT

ULLAGE, DIRECT ROTATION, AND THE SPS SOLENOID VALVES. EITHER ONE OF THE TWO BUSES IS SUFFICIENT TO PROVIDE A +X ULLAGE MANEUVER, THREE AXIS ROTATIONAL CONTROL, AND TURN-ON OF THE SPS ENGINE.

MANUAL DIRECT ROTATION CAN BE USED ANYTIME THE DIRECT CONTROL CIRCUIT BREAKERS ARE IN AND THE DIRECT MODE SWITCH ON. DIRECT ULLAGE IS AVAILABLE WHENEVER THE CIRCUIT BREAKERS ARE IN. AS A BACKUP CAPABILITY, THE SPS ENGINE COULD BE TURNED ON SIMPLY BY PUTTING THE THRUST CONTROL SWITCH IN THE DIRECT ON POSITION. THUS, IT CAN BE SEEN THAT THE POWER FROM DIRECT CONTROL CIRCUIT BREAKERS PROVIDES A BACKUP MEANS FOR THE CRITICAL MANEUVERS OF ULLAGE, ROTATION, AND SPS ENGINE THRUST ON. THESE BACKUP CAPABILITIES ARE INDEPENDENT OF THE SCS POWER SWITCHES AND WOULD BE AVAILABLE EVEN IF THE REST OF THE SCS WERE TO LOSE POWER.

6.3 GROUP 1 POWER

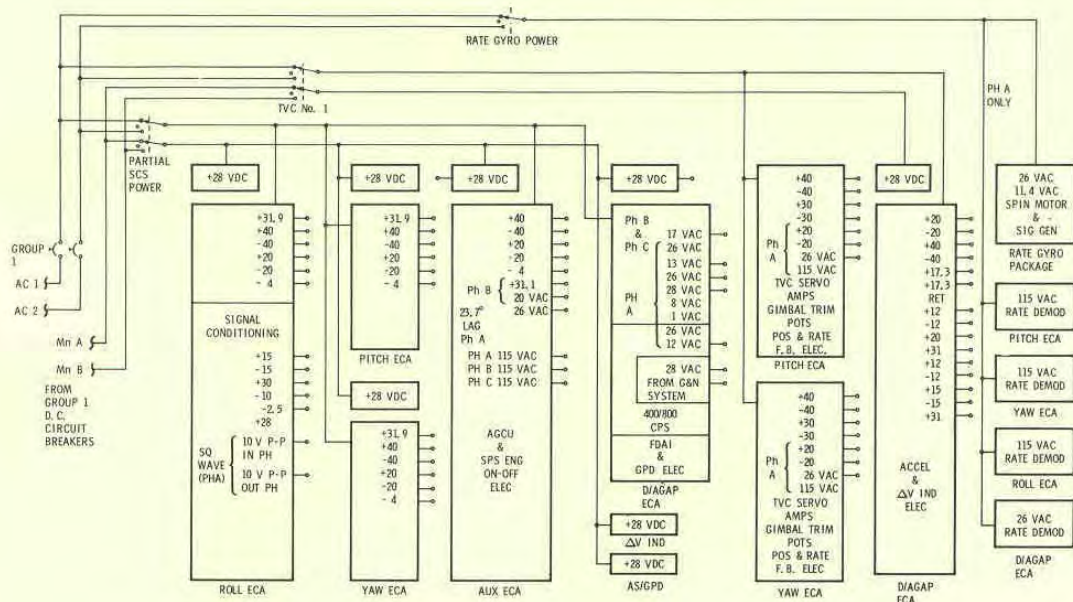
THERE ARE THREE SCS GROUP 1 POWER SWITCHES WHICH SUPPLY 28 VDC AND 115 VAC POWER TO THE SCS. THESE THREE SWITCHES ARE SHOWN IN FIGURE 6-3 AND ARE LABELED:

- PARTIAL SCS POWER
- TVC NO. 1
- RATE GYRO POWER

EACH SWITCH SELECTS EITHER THE COMBINATIONS OF AC 1 AND MN A OR AC 2 AND MN B, OR OFF. THE POWER DISTRIBUTION FROM THESE SWITCHES WILL BE DISCUSSED ONE AT A TIME.

6-5

GROUP 1 POWER DISTRIBUTION



SCS-47A

FIGURE 6-3

6-6

6.3.1 PARTIAL SCS POWER

THE PARTIAL SCS POWER SWITCH DISTRIBUTES POWER TO SEVEN UNITS IN THE SCS; THE ROLL, PITCH, YAW, AUXILIARY, AND DISPLAY/AGAP ECA'S, AS WELL AS THE DELTA V INDICATOR AND ATTITUDE SET/GIMBAL POSITION DISPLAY. EACH OF THE FIVE ECA'S CONTAINS RECTIFIERS AND VOLTAGE REGULATORS FOR GENERATING DC VOLTAGES FROM THE 115 VAC SUPPLY. UNLESS IT IS INDICATED OTHERWISE ON FIGURE 6-3, THE VARIOUS VOLTAGES ARE GENERATED USING ALL THREE PHASES OF THE 3 PHASE SOURCE. FURTHERMORE, THE SYMBOL (STRAIGHT LINE WITH A CIRCLE) OPPOSITE MOST OF THE VOLTAGE SUPPLIES INDICATES A TEST POINT ON ONE OF THE THREE TEST CONNECTORS ON THE FACE OF EACH ECA. THESE TEST POINTS CAN BE USED TO CHECK THE INDICATED VOLTAGE LEVEL. THE INDICATED VOLTAGES ARE DC UNLESS EXPLICITLY LABELED AC.

THE DC VOLTAGES GENERATED IN THE PITCH AND YAW ECA'S ARE USED TO POWER THE CONTROL ELECTRONICS WITHIN THOSE UNITS. THE ROLL ECA GENERATES POWER FOR ITS CONTROL ELECTRONICS AS WELL AS THE POWER FOR THE SIGNAL CONDITIONING CIRCUITS WHICH ARE USED IN TELEMETERING SCS INFORMATION TO THE GROUND STATIONS.

THE POWER SUPPLY IN THE AUXILIARY ECA IS USED FOR THE ELECTRONICS IN THE AGCU AND IN THE SPS ENGINE ON-OFF ELECTRONICS. THE FDAI AND GIMBAL POSITION DISPLAY ELECTRONICS RECEIVE THEIR POWER FROM THE D/AGAP ECA.

6.3.2 TVC No. 1 POWER

THE TVC No. 1 POWER SWITCH FEEDS 115 VAC TO THE PITCH AND YAW TVC POWER SUPPLIES AS WELL AS 28 VDC AND 115 VAC TO A POWER SUPPLY IN THE D/AGAP ECA. THE PITCH TVC POWER SUPPLY IS USED FOR OPERATING THE PITCH SPS GIMBAL DRIVE MECHANISM, WHICH CONSISTS OF A SERVO AMPLIFIER, GIMBAL POSITION AND RATE TRANSDUCERS, DEMODULATORS, AND GIMBAL TRIM POTENTIOMETER. SIMILARLY, THE YAW POWER SUPPLY FEEDS POWER TO THE YAW CHANNEL.

THE POWER SUPPLY IN THE D/AGAP ECA GENERATES THE VOLTAGES NECESSARY FOR OPERATING THE ACCELEROMETER AND DELTA V INDICATOR ELECTRONICS.

6.3.3 RATE GYRO POWER

THE RATE GYRO POWER SWITCH ROUTES AC POWER ONLY TO THE RATE GYRO PACKAGE AS WELL AS TO THE YAW, PITCH, ROLL, AND D/AGAP ECA'S.

ALL THREE PHASES OF THE 115 VAC ARE USED IN THE RATE GYRO PACKAGE FOR OPERATING THE SPIN MOTOR AND SIGNAL GENERATOR. PHASE A ONLY IS USED IN THE FOUR ECA'S FOR THE DEMODULATOR REFERENCES.

6.4 GROUP 2 POWER

THE GROUP 2 SWITCHES SUPPLY POWER TO THOSE COMPONENTS OF THE SCS WHICH ARE NECESSARY FOR MANUAL

6-7

THRUST VECTOR CONTROL. THE THREE GROUP 2 SWITCHES ARE SHOWN IN FIGURE 6-4 AND ARE LABELED:

- A. BMAG POWER
- B. TVC NO. 2 POWER
- C. ROTATION CONTROL POWER

6.4.1 BMAG POWER

THIS SWITCH SUPPLIES 115 VAC AND 28 VDC TO THE ROLL, PITCH, YAW, AND D/AGAP ECA'S. THE VOLTAGES GENERATED IN THE D/AGAP ECA ARE USED FOR OPERATING THE BMAG'S TOGETHER WITH THE TORQUING AMPLIFIERS AND PRE-AMPLIFIERS IN THE AGAP. 115 VAC, PHASE A POWER IS ALSO SUPPLIED TO THE YAW, PITCH, AND ROLL ECA'S FOR DEMODULATOR REFERENCES.

6.4.2 TVC No. 2 POWER

THIS SWITCH SUPPLIES ONLY 115 VAC POWER TO THE REDUNDANT SET OF TVC POWER SUPPLIES IN THE PITCH AND YAW ECA'S. THERE ARE TWO SETS OF THESE POWER SUPPLIES FOR REDUNDANCY. ONE SET RECEIVES POWER FROM THE TVC 1 POWER SWITCH, AND HAS BEEN DISCUSSED PREVIOUSLY IN THE GROUP 1 POWER SECTION. THE SECOND SET RECEIVES ITS POWER FROM THE TVC 2 POWER SWITCH. THIS SECOND SET OF TVC POWER SUPPLIES IN THE PITCH AND YAW ECA'S IS USED FOR OPERATING A SECOND GIMBAL DRIVE MECHANISM WHICH CONSISTS OF SERVO AMPLIFIERS, SUMMING AMPLIFIERS, GIMBAL POSITION AND RATE TRANSDUCERS, DEMODULATORS, AND GIMBAL TRIM POTENTIOMETERS. IF AN IMPROPER GIMBAL DRIVE CLUTCH CURRENT IS SENSED IN THE TVC 1 MECHANISM

DURING AN SPS ENGINE FIRING, THERE IS AN AUTOMATIC SWITCHOVER TO THE TVC 2 MECHANISM. THIS SWITCHOVER IS ACCOMPLISHED IN BOTH CHANNELS IF A MANUAL THRUST VECTOR CONTROL SIGNAL IS GIVEN BY TWISTING THE TRANSLATION CONTROL HANDLE CLOCKWISE.

6.4.3 ROTATION CONTROL POWER

FROM THIS SWITCH, 115 VAC (PHASE A ONLY) POWER IS DISTRIBUTED TO THE ROLL, PITCH, AND YAW ECA'S. 26 VAC IS GENERATED IN THE PITCH AND YAW ECA'S FOR EXCITING THE ROTATION CONTROL TRANSDUCERS. IN ADDITION, 115 VAC IS SUPPLIED FOR THE DEMODULATOR REFERENCES.

6.5 SUMMARY

THE SCS RECEIVES ITS POWER THROUGH 18 CIRCUIT BREAKERS. SOME OF THE POWER IS DISTRIBUTED TO THE SCS THROUGH SIX POWER SWITCHES, AND SOME IS DISTRIBUTED TO THE SCS DIRECTLY. VARIOUS CAPABILITIES OF THE SCS, CONSEQUENTLY, ARE DEPENDENT UPON THE STATE OF THE SIX SCS POWER SWITCHES. MANUAL DIRECT ROTATION, DIRECT ULLAGE, AND SPS ENGINE ON CAN BE ACCOMPLISHED WITH ALL SIX POWER SWITCHES OFF. THE TWO INERTIAL SENSOR PACKAGES (RATE GYROS AND BMAG'S) RECEIVE THEIR POWER FROM THE RATE GYRO POWER SWITCH AND THE BMAG POWER SWITCH. THE ROTATION CONTROLS RECEIVE POWER, FOR MANUAL PROPORTIONAL ROTATION, FROM A ROTATION CONTROL POWER SWITCH. THE TWO REDUNDANT SYSTEMS FOR CONTROLLING THE SPS ENGINE GIMBALS RECEIVE THEIR POWER FROM THE TVC 1 POWER SWITCH AND THE TVC 2 POWER SWITCH. ONE MIGHT SAY THAT THE PARTIAL SCS POWER SWITCH DISTRIBUTES POWER TO

6-8

GROUP 2 POWER DISTRIBUTION

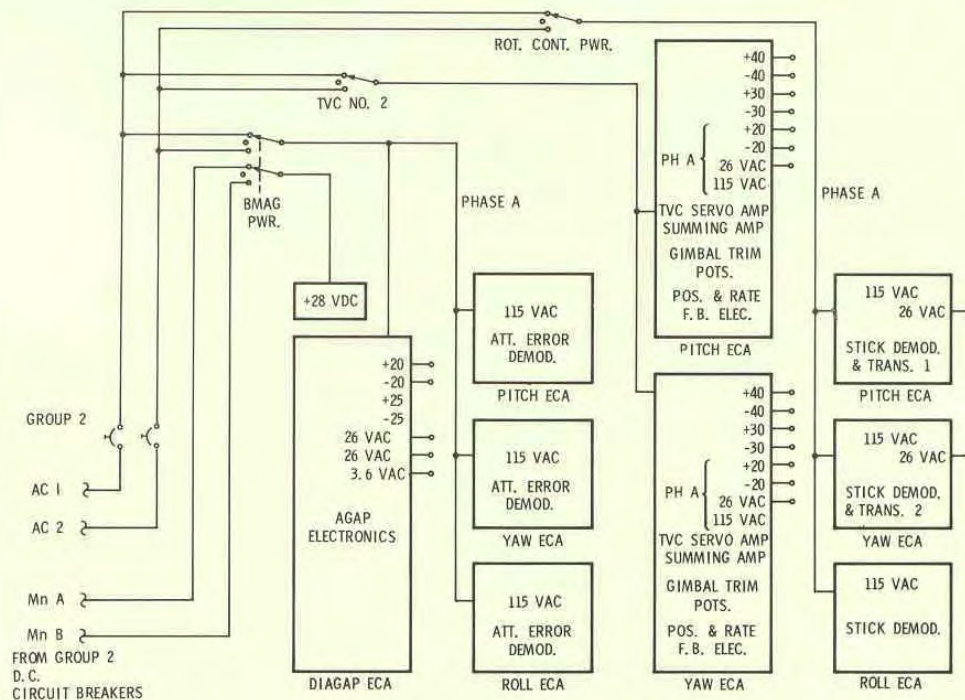


FIGURE 6-4

SCS-438A
6-9

THOSE PARTS OF THE SCS WHICH NEITHER RECEIVE POWER DIRECTLY NOR RECEIVE POWER FROM THE OTHER FIVE POWER SWITCHES.

KEEPING IN MIND WHICH COMPONENTS OF THE SCS RECEIVE POWER FROM WHICH SWITCHES, TABLE 6-1 CAN BE SEEN TO BE A SYNOPSIS OF SYSTEM CAPABILITIES IN SO FAR AS THEY ARE DEPENDENT UPON THE STATE OF THE SIX SCS POWER SWITCHES.

SCS POWER V.S. SYSTEM CAPABILITY

SCS POWER VS SYSTEM CAPABILITY

	PARTIAL SCS POWER	RATE GYRO POWER	BMAG POWER	ROT CON POWER	TVC NO. 1	TVC NO. 2
BACKUP RATE	•		•			
CHANNEL ENABLE						
DIRECT CSS						
PROPORTIONAL CSS	•	•	•	•		
ATTITUDE IMP	•					
G&N SYNC						
TRANSLATION	•					
ΔV SET					•	
SPS ENG IGN	•					
MAN. SPS GIMBAL TRIM	•				•	•
DIRECT ULLAGE						
THRUST VECTOR CONT	•	•	•		•	•
MAN. TVC			•	•		•
ATTITUDE HOLD	•	•	•			
RATE DAMPING	•	•	•			
FDAI ALIGN	•					
RATE NEEDLES VALID	•	•	•			
BALL & ROLL BUG DRIVEN	•					
ATT ERROR NEEDLES VALID	•		•			

- IF BACKUP RATE HAS BEEN SELECTED IN ANY AXIS. IF BUR HAS BEEN SELECTED IN ALL 3 AXES, RATE GYRO POWER NEED NOT BE ON.
- PARTIAL SCS POWER MUST BE ON IF ΔV SWITCH IS IN "NORMAL" POSITION. HOWEVER, ENG CAN BE TURNED ON EVEN IF ALL POWER SWITCHES ARE OFF, BY PLACING ΔV SWITCH IN DIRECT "ON" POSITION
- TVC NO. 2, RATHER THAN TVC NO. 1, MUST BE ON IF SYSTEM IS IN MAN. TVC, OR SERVO DRIVE NO. 1 HAS BEEN DISABLED.
- SCS ΔV MODE ONLY. HOWEVER, IN G&N ΔV MODE, BMAG POWER MUST BE ON IF BACKUP RATE HAS BEEN SELECTED IN ANY AXIS. IN G&N ΔV MODE, IF BUR HAS BEEN SELECTED IN ALL 3 AXES, RATE GYRO POWER NEED NOT BE ON.
- SCS MODES ONLY. ALSO G&N MODES IF BACKUP RATE HAS BEEN SELECTED IN ANY CHANNEL
- SCS MODES ONLY, PROVIDED THAT BACKUP RATE HAS NOT BEEN SELECTED.
- NECESSARY FOR ENTRY. NOT ABSOLUTELY NECESSARY FOR NON ENTRY

SCS-803B



TABLE 6-1

SECTION VII

CONTROL MODE UTILIZATION

7.1 INTRODUCTION

THIS SECTION CONTAINS A DESCRIPTION OF EACH CONTROL MODE USED IN PERFORMING THE OPERATIONS REQUIRED OF THE CREW AND OF THE SPACECRAFT SYSTEMS. EACH MODE IS DISCUSSED TO A FUNCTIONAL BLOCK DIAGRAM LEVEL AS A SUMMARY OF THE SCS AND AS AN INTEGRATION OF THE MATERIAL CONTAINED IN THE PREVIOUS SECTIONS. THIS SUMMATION ALLOWS THE INSTRUCTOR TO DELVE INTO ALL THREE MAJOR SUB-SYSTEMS OF THE SCS AS REQUIRED TO EXPLAIN CONTROL MODE UTILIZATION.

7.2 MONITOR MODE

THE MONITOR MODE PROVIDES DISPLAY INFORMATION FOR THE ASTRONAUT TO MONITOR BOOST VEHICLE STABILITY IN THE ASCENT PHASE OF THE APOLLO MISSION. OTHER INFORMATION WILL BE DISPLAYED IN GROSS VALUES. THIS MODE ALSO PROVIDES RATE DAMPED CONTROL WHEN AND IF REQUIRED THROUGHOUT THE MISSION. FIGURE 7-1 IS USED TO DEPICT THE MONITOR MODE OF OPERATION.

7.2.1 NORMAL ASCENT

FOR DISCUSSION PURPOSES THE MONITOR MODE CAN BE BROKEN INTO FOUR SECTIONS; ATTITUDE CONTROL, ATTITUDE REFERENCE, THRUST VECTOR CONTROL, DELTA V

ACCELEROMETER, AND DISPLAY SECTION. DURING A NORMAL ASCENT, ALL SECTIONS OF THE MONITOR MODE WILL BE ACTIVE. THE ATTITUDE CONTROL SECTION WILL BE PERFORMING NO ATTITUDE CONTROL FUNCTION WITH THE BOOST VEHICLE ATTACHED TO THE S/C. THE CONTINUITY PATH WOULD BE BROKEN AT K23 PREVENTING COMMAND SIGNALS FROM REACHING THE REACTION CONTROL SYSTEM.

THE BACKUP ATTITUDE REFERENCE WOULD NOT BE PROVIDING ATTITUDE TO THE FDAI, BUT IT WOULD BE OPERATIONAL AND FOLLOWING VEHICLE ATTITUDE CHANGES. RELAY K11 AND K12 WOULD BE CLOSED TO COMPLETE THE CONTINUITY PATH REQUIRED FOR DRIVING THE AGCU AND TORQUING THE BMAG'S.

THE DISPLAY OF TOTAL ATTITUDE AND ATTITUDE ERROR ARE PROVIDED FROM THE G&N SYSTEM. THE TOTAL ATTITUDE WILL INDICATE THE CHANGES IN LAUNCH VEHICLE ATTITUDE AS IT CHANGES FROM LAUNCH PAD ALIGNMENT. IT WILL BE SUPPLIED BY THE IMU THROUGH RELAY K3 FOR DISPLAY. THE ATTITUDE ERROR DISPLAYED WILL REPRESENT DEVIATION FROM THE DESIRED TRAJECTORY FOR THE FIRST STAGE BOOSTER, BUT THEY PROVIDE NO USEFUL DATA AFTER THE SIVB IS IGNITED FOR FINAL BOOST INTO ORBIT. A DIFFERENT GUIDANCE TECHNIQUE IS USED IN THE SIVB GUIDANCE PACKAGE THAN IN THE AGC; THEREFORE, RATHER LARGE ERRORS COULD EXIST BETWEEN THE TWO SYSTEMS WITH EACH

7-1

GUIDANCE & CONTROL SYSTEM

CONTROL MODES

MONITOR MODE

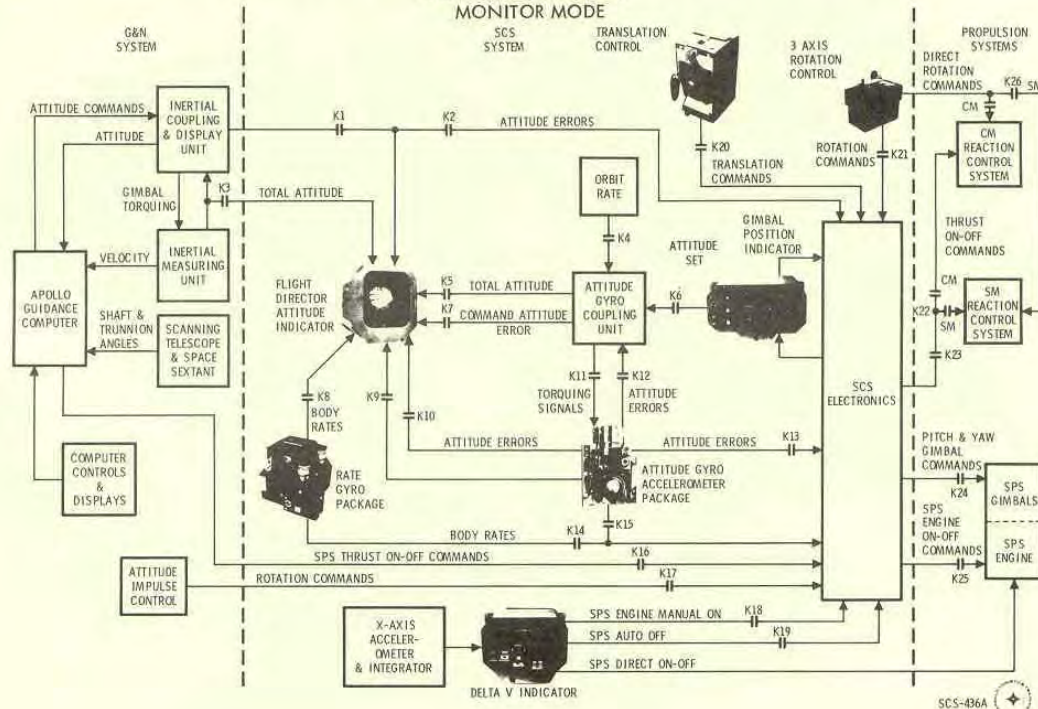


FIGURE 7-1

7-2

HAVING THE CORRECT GUIDANCE CALCULATIONS FOR THE TECHNIQUE USED. THE SIVB IS PRIMARY; THEREFORE, THE G&N ATTITUDE ERROR SUPPLIED THROUGH RELAY K1 WILL BE OF LITTLE USE IN A NORMAL ASCENT. THE DISPLAY SCALE VALUES ARE GIVEN IN TABLE 2-2 OF SECTION II.

THE ATTITUDE RATES ARE PROVIDED TO THE FDAI THROUGH RELAY K8 FROM THE SCS RATE GYROS. THE RATES DISPLAYED REPRESENTS C/M ANGULAR RATES. IT IS NOT THE TRUE RATE OF THE LAUNCH VEHICLE BECAUSE OF BODY BENDING AND OTHER CONTRIBUTING FACTORS. THE DISPLAY SCALE VALUES ARE GIVEN IN TABLE 2-3 OF SECTION II.

THE X AXIS ACCELEROMETER HAS NO MECHANICAL CAGING CAPABILITY BUT IT WILL BE ENERGIZED DURING THE ASCENT PHASE TO PROVIDE AN ABORT DELTA V CAPABILITY. HOWEVER, IT WILL NOT HAVE AN ACTIVE DISPLAY UNLESS AN SPS ABORT IS INITIATED. THE ACCELEROMETER HAS A NORMAL OPERATING RANGE OF ABOUT 2 G'S, BUT WILL EXPERIENCE NO DAMAGE FOR OVER TWICE THE FORCES EXPERIENCED IN ASCENT.

THE THRUST VECTOR CONTROL ELECTRONICS WILL BE ACTIVATED TO HOLD THE SPS ENGINE STATIONARY THROUGHOUT ASCENT TO PREVENT DAMAGE BY IT SWINGING INTO THE HIGH GAIN ANTENNA OR OTHER OBJECTS SURROUNDING THE SPS ENGINE AND TO PROVIDE TVC FOR SPS ABORTS. TVC 1 POWER SWITCH WOULD BE ON ONE SET OF BUSES (AC & DC), AND TVC 2 POWER SWITCH WOULD BE ON THE REDUNDANT BUSES TO PRECLUDE A POWER FAILURE FROM LETTING THE SPS ENGINE SWING FREE.

7.2.2 ABORTS

THERE ARE SEVERAL TYPES OF ABORTS AND EVENTS THAT OCCUR DEPENDING UPON WHERE IN THE ASCENT PHASE THE ABORT IS INITIATED. THE SCS WILL HAVE NO ACTIVE CONTROL INPUTS IF AN ABORT IS INITIATED WITHIN 42 SECONDS OR LESS AFTER LIFT OFF. FOR ABORTS WHERE THE TIME LAPSE IS GREATER THAN 42 SECONDS AFTER LIFT OFF, THE SCS WILL BE REQUIRED TO PRODUCE CONTROL SIGNALS.

7.2.2.1 LES ABORTS

WHEN A LES ABORT IS INITIATED REQUIRING SCS OPERATION, THE SCS WILL BE ENABLED 1 SECOND AFTER THE LAUNCH ESCAPE MOTOR IS IGNITED. RELAY K23 WILL BE CLOSED AND K22 WILL SELECT THE C/M POSITION. RELAY K14 WILL NORMALLY BE CLOSED IN THE MONITOR MODE, AND THE RATE GYROS WILL PROVIDE THE RATE INPUT SIGNALS TO THE SCS ELECTRONICS TO AUTOMATICALLY RATE DAMP THE S/C WITH K23 CLOSED AND K22 IN THE C/M POSITION. THE EXACT USE OF THE SCS OTHER THAN RATE DAMPING IS DEPENDENT UPON ALTITUDE, VELOCITY, IF CANARDS ARE RETAINED, AND ETC. IN ANY EVENT, THE SCS WOULD BE DISABLED AT 24K FEET BY RELAY K23 IN THE DESCENT FOR LANDING.

7.2.2.2 SPS ABORT

ALL ABORTS AFTER THE LAUNCH ESCAPE TOWER IS JETTISONED WILL BE SPS ABORTS. THE ABORTS WILL BE INITIATED BY THE CCW SWITCH IN THE TRANSLATION CONTROL.

7-3

THE SWITCH CLOSURE WILL CAUSE THE MESC TO COMMAND A +X TRANSLATION WITH THE DIRECT COILS OF THE S/M RCS. RELAY K26 AND K22 WILL BE CONNECTED TO C/M OR S/M POSITIONS AT ALL TIMES. THEY WILL BE IN THE S/M POSITION UNTIL C/H-S/M SEPARATION IS COMMANDED OR THE C/M-S/M TRANSFER SWITCH IS ACTIVATED. THE DIRECT +X TRANSLATION PROVIDES THE TENSION NECESSARY TO SEPARATE THE COMMAND SERVICE MODULE COMBINATION FROM THE BOOST VEHICLE. VARIOUS LENGTHS OF DIRECT +X TRANSLATION CAN BE OBTAINED FROM THE SEPARATION SEQUENCE DEPENDING UPON THE OPERATION OF THE CCW SWITCH IN THE TRANSLATION CONTROL. MAXIMUM DIRECT +X TRANSLATION WILL BE 12 SECONDS.

A DELTA V MODE WOULD BE SELECTED AND INITIATED BEFORE 12 SECONDS HAS ELAPSED TO PERFORM A DELTA V WITH THE SPS ENGINE. IT WOULD BE PERFORMED WITH NO RE-ALIGNMENT OF THE SPS ENGINE THRUST VECTOR FROM THE NORMAL HOLD POSITION FOR ASCENT. THE ABORT COULD BE ON INJECTION INTO EARTH ORBIT OR SELECTION OF A DOWN RANGE LANDING SITE. THE PRIMARY OBJECTIVE WILL BE TO GET A SAFE SEPARATION DISTANCE BETWEEN THE C/M-S/M AND THE BOOST VEHICLE.

7.3 G&N ATTITUDE CONTROL MODE

THE G&N ATTITUDE CONTROL MODE WILL PROVIDE AN INERTIALLY STABILIZED ATTITUDE. IT WILL UTILIZE ATTITUDE INFORMATION FROM THE IMU. A BLOCK DIAGRAM OF THIS MODE IS SHOWN IN FIGURE 7-2.

THE G&N ATTITUDE CONTROL MODE OF OPERATION CAN BE USED TO CONTROL S/C ATTITUDE IN EARTH ORBIT

OPERATION. SINCE THE G&N SYSTEM MUST BE COMPLETELY OPERATIONAL, IT REPRESENTS A POWER PENALTY TO USE THIS MODE EXTENSIVELY. THE G&N ATTITUDE CONTROL MODE BASICALLY CONSISTS OF THE ATTITUDE REFERENCE SYSTEM AND THE ATTITUDE CONTROL SYSTEM.

THE ATTITUDE REFERENCE SYSTEM CONSISTS PRIMARILY OF THE G&N SYSTEM AND ITS INPUTS TO THE FDAI. THE SCS PORTION OF THE ATTITUDE REFERENCE SYSTEM WILL BE IN A FOLLOW CONDITION BY CLOSING RELAYS K11 AND K12 TO INSURE THAT WHEN THE SCS ATTITUDE CONTROL MODE IS SELECTED, THE AGCU WILL HAVE THE SAME INFORMATION AS THE IMU IF THE AGCU IS INITIALLY ALIGNED TO AGREE WITH THE G&N ALIGNMENT. THIS WILL PREVENT CHANGES TO THE FDAI BALL INDICATIONS AT THE TIME OF MODE CHANGEOVER. THE ATTITUDE CONTROL ELECTRONICS SECTION FOR THE G&N ATTITUDE CONTROL MODE WILL PROVIDE STABILIZATION OF THE SPACECRAFT TO ENABLE HOLDING A SPECIFIC ATTITUDE WITH RESPECT TO THE INERTIAL REFERENCE FRAME. ATTITUDE ERRORS FROM THE G&N SYSTEM, THROUGH RELAYS K1 AND K2, WILL BE USED BY THE SCS ELECTRONICS TO PROVIDE ATTITUDE CORRECTIONS. A DEADBAND SET UP IN THE SCS CONTROL ELECTRONICS WILL PREVENT ATTITUDE CORRECTION SIGNALS FROM BEING SENT TO THE RCS UNLESS THE ERRORS EXCEED THE SELECTED DEADBAND. MANUAL SELECTION OF THE DEADBAND WILL BE BASED ON THE FUNCTIONAL REQUIREMENTS USING THE TWO-POSITION SWITCH (MAX OR MIN) LOCATED ON THE SCS CONTROL PANEL. FOR EXAMPLE, DURING NAVIGATIONAL SIGHTINGS MINIMUM DEADBAND WOULD BE REQUIRED. THE ATTITUDE WILL BE MAINTAINED WITHIN THE SELECTED DEADBAND BY USING THE ATTITUDE ERROR SIGNAL AS A COMMAND MANEUVER INPUT TO THE SCS. THE FDAI TOTAL ATTITUDE INDICATOR

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GUIDANCE & CONTROL SYSTEM

CONTROL MODES G & N ATTITUDE CONTROL MODE

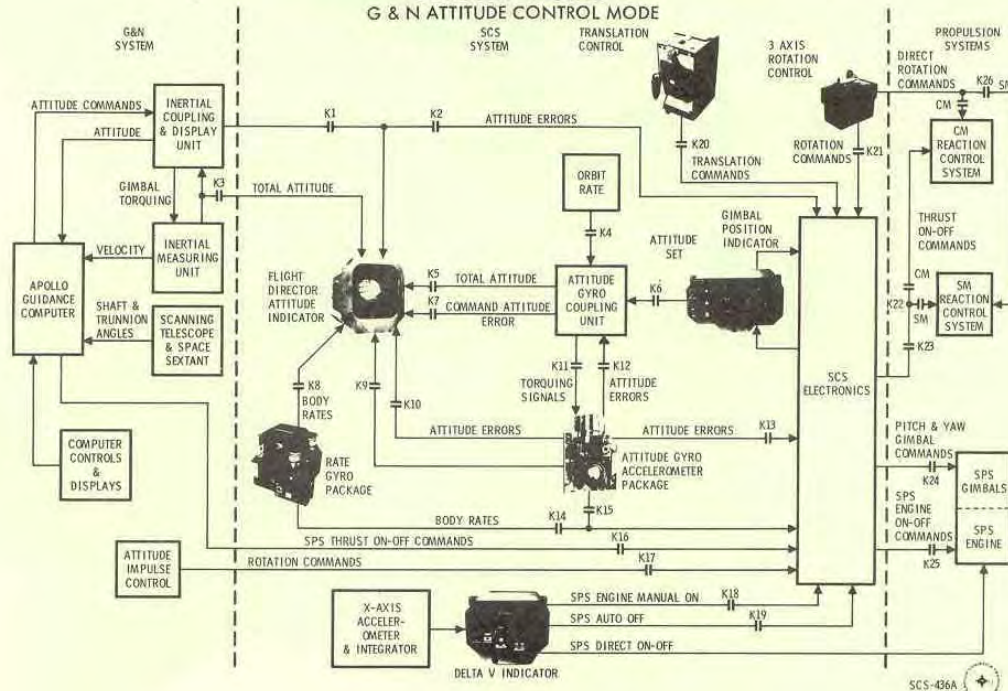


FIGURE 7-2

7-5

WILL BE DRIVEN BY THE IMU. THE ATTITUDE ERROR INDICATORS ARE DRIVEN BY THE CDU OUTPUTS FOR EACH CHANNEL TO DISPLAY THE DIFFERENCE BETWEEN THE IMU GIMBAL POSITION AND THE GUIDANCE COMPUTER COMMANDED POSITION. THE RGP WITHIN THE SCS WILL DRIVE THE ATTITUDE RATE INDICATORS WITH A SCALE RANGE OF $\pm 1^\circ/\text{SEC}$.

7.3.1 ATTITUDE MANEUVER

THE ASTRONAUT CAN USE THE AGC KEYBOARD TO INSERT COMMANDS WHICH WILL RESULT IN COMMANDED ATTITUDE CHANGES FROM THE AGC. THE SCS WILL FOLLOW THE ATTITUDE ERROR SIGNAL INPUTS FROM THE CDU IN RESPONSE TO AGC INPUTS FOR MANEUVERING TO THE COMMANDED ATTITUDE. A MANUAL MANEUVER CAPABILITY EXISTS WITH THE G&N SYNC SWITCH. THIS SWITCH, WHEN COUPLED WITH THE ROTATION CONTROL BREAKOUT SWITCH, WILL CAUSE THE CDU'S TO FOLLOW S/C ATTITUDE CHANGES. THE G&N SYNC SWITCH ALSO PREVENTS THE AGC FROM COMMANDING A NEW POSITION TO THE CDU WHEN THE ROTATION CONTROL IS RETURNED TO NEUTRAL. RETURNING THE G&N SYNC SWITCH TO THE OFF POSITION WILL RETURN THE CDU'S TO AGC CONTROL.

7.3.2 TRANSLATION MANEUVERS

TRANSLATIONS CAN ONLY BE COMMANDED MANUALLY THROUGH USE OF THE TRANSLATION CONTROL OR THE DIRECT ULLAGE SWITCH. THE NORMAL ATTITUDE HOLD FUNCTION WILL PROVIDE ATTITUDE CONTROL EXCEPT FOR *X TRANSLATIONS COMMANDED WITH THE DIRECT ULLAGE SWITCH. TRANSLATION IS PROVIDED BY THE S/M RCS AND THEREFORE CANNOT BE

ACCOMPLISHED AFTER C/M-S/M SEPARATION.

7.3.3 MINIMUM IMPULSE MANEUVERS

WHEN PERFORMING NAVIGATIONAL SIGHTINGS IT IS NECESSARY TO PERFORM MANEUVERS OF MINUTE ROTATION RATES. THE ATTITUDE IMPULSE CONTROL HAS BEEN PROVIDED FOR THIS PURPOSE. BY SWITCHES AT THE NAVIGATOR'S STATION, THE COMMAND AND STABILIZATION SIGNALS CAN BE DISABLED, EFFECTING A FREE DRIFT CONDITION. THE ATTITUDE IMPULSE CAN PROVIDE ROTATION COMMANDS IN ONE OR MORE AXES SIMULTANEOUSLY TO THE SCS ELECTRONICS. THE COMMAND INPUTS WILL GENERATE A MINIMUM IMPULSE FROM THE SELECTED PAIR OF RCS ENGINES FOR EACH SWITCH CLOSURE. THE OUTPUT COMMAND WILL ENERGIZE THE RCS ENGINE SOLENOIDS FOR 18 ± 4 MS. A MINIMUM IMPULSE FROM THE RCS WILL PROVIDE AN ANGULAR BODY RATE OF ABOUT 3 ARC MIN/SECOND . THE ATTITUDE IMPULSE CONTROL CAN BE USED ONLY IN THE G&N ATTITUDE CONTROL AND SCS ATTITUDE CONTROL MODES.

7.4 SCS ATTITUDE CONTROL & SCS LOCAL VERTICAL MODES

THE SCS ATTITUDE CONTROL AND SCS LOCAL VERTICAL MODES (FIGURE 7-3) ARE SIMILAR IN MECHANIZATION, BUT THEY PERFORM TWO DIFFERENT CONTROL FUNCTIONS. THE SCS LOCAL VERTICAL MODE WILL MAINTAIN THE S/C AT APPROXIMATELY A CONSTANT ATTITUDE WITH RESPECT TO THE EARTH'S SURFACE WHILE IN EARTH ORBIT. IT IS NOT A PRECISE ATTITUDE DUE TO THE OPEN LOOP CONTROL THAT IS MECHANIZED AND OTHER EFFECTS. THE SCS ATTITUDE CONTROL

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GUIDANCE & CONTROL SYSTEM

CONTROL MODES

SCS ATTITUDE CONTROL & SCS LOCAL VERTICAL MODES

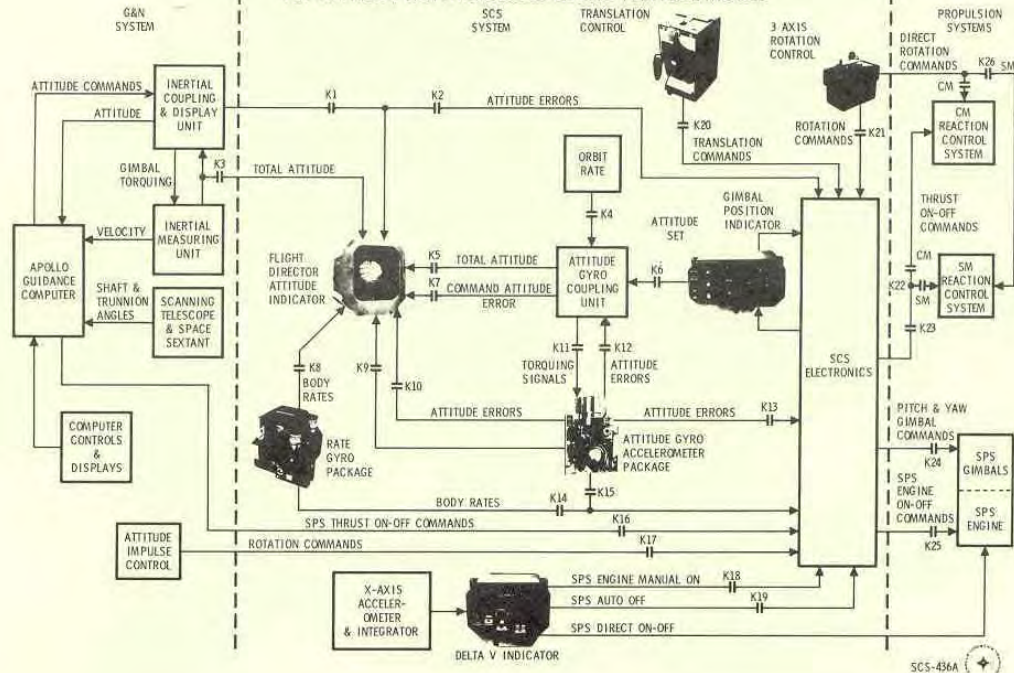


FIGURE 7-3

7-7

MODE WILL HOLD AN INERTIAL REFERENCE ATTITUDE IN EARTH ORBIT. BOTH OPERATING MODES INCORPORATE THE CAPABILITY OF PERFORMING MANUAL MANEUVER USING THE ROTATION CONTROLS.

7.4.1 SCS ATTITUDE CONTROL MODE

IN THE SCS ATTITUDE CONTROL MODE THE FOLLOWING RELAYS WILL BE CLOSED: K5 APPLYING TOTAL ATTITUDE TO THE FDAI FOR TOTAL ATTITUDE DRIVE DURING MANEUVER, K8 FOR DISPLAY OF BODY RATES ON THE FDAI, K10 TO DISPLAY ATTITUDE ERRORS ON THE FDAI, K13 APPLYING ATTITUDE ERRORS TO THE SCS ELECTRONICS, K14 TO APPLY BODY RATES TO THE SCS ELECTRONICS, AND K23 FOR THRUST ON-OFF COMMANDS TO THE S/M RCS.

7.4.1.1 FDAI/AGCU ALIGN

AS IT BECOMES NECESSARY TO ALIGN THE AGCU AND FDAI IN THE APOLLO MISSION, THE CREW MEMEBERS WILL DETERMINE THE S/C'S ATTITUDE FROM NAVIGATION SIGHTINGS AND GROUND BASE COMMUNICATIONS. THE THREE INERTIAL ANGLES OBTAINED ARE THEN DIALED INTO THE ATTITUDE SET DIALS AND THE FDAI ALIGN BUTTON, ON THE ATTITUDE SET/GIMBAL POSITION PANEL, IS DEPRESSED. THIS CAUSES RELAY K6 TO CLOSE AND THE AGCU WILL DRIVE TO THE NEW ATTITUDE, THEREBY REPOSITIONING THE FDAI. THE ATTITUDE ERROR SIGNALS TO THE SCS ELECTRONICS WILL NOT BE CHANGED NOR WILL THE BMAG OUTPUT SIGNALS.

7.4.1.2 MANUAL ATTITUDE MANEUVERS

IF THE CREW DESIRES TO MANEUVER TO A NEW ATTITUDE AND THE AGCU IS ALIGNED TO THE PRESENT S/C

ATTITUDE, THE NEW ATTITUDE IS INSERTED ON THE ATTITUDE SET DIALS. THE ATT SET SWITCH IS PLACED TO THE ATT SET POSITION. THIS CLOSES RELAYS K6 AND K7 AND OPENS RELAY K10, APPLYING AN ERROR INTO THE FDAI FROM THE AGCU THAT IS EQUAL TO THE DIFFERENCE BETWEEN THE ATTITUDE SET DIAL POSITION AND THE POSITION OF THE AGCU, AND REMOVES THE BMAG ERROR SIGNALS FROM THE FDAI. THE ATTITUDE ERROR PLACED INTO THE FDAI MAY EXCEED THE $\pm 5^\circ$ MAXIMUM RANGE OF THE INDICATOR BUT THE FULL SCALE DISPLACEMENT IS CONTROLLED BY ELECTRICAL LIMITS. THE CREW MAY NOW REMOVE THE INDICATED ERRORS IN PITCH, YAW, AND ROLL BY USING THE ROTATION CONTROL TO FLY THEM OUT. WHEN THE ROTATION CONTROL IS MOVED FROM THE NEUTRAL POSITION, RELAY K21 CLOSES AND ROTATION COMMAND SIGNALS ARE APPLIED TO THE SCS ELECTRONICS. THE SCS ELECTRONICS WILL APPLY THRUST ON-OFF COMMANDS TO THE S/M RCS THROUGH RELAY K23. ALSO, MOVING THE ROTATION CONTROL FROM NEUTRAL CLOSES RELAYS K11 AND K12 CAGING THE BMAG'S. THIS IS DONE TO STOP THE AGCU AS THE S/C ROTATES, KEEP THE BMAG'S FOLLOWING S/C ROTATION, AND RE-POSITION THE ATTITUDE BALL. WHEN THE ROTATION CONTROL IS RETURNED TO THE NEUTRAL POSITION, THE BMAG'S ARE UNCAGED TO HOLD THE NEW ATTITUDE AND THEIR ATTITUDE ERROR SIGNALS ARE NOW INSERTED INTO SCS ATTITUDE CONTROL ELECTRONICS. THE DEADBAND NOW FUNCTIONS AND THE S/C HOLDS ITS PRESENT POSITION WITHIN THE SELECTED DEADBAND. ATTITUDE ERRORS WILL NOT BE DISPLAYED ON THE FDAI FROM THE BMAG'S UNTIL THE ATT SET SWITCH IS RETURNED TO THE OFF POSITION.

A TEMPORARY (SHORT TIME AND SMALL ANGLES) CHANGE IN ATTITUDE MAY BE ACCOMPLISHED SIMPLY BY MOVING THE ROTATION CONTROL. THE BMAG'S WILL BE CAGED BY THE BREAKOUT SWITCH CLOSURE AND UNCAGED WHEN THE

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CONTROL IS RETURNED TO DETENT AND THE SWITCH OPENS. THE SCS WILL MAINTAIN THIS NEW POSITION WITHIN THE SELECTED DEADBAND. THE ATTITUDE ERROR NEEDLES NOW INDICATE THE DEADBANDING AT THE NEW POSITION AND THE FDAI BALL INDICATES THE PRESENT ATTITUDE OF THE SPACECRAFT. WHEN THE CREW DESIRES TO RETURN TO THE ORIGINAL ATTITUDE, THE ATT SET SWITCH IS PLACED TO THE ATT SET POSITION, PROVIDED THE ORIGINAL ATTITUDE WAS PREVIOUSLY SET IN ON THE ATTITUDE SET DIALS. THE ERROR NEEDLES WILL IMMEDIATELY INDICATE THE ERROR BETWEEN THE PRESENT POSITION AND ORIGINAL POSITION. IF THIS ERROR IS GREATER THAN $\pm 5^\circ$, THE NEEDLES WILL BE AT FULL SCALE. THE CREW WILL MANUALLY FLY-OUT THE ATTITUDE ERRORS USING FDAI BALL MARKINGS IF THE NEEDLES ARE AT FULL SCALE OR FLY-TO THE ATTITUDE ERROR NEEDLES. AS THE S/C APPROACHES TO WITHIN FIVE DEGREES OF THE ORIGINAL ATTITUDE, THE ERROR NEEDLES WILL COME OFF THE FULL SCALE DEFLECTION AND INDICATE THE AMOUNT OF ERROR REMAINING.

THE ATTITUDE ERROR OBTAINED FROM AGCU WITH THE ATT SET SWITCH IN THE ATT SET POSITION WILL NOT PERFORM ANY AUTOMATIC CONTROL FUNCTIONS. IT IS FOR DISPLAY ONLY. THE SCS CHANNEL ENABLE SWITCHES ON THE SCS CONTROL PANEL MAY BE USED TO DEACTIVATE ANY CHANNEL IF A FREE DRIFT IS DESIRED. DEACTIVATION OF THE CHANNELS BY THE SCS CHANNEL ENABLE SWITCHES WILL OPEN RELAY K23, INHIBITING THE RCS AND CLOSE RELAYS K11 AND K12, CAGING THE BMAG'S IN ALL AXES. THE ANGLE THROUGH WHICH THE S/C DRIFTS IS CALCULATED AND CONTINUOUSLY DISPLAYED ON THE FDAI ATTITUDE BALL IF THE RATES ARE NOT TOO LOW. DEACTIVATION OF ONE CHANNEL REMOVES ATTITUDE HOLD IN

THE OTHER TWO FOR THE SCS ATTITUDE CONTROL. THIS FREE DRIFT CAN BE USED IN THE G&N ATTITUDE CONTROL MODE IN A SIMILAR MANNER EXCEPT COMPLETE ATTITUDE HOLD IS NOT LOST WHEN ONE CHANNEL IS DEACTIVATED. WHEN FREE DRIFT IS DESIRED FOR EXTENDED PERIODS OF TIME, THE GYROS CAN BE TURNED OFF FOR POWER CONSERVATION. RCS PROPELLANTS ARE ALSO CONSERVED IN A FREE DRIFT CONDITION.

7.4.2 SCS LOCAL VERTICAL MODE

THE SCS LOCAL VERTICAL MODE CLOSING ONE ADDITIONAL RELAY ON FIGURE 7-3. IT IS RELAY K4 WHICH PROVIDES THE ORBIT RATE SOURCE. THE ORBIT RATE SOURCE IS A PRESET LEVEL AND WILL BE MOST ACCURATE FOR THE PREDICTED ORBIT PRIOR TO LAUNCH. FOR THE 100 NMI CIRCULAR ORBIT, THE TORQUING RATE WILL BE APPROXIMATELY $246^\circ/\text{HR}$.

THE LOCAL VERTICAL MODE CAN MAINTAIN THE APPROXIMATE ATTITUDE WITH RESPECT TO THE EARTH'S SURFACE ONLY WHEN THE AGCU IS ALIGNED TO REPRESENT THE S/C ATTITUDE WITH RESPECT TO THE EARTH SURFACE WHEN THE MODE IS SELECTED. AFTER PROPER ALIGNMENT, BEFORE ENTERING THE SCS LOCAL VERTICAL MODE, THE ROTATION CONTROL CAN BE USED TO MODIFY THE LOCAL VERTICAL ATTITUDE THEREBY PERMITTING MANUAL ATTITUDE MANEUVERS IN THIS MODE. ALL THREE CHANNELS OF ATTITUDE CONTROL MUST BE ENABLED BY THE SCS CHANNEL ENABLE SWITCHES BEFORE THIS MODE CAN BE USED.

7-9

THE TRANSLATION CONTROL IS ACTIVE FOR BOTH OF THE SCS ATTITUDE CONTROL AND LOCAL VERTICAL MODES. IT CAN BE USED, AS REQUIRED FOR THE MISSION, WITHOUT AFFECTING THE ATTITUDE HOLD CAPABILITY OF EACH MODE. ITS INPUT WOULD BE THROUGH RELAY K20.

7.5 G&N DELTA V MODE

THE G&N DELTA V MODE IS THE PRIME MODE OF OPERATION FOR VELOCITY CHANGES IMPARTED TO THE S/C BY THE SPS ENGINE. IF THE VELOCITY TO BE GAINED IS LESS THAN THE MINIMUM FEASIBLE IMPULSE OF THE SPS ENGINE, IT WOULD NOT BE USED. FOR EARTH ORBIT MISSIONS, ALL DELTA V'S SHOULD EXCEED THE MINIMUM IMPULSE OF THE SPS ENGINE. FIGURE 7-4 SHOWS A BLOCK DIAGRAM OF THE SCS AS IT IS CONFIGURED FOR THE G&N DELTA V MODE.

7.5.1 RELAY CONFIGURATION

WHILE IN THE G&N DELTA V MODE AND PRIOR TO THRUST INITIATION, THE SCS WILL PERFORM AS IN A G&N ATTITUDE CONTROL MODE. THAT IS, RELAYS K1 AND K2 APPLYING ATTITUDE ERROR TO THE FDAI AND SCS ELECTRONICS, K3 APPLYING TOTAL ATTITUDE TO THE FDAI, K8 AND K14 BODY RATES TO THE FDAI AND SCS ELECTRONICS, AND K23 THRUST ON-OFF COMMANDS TO THE S/M RCS. AFTER SPS IGNITION, THE SCS WILL CONTINUE TO MAINTAIN THE ATTITUDE BY POSITIONING THE SPS GIMBALS THROUGH RELAY K24 IN PITCH AND YAW, AND ROLL ATTITUDE THROUGH RELAY K23 TO THE S/M RCS.

7.5.2 OPERATION

ATTITUDE INFORMATION FROM THE IMU IS DISPLAYED ON THE ATTITUDE BALL. ATTITUDE ERRORS FROM THE CDU'S ARE SHOWN ON THE ATTITUDE ERROR NEEDLES ($\pm 5^\circ$ SCALE) AND ACTED UPON BY THE SCS TO HOLD OR CHANGE ATTITUDE IN RESPONSE TO COMPUTER COMMANDS. RATES ARE DISPLAYED WITH A SCALE RANGE OF $\pm 5^\circ/\text{SECOND}$. IN THIS CONTROL MODE, THE DELTA V DISPLAY IS USED TO MONITOR THE AUTOMATIC VELOCITY CONTROL EXERCISE BY THE COMPUTER. THE DELTA V DISPLAY WILL BE SET UP BASED UPON THE INFORMATION OBTAINED FROM THE G&N SYSTEM. THE DELTA V DISPLAY WILL BE ACTIVATED BY TVC 1 POWER SWITCH. THE DELTA V SET SLEW SWITCH WILL BE USED TO SET IN THE DELTA V MANEUVER WILL BE SET IN ON THE EVENT CLOCK. TO PERFORM THE DELTA V MANEUVER, THE SPACECRAFT WILL BE POSITIONED SO THAT THE SPS THRUST VECTOR WILL BE THROUGH THE CENTER OF GRAVITY IN THE DESIRED DIRECTION OF THE VELOCITY CHANGE. THE ATTITUDE MANEUVER CAN BE PERFORMED MANUALLY OR AUTOMATICALLY BY A PROCEDURE OPTION. AFTER THE G&N DELTA V MODE IS SELECTED, THE MINIMUM DEADBAND WILL BE SELECTED IF IT HAS NOT BEEN PREVIOUSLY SELECTED. AT SOME DEFINITE TIME BEFORE THE DELTA V MANEUVER IS TO START, THE FOUR GIMBAL ACTUATOR MOTORS WILL BE TURNED ON SEQUENTIALLY FROM THE EMERGENCY DETECTION AND GIMBAL DRIVE CONTROL PANEL.

THE GIMBAL TRIM ANGLES REQUIRED FOR THE DELTA V MANEUVER WILL BE OBTAINED FROM ON BOARD CHARTS OF CONSUMABLES REMAINING (PROPELLANTS, CRYOGENICS AND

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GUIDANCE & CONTROL SYSTEM

CONTROL MODES

G & N ΔV MODE

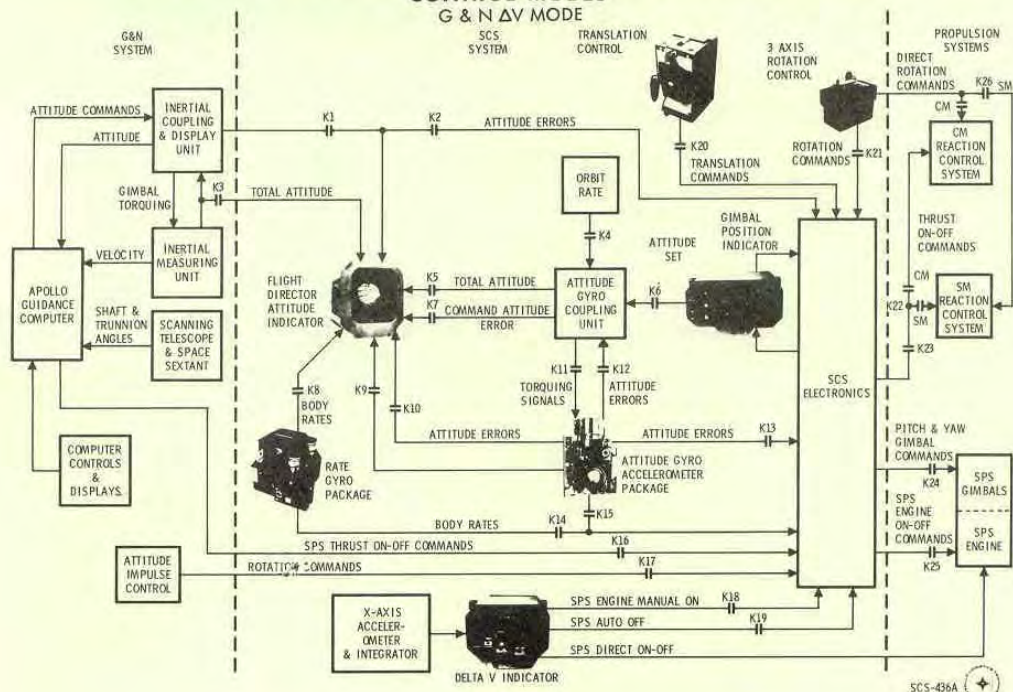


FIGURE 7-4

7-11

ETC.). THE TRIM ANGLES WILL BE SET IN BY USE OF THE GIMBAL POSITION TRIM CONTROLS AS REQUIRED PRIOR TO EACH ΔV MANEUVER. THE GIMBAL TRIM ANGLES ARE VERIFIED FOR EACH AXIS (PITCH AND YAW) ON THE GIMBAL POSITION DISPLAY. THE TVC 1 AND 2 POWER SWITCHES WOULD BE SET AS INDICATED IN PARAGRAPH 7.2.1, AND THE THRUST CONTROL SWITCH ON THE ΔV DISPLAY WILL BE PLACED TO THE NORMAL POSITION.

THE ASTRONAUT NOW WILL WATCH THE EVENT TIME CLOCK COUNTDOWN TO ZERO. AT SOME TIME PRIOR TO $T=0$, HE INITIATES THE ULLAGE MANEUVER BY COMMANDING A +X TRANSLATION WITH THE TRANSLATION CONTROL. MOVING THE TRANSLATION CONTROL TO THE STOP WILL CLOSE RELAY K20 AND APPLY COMMANDS TO THE SCS ELECTRONICS. THE AGC WILL INITIATE AN ENGINE FIRE COMMAND THROUGH RELAY K16 TO THE SCS ELECTRONICS AT $T=0$. THIS SIGNAL WILL BE INDICATED BY A LIGHT BEHIND THE THRUST-ON BUTTON ON THE ΔV DISPLAY AND ALSO APPLIED TO THE SPS ENGINE THROUGH RELAY K25. UPON SENSING THE IGNITION OF THE SPS ENGINE, THE JET SELECTION LOGIC WILL BE INHIBITED AND TERMINATE THE +X TRANSLATION APPROXIMATELY 1 SECOND AFTER ENGINE IGNITION. PITCH AND YAW ATTITUDE ERROR AND RATE SIGNALS ARE INSERTED INTO THE THRUST VECTOR CONTROL ELECTRONICS AT ENGINE IGNITION. ATTITUDE CONTROL OF THE S/C IS ACCOMPLISHED IN THE PITCH AND YAW AXES BY GIMBAL CONTROL WHILE THRUSTING. THE ROLL ATTITUDE WILL BE CONTROLLED BY THE ROLL REACTION JETS AT ALL TIMES. THE ASTRONAUT WILL SELECT THE MAXIMUM DEADBAND SHORTLY AFTER SPS ENGINE IGNITION. THE CREW MEMBERS WILL MONITOR S/C ATTITUDE CONTROL ON THE FDAI

AND THE VELOCITY CHANGE ON THE ΔV DISPLAY. WHEN THE ΔV REMAINING INDICATOR INDICATES ZERO, THE AGC SHOULD REMOVE THE THRUST ON COMMAND, AND ILLUMINATION OF THE THRUST ON PUSH BUTTON SHOULD CEASE. IF THRUSTING DOES NOT TERMINATE, THE THRUST CONTROL SWITCH, ON THE ΔV DISPLAY, WILL BE PLACED IN THE OFF POSITION TO PERFORM EMERGENCY CUT OFF OF THE SPS ENGINE. IGNITION OF THE ENGINE IS PREVENTED WITH THE THRUST CONTROL SWITCH IN THE OFF POSITION. WITH REMOVAL OF THE THRUST ON SIGNAL, PITCH AND YAW CONTROL REVERTS BACK TO SCS AND RCS FOR ATTITUDE CONTROL APPROXIMATELY ONE SECOND AFTER THE THRUST ON COMMAND IS REMOVED. THE ΔV REMAINING INDICATOR WILL MEASURE THE TAIL OFF VELOCITY IMPARTED TO THE S/C BY THE RESIDUAL THRUST FROM THE SPS ENGINE. THIS VALUE WOULD BE INSERTED, WHERE REQUIRED, FOR TRAJECTORY CALCULATIONS. OTHER OPERATING MODES CAN NOW BE SELECTED AND THE SPS ACTUATOR MOTORS, TVC ELECTRONICS, ETC., CAN BE TURNED OFF IF NOT REQUIRED FOR THE OPERATING MODE SELECTED.

7.6 SCS ΔV MODE

SCS ΔV IS A BACKUP MODE OF OPERATION FOR VELOCITY CHANGES IMPARTED TO THE S/C BY THE SPS ENGINE. THE SAME CRITERIA (MAGNITUDE AND DIRECTION OF VELOCITY CHANGE) WOULD DETERMINE IF AN SCS ΔV MODE SHOULD BE USED, AS WITH THE G&N ΔV MODE. FIGURE 7-5 IS A BLOCK DIAGRAM SHOWING THE SCS CONFIGURATION DURING AN SCS ΔV MODE.

7-12

GUIDANCE & CONTROL SYSTEM

CONTROL MODES

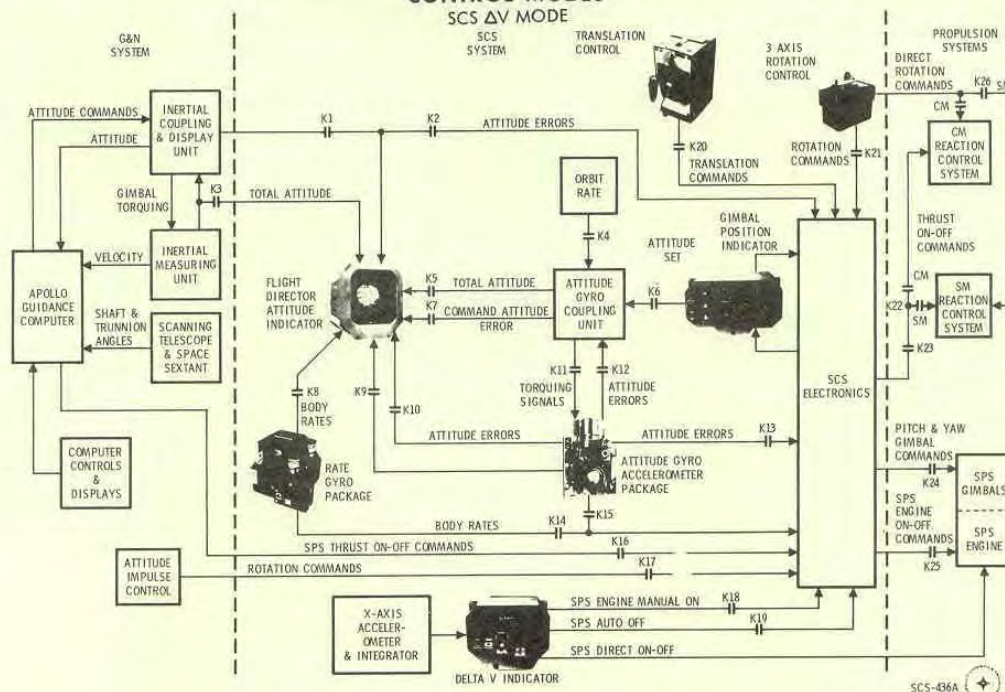


FIGURE 7-5

7-13

7.6.1 RELAY CONFIGURATION

BEFORE SPS ENGINE IGNITION, THE SCS DELTA V MODE WILL PERFORM THE SAME FUNCTION AS AN SCS ATTITUDE CONTROL MODE BY MAINTAINING PRESENT ATTITUDE WITHIN THE SELECTED DEADBAND. THAT IS, RELAYS K10 AND K19 APPLYING ATTITUDE ERRORS TO THE FDAI AND SCS ELECTRONICS, K5 TOTAL ATTITUDE TO THE FDAI, K8 AND K14 BODY RATES TO THE FDAI AND SCS ELECTRONICS, AND K23 APPLYING THRUST ON-OFF COMMANDS TO THE S/M RCS. AFTER SPS IGNITION, THE SCS WILL CONTINUE TO MAINTAIN THE ATTITUDE BY POSITIONING THE SPS GIMBALS THROUGH RELAY K24 IN PITCH AND YAW, AND ROLL ATTITUDE THROUGH RELAY K23 TO THE S/M RCS.

7.6.2 OPERATION

THE ASTRONAUT WILL PROCEDURALLY SET THE DELTA V REMAINING INDICATOR, POSITION THE SPS GIMBAL TO THE CORRECT GIMBAL POSITION TRIM ANGLE, TURN ON THE GIMBAL ACTUATOR MOTORS, SET TIME ON EVENT TIMER CLOCK, AND SET THE SCS TVC POWER SWITCH ON SEPARATE BUS COMBINATION AS REQUIRED FOR THE G&N DELTA V MODE, AND THE THRUST CONTROL SWITCH ON THE DELTA V DISPLAY IN THE NORMAL POSITION. WITH THE CORRECT S/C ATTITUDE, THE ASTRONAUT WOULD INITIATE A *X TRANSLATION (ULLAGE) A PREDETERMINED AMOUNT OF TIME BEFORE T=0 FOR SPS IGNITION. AT T=0 WITH THE ULLAGE IN PROCESS, THE THRUST ON BUTTON ON THE DELTA V DISPLAY WOULD BE DEPRESSED TO INITIATE THE SPS THRUST ON COMMAND. THERE IS NO INTERLOCK TO PREVENT THE MANUAL THRUST ON COMMAND FROM IGNITING THE SPS ENGINE WITHOUT AN ULLAGE. THE TIME DELAY FOR INHIBITING THE

RCS ELECTRONICS IS IDENTICAL TO THE G&N DELTA V MODE.

THE DELTA V REMAINING INDICATOR WILL START COUNTING DOWN AT THE INITIATION OF THE ULLAGE MANEUVER AND THE ATTITUDE ERROR AND RATES WILL BE DISPLAYED ON THE FDAI. THE ATTITUDE BALL WILL NOT BE DRIVEN IN THE SCS DELTA V MODES EXCEPT FOR MANUAL ATTITUDE MANEUVER WITH THE RCS.

RELAY K18 CLOSURE REPRESENTS DEPRESSING THE THRUST ON BUTTON AND K25 REPRESENTS THE THRUST CONTROL LOGIC THRUST ON COMMAND. THE ASTRONAUT WILL MONITOR THE ATTITUDE ERROR AND RATE DISPLAYS ON THE FDAI FOR ANY MALFUNCTIONS THAT MAY OCCUR AND BE DISPLAYED, AND THE DELTA V REMAINING INDICATOR TO SEE THAT A THRUST OFF COMMAND IS GENERATED AUTOMATICALLY WHEN THE DELTA V REMAINING INDICATOR REACHES ZERO. THE THRUST ON BUTTON WILL BE ILLUMINATED AT THRUST ON AND EXTINGUISHED AT THRUST OFF AS IT WAS FOR THE G&N DELTA V MODE. RELAY K19 REPRESENTS THE AUTOMATIC THRUST OFF COMMAND ISSUED BY THE DELTA V REMAINING INDICATOR.

7.7 MANUAL THRUST VECTOR CONTROL MODE

THE MANUAL THRUST VECTOR CONTROL (MTVC) MODE IS NOT SELECTABLE FROM THE SCS CONTROL PANEL, BUT IS SELECTED BY A FULL CW ROTATION OF THE T HANDLE ON THE TRANSLATION CONTROL WITH THE SCS IN A G&N OR SCS DELTA V MODE. THE BMAG'S WILL BE CAGED INTO BACKUP RATE MODE AND INSERTED INTO THE MTVC ELECTRONICS. THIS IS ACCOMPLISHED BY OPENING RELAY K14 AND CLOSING K15; HOWEVER, THE ACTUAL RATE INPUT PATH WOULD BE

ROUTED THROUGH A SEPARATE CIRCUIT, SHOWN IN FIGURE 5-2. THE ATTITUDE ERROR OUTPUT IS REMOVED BY OPENING RELAY K13. OTHER SWITCHING OCCURRING IN THE SCS ELECTRONICS REMOVES ALL NORMAL ATTITUDE ERROR AND RATE SIGNALS FROM THE SERVO AMPLIFIER AND SWITCHES THE RMAG RATE SIGNALS INTO THE REDUNDANT TVC ELECTRONICS. THE OUTPUT OF THE ROTATION CONTROL TRANSDUCERS ARE SWITCHED INTO THE MTVS ELECTRONICS TO PROVIDE RATE DAMPED MANUAL CONTROL OF THE SPS GIMBALS.

THE RATE DAMPED OR ATTITUDE OUT MODE REMOVES THE ATTITUDE ERROR INPUTS TO ALL THREE AXES BUT WILL NOT REMOVE THE ATTITUDE AND ATTITUDE ERROR SIGNALS FROM THE FDAI IN THE G&N DELTA V, G&N ATTITUDE CONTROL, AND G&N ENTRY MODES. THEREFORE, ROTATION CONTROL COMMANDS CAN BE USED TO FLY G&N PROGRAMMED ATTITUDE MANEUVERS. FOR THE SCS LOCAL VERTICAL, ATTITUDE CONTROL, AND ENTRY MODES, TRANSLATION CONTROL CW SWITCH CLOSURE WILL REMOVE THE ATTITUDE HOLD CAPABILITY OF EACH AND THE ATTITUDE BALL WILL BE DRIVEN TO FOLLOW S/C ROTATIONS.

7.8 G&N ENTRY MODE

THE G&N ENTRY MODE IS THE PRIMARY MODE OF CONTROL FOR ENTRY INTO THE EARTH'S ATMOSPHERE. THIS MODE PROVIDES AN AUTOMATIC ATTITUDE HOLD AND MANEUVER CAPABILITY PRIOR TO, AND THROUGHOUT THE AERODYNAMIC ENTRY. A BLOCK DIAGRAM OF THE SCS CONFIGURATION IN THE G&N ENTRY MODE IS SHOWN IN FIGURE 7-6.

IN ALL PREVIOUS MODES THE RATE COMMANDS TO THE SCS HAVE BEEN LIMITED APPROXIMATELY $.65^\circ/\text{SECOND}$. SELECTION OF EITHER ENTRY MODE CHANGES THIS RATE LIMIT TO $17^\circ/\text{SECOND}$ IN THE ROLL AXIS. THE PITCH AND YAW RATE COMMANDS ARE LIMITED TO $5^\circ/\text{SECOND}$. SELECTION OF EITHER ENTRY MODE WILL NOT NORMALLY OCCUR UNTIL AFTER SERVICE MODULE SEPARATION. THE RATE DISPLAY SCALE RANGE IS SWITCHED TO $\pm 25^\circ/\text{SECOND}$ IN ROLL AND $\pm 5^\circ/\text{SECOND}$ IN PITCH AND YAW. THE DEADBAND SETTING FOR COMMANDS WILL NORMALLY BE SET TO MAXIMUM. A RATE DEADBAND OF $\pm 2^\circ/\text{SECOND}$ IS INCORPORATED BY SELECTING EITHER ENTRY MODE.

ATTITUDE ERROR INFORMATION COMES FROM THE G&N SYSTEM THROUGH RELAYS K1 AND K2 TO THE SCS ELECTRONICS AND FDAI FOR ATTITUDE CONTROL AND DISPLAY PRIOR TO 0.05G SWITCHING. ALSO, RELAYS K8 AND K14 CONNECT BODY RATES TO THE FDAI AND SCS ELECTRONICS AND RELAY K9 APPLIES TOTAL ATTITUDE TO THE FDAI. AT 0.05G, THE .05G ENTRY SWITCH, ON THE SCS CONTROL PANEL, IS PLACED IN THE .05G ENTRY POSITION. AT THIS TIME, SWITCHING IN THE SCS ELECTRONICS CAUSES THE PITCH AND YAW CHANNELS TO PERFORM RATE STABILIZATION ONLY.

AS A BACKUP TO THE AUTOMATIC CONTROL CAPABILITIES THROUGH THE SCS, THE CW SWITCH IN THE TRANSLATION CONTROL CAN BE USED TO REMOVE ATTITUDE ERRORS FROM THE ACS. THE ASTRONAUTS MAY THEN USE THE ROTATION CONTROL TO FLY OUT COMMAND ATTITUDE ERRORS DISPLAYED ON THE

7-15

GUIDANCE & CONTROL SYSTEM

CONTROL MODES G & N ENTRY MODE

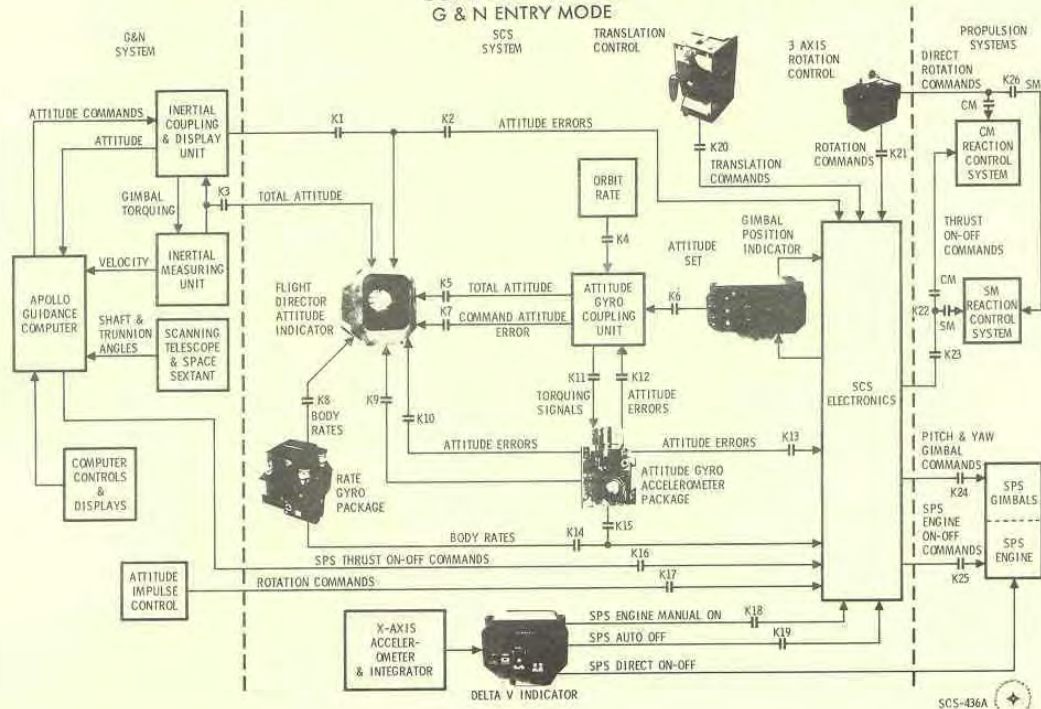


FIGURE 7-6

7-16

FDAI FROM THE G&N SYSTEM. AFTER .05G ENTRY SWITCHING AND AERODYNAMIC BUILDUP, THE ROTATION CONTROL MAY BE USED TO EFFECTIVELY COMMAND ROLL ATTITUDE CHANGES. PITCH AND YAW COMMANDS ARE OPPOSED BY AERODYNAMIC FORCES. SELECTION OF THE G&N ENTRY MODE WILL CAGE THE BMAG'S THROUGH THE AGCU TO PROVIDE BACKUP ATTITUDE REFERENCE IF REQUIRED.

COMMANDS MAY ALSO BE ENTERED BY WAY OF THE AGC KEYBOARD AS A BACKUP TO THE G&N SYSTEM EARLY IN THE ENTRY PHASE WHEN THE PILOT CAN STILL SEE AND REACH THE COMPUTER DISPLAY. THE COMPUTER CAN DISPLAY ENTRY ANGLE, REQUIRED PULL-OUT ANGLE, AND OTHER ENTRY DATA. IF A MALFUNCTION SHOULD OCCUR IN THE AUTOMATIC ENTRY, THE ASTRONAUT WOULD MANUALLY TAKE OVER AND FLY A CONTROLLED G LEVEL ENTRY IN THE SCS ENTRY MODE.

7.9 SCS ENTRY MODE

SCS ENTRY MODE IS A BACKUP TO THE G&N ENTRY MODE AND WILL NOT BE USED UNLESS A MALFUNCTION OCCURS IN THE G&N SYSTEM (FIGURE 7-7).

TOTAL ATTITUDE INFORMATION IS APPLIED TO THE FDAI THROUGH RELAY K5 FROM THE AGCU WHEN MANEUVERING PRIOR TO .05g, AND ALL THE TIME AFTER .05g. THE BMAG'S PROVIDE ATTITUDE ERRORS THROUGH RELAYS K10 AND K13 TO THE FDAI AND SCS ELECTRONICS, UNTIL 0.05g.

WHEN THE 0.05g ENTRY SWITCH IS PLACED IN THE .05g ENTRY POSITION, THE BMAG ATTITUDE ERRORS ARE REMOVED FROM THE FDAI AND SCS ELECTRONICS BY OPENING

RELAYS K10 AND K13. THE BMAG'S ARE CAGED THROUGH RELAYS K11 AND K12 TO THE AGCU. FROM THIS POINT ON, THE FDAI WILL NOT HAVE AN ATTITUDE ERROR INDICATION. THE ATTITUDE CONTROL ELECTRONICS WILL NOT RECEIVE ATTITUDE ERROR INPUTS. THEREFORE, THE S/C WILL NOT HAVE AUTOMATIC ATTITUDE CONTROL BUT WILL BE RATE STABILIZED. THE RATE GYRO SIGNALS THROUGH THE CONTROL ELECTRONICS WILL OPPOSE ANY ANGULAR MOTION OF THE S/C. THIS WILL NOT ELIMINATE ANY ATTITUDE ERROR, BUT IT WILL REDUCE THE RATES TO 2°/SECOND. THE FDAI WILL CONTINUE TO INDICATE S/C TOTAL ATTITUDE AND THE CREW WILL INITIATE THE NECESSARY MANUAL ROLL MANEUVERS.

AFTER 0.05g, IF ANY ONE OF THE BMAG'S IS PLACED IN A BACKUP RATE CONDITION (RELAYS K15 AND K9 CLOSE AND K8 AND K14 OPEN), THE OTHER TWO BMAG'S WILL ALSO ASSUME A BACKUP RATE CONDITION. THIS WILL ALSO REMOVE TOTAL ATTITUDE INFORMATION FROM THE FDAI BECAUSE THE AGCU CANNOT OPERATE WITH ONE BMAG IN A BACKUP RATE CONFIGURATION. HOWEVER, ONLY THE BMAG SELECTED BY THE RATE GYRO SELECTION SWITCH WILL HAVE AN INPUT TO THE SCS FOR RATE STABILIZATION.

THE ASTRONAUTS WILL CONTROL THE LIFT VECTOR DIRECTION BY USING THE ROTATION CONTROL TO COMMAND THE DESIRED S/C ROLL ATTITUDE. THE POINTING DIRECTION OF LIFT VECTOR (UP, DOWN, ETC.) WILL BE USED TO CONTROL THE G LEVEL FOR ENTRY. LIFT VECTOR UP WILL DECREASE THE G LEVEL, AND LIFT VECTOR DOWN WILL INCREASE THE G LEVEL.

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GUIDANCE & CONTROL SYSTEM

CONTROL MODES

SCS ENTRY MODE

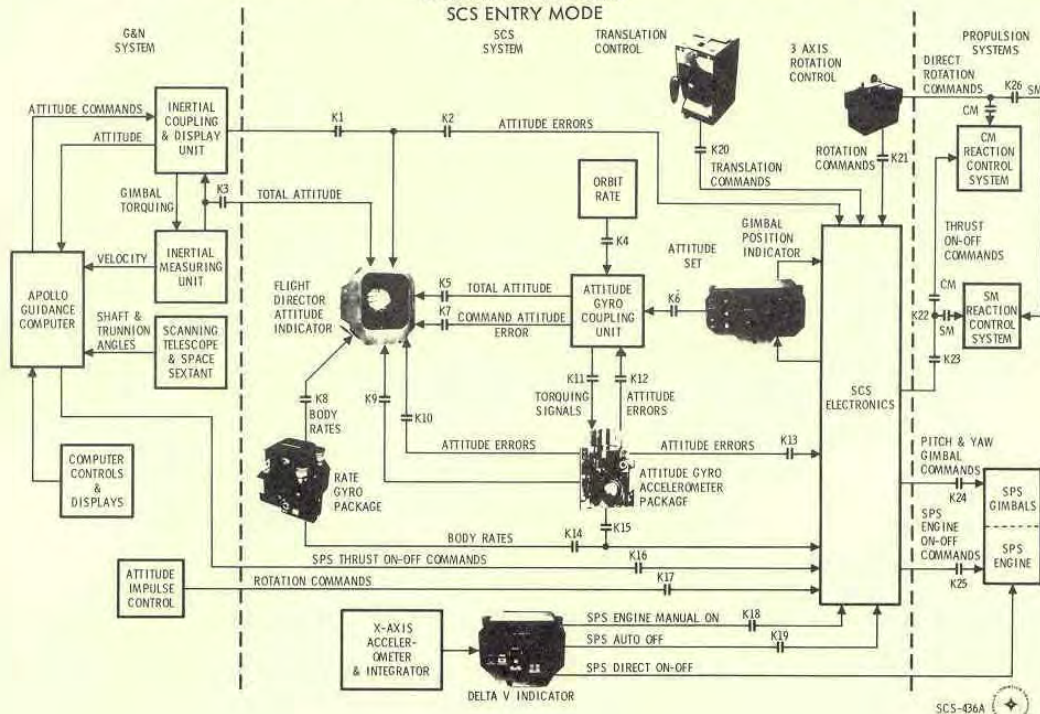


FIGURE 7-7

7-18

THE RELAY CLOSURES ON SCS-436A ARE TO REPRESENT FUNCTIONAL SIGNAL INPUTS. THEY DO NOT REPRESENT ACTUAL SYSTEM RELAYS.

K1 IS CLOSED BY MODE SELECTION TO PROVIDE ATTITUDE ERROR TO THE FDAI ATTITUDE ERROR NEEDLE WHEN MONITOR, G&N ATTITUDE CONTROL G&N DELTA V, OR G&N ENTRY MODE IS SELECTED.

K2 IS CLOSED BY MODE SELECTION LOGIC TO PROVIDE ATTITUDE ERROR INTO THE SCS ELECTRONICS WHEN G&N ATTITUDE CONTROL, G&N DELTA V OR G&N ENTRY MODES ARE SELECTED EXCEPT FOR ATTITUDE IMPULSE ENABLED IN THE G&N ATTITUDE CONTROL MODE OR THE G&N ENTRY MODE, ROLL ATTITUDE ERROR WILL PASS THROUGH RELAY K2 AFTER .05G ENTRY SWITCHING IS PERFORMED.

K3 IS CLOSED BY MODE SELECTION TO PROVIDE TOTAL ATTITUDE TO THE FDAI ATTITUDE BALL IF THE MONITOR, G&N ATTITUDE CONTROL, G&N DELTA V, OR G&N ENTRY MODE IS SELECTED.

K4 IS CLOSED BY MODE SELECTION TO PROVIDE A TORQUING VOLTAGE THROUGH AGCU FOR THE BMAG'S IN THE SCS LOCAL VERTICAL MODE.

K5 IS CLOSED BY MODE SELECTION TO PROVIDE TOTAL ATTITUDE TO THE FDAI ATTITUDE BALL FROM THE AGCU TOTAL ANGLE RESOLVERS. CLOSURE IS INITIATED

BY SELECTION OF SCS LOCAL VERTICAL, SCS ATTITUDE CONTROL, SCS DELTA V OR SCS ENTRY MODE.

K6 IS CLOSED BY PLACING THE ATT SET SWITCH TO THE ATT SET POSITION. IT PROVIDES INERTIAL ATTITUDE ERROR TO THE AGCU FROM A COMPARISON OF THE TOTAL ATTITUDE SHAFT RESOLVER IN THE AGCU AND THE ATTITUDE SET DIALS. THIS RELAY WOULD ALSO BE USED DURING FDAI ALIGN. THESE ERRORS WOULD BE DRIVEN TO ZERO AS THE AGCU IS DRIVEN BY THE ERROR INPUT AND THE ALIGNMENT PROCESS IS COMPLETED.

K7 IS CLOSED BY MODE SELECTION LOGIC IN ALL NORMAL OPERATING MODES. PLACING A BMAG IN A BACKUP RATE CONDITION WILL INHIBIT RATE GYRO INPUT TO THE CHANNEL SELECTED AND SUPPLY RATE INFORMATION FROM THE CAGED BMAG.

K9 IS CLOSED BY AXIS AS THE RATE SELECTION SWITCHES ON THE SCS CONTROL PANEL ARE SWITCHED, PLACING THE BMAG'S IN A BACKUP RATE CONFIGURATION. IF RELAY K9 IS CLOSED FOR ONE CHANNEL, K8 WOULD BE OPEN FOR THE SAME CHANNEL.

K10 IS CLOSED BY MODE SELECTION LOGIC IN ALL FOUR SCS OPERATING MODES WITH THE FOLLOWING EXCEPTION: ATT SET SWITCH TO ATT SET POSITION, AFTER .05G ENTRY SWITCHING, AND AS THE RATE BACKUP CONFIGURATION FOR EACH CHANNEL.

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K11 IS CLOSED BY MODE SELECTION LOGIC FROM THE MONITOR, G&N ATTITUDE CONTROL, AND G&N ENTRY MODE. IT IS ALSO CLOSED FOR SCS LOCAL VERTICAL, ROTATION CONTROL BREAKOUT SWITCH (CSS) IN ALL FOUR SCS MODES, ONE OR MORE CHANNELS DISABLED FOR RCS CONTROL ON THE SCS CONTROL PANEL IN THE SCS MODES, ATTITUDE IMPULSE ENABLED IN SCS ATTITUDE CONTROL MODE, AND .05G ENTRY SWITCHES IN THE SCS LOCAL VERTICAL.

K12 IS CLOSED AT ALL TIMES WHEN K11 IS CLOSED EXCEPT FOR SCS LOCAL VERTICAL.

K13 IS CLOSED BY MODE SELECTION LOGIC WITH SELECTION OF ANY ONE OF THE FOUR SCS MODES EXCEPT FOR THE FOLLOWING CONDITIONS: ROTATION CONTROL BREAKOUT SWITCH CLOSED; ONE OR MORE CONTROL CHANNELS DISABLED; ATTITUDE IMPULSE ENABLED IN THE SCS ATTITUDE CONTROL MODE; AND .05G ENTRY SWITCHING IN THE SCS ENTRY MODE.

K14 IS CLOSED BY MODE SELECTION LOGIC IN ALL OPERATING MODES EXCEPT WHEN A BMAG IS CAGED FOR BACKUP RATE OPERATION PER CHANNEL OR ATTITUDE IMPULSE ENABLE IN THE G&N OR SCS ATTITUDE CONTROL MODES.

K15 IS CLOSED BY PLACING THE RATE GYRO CONTROL SWITCHES ON THE SCS CONTROL PANEL TO THE BMAG POSITION PER CHANNEL OF CONTROL.

K16 IS CLOSED WHEN THE AGC INITIATES A SPS THRUST ON COMMAND.

K17 IS CLOSED WHEN THE ATTITUDE IMPULSE CONTROL IS ENABLED IN THE G&N OR SCS ATTITUDE CONTROL MODES.

K18 IS CLOSED WHEN THE THRUST ON BUTTON IS DEPRESSED ON THE DELTA V DISPLAY WITH THE SCS OR G&N DELTA V MODES SELECTED.

K19 IS CLOSED WHEN THE DELTA V REMAINING INDICATOR GENERATES A THRUST OFF COMMAND TO THE SCS ELECTRONICS.

K20 IS CLOSED WHEN A TRANSLATION COMMAND IS INITIATED AFTER BOOSTER SEPARATION AND BEFORE C/M-S/M SEPARATION.

K21 IS CLOSED WHEN A ROTATION COMMAND IS INITIATED TO THE SCS ELECTRONICS, EXCEPT FOR PITCH AND YAW WHILE THE SPS ENGINE IS THRUSTING.

K22 WILL BE CLOSED TO THE SM POSITION WHILE THE S/M IS ATTACHED AND WILL TRANSFER TO THE CM POSITION AFTER SEPARATION.

K23 IS CLOSED BY THE MESC AT ADAPTER OR ABORT SEPARATION TO ENABLE THE SOLENOID DRIVERS.

K24 IS CLOSED WHEN THE TVC ELECTRONICS IS GIMBALLING THE SPS ACTUATOR.

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K25 IS CLOSED WHEN THE SPS THRUST ON-OFF
ELECTRONICS HAS A THRUST ON COMMANDED.

K26 OPERATES IDENTICALLY TO K22.