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From buckley@Colorado.EDU Fri Jan  1 01:19:35 1999
Path: brokaw.wa.com!nwnews.wa.com!news-out.cwix.com!news1.cwix.com!newsfeed.cwix.com!199.117.161.1!c
From: buckley@Colorado.EDU (Charles Buckley)
Newsgroups: sci.space.history
Subject: Re: Apollo Spacecraft Guidance Computers
Date: 31 Dec 1998 16:28:15 GMT
Organization: University of Colorado, Boulder
Lines: 2887
Message-ID: <76g8mv$1ef@lace.colorado.edu>
References: <19981230161226.05480.00004200@ng-fa2.aol.com> <slrn78m297.2dc.amalmin@skaro.skaro.org>
NNTP-Posting-Host: refuge.colorado.edu
NNTP-Posting-User: buckley
Xref: brokaw.wa.com sci.space.history:30439
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In article <F2Ei2.755$L91.868@fozzy.nit.gwu.edu>,
Dwayne Allen Day  <wayneday@gwis2.circ.gwu.edu> wrote:
>Audin Malmin <amalmin@halcyon.com> wrote:
>:>I am looking for any information I can get concerning the computers on board
>:>the Apollo spacecraft.
>
>: Check out "Computers in Spaceflight: The NASA Experience", which you can find
>: in an HTML version here:
>
>:       http://www.hq.nasa.gov/office/pao/History/computers/Compspace.html
>
>Thanks for that link!  I knew that there was a book which dealt with this
>and it had at least a chapter on the Apollo computers, but I had no other
>information.
>
>To add a little to the discussion:  NASA recently got permission (along
>with the Air Force, NRO and one or two other govt. agencies) to
>manufacture radiation hardened Pentium chips.  Intel gave them permission
>to do this with the Pentium, but not the Pentium II.  I believe that the
>estimates are that it will be 3-5 years before the government can produce
>them.  The Pentium is already one generation out of date.  Isn't chip life
>about 18 months between generations now? (and A] we're already over half
>through the Pentium II generation, and B] I believe that the time between
>generations is expected to decrease soon too, although others who are more
>computer literate than I will know more)  If this is so, then by the time
>these rad-hardened chips enter service, they will already be at least 3-4
>generations out of date, which is an eternity in the computer world.
>
>
>
>DDAY
```

The Apollo Guidance Computer (AGC)

Periodically there are questions on alt.folklore.computers about what kind of computers were used on board the spacecraft in the Apollo moon program. Here are the definitive answers, reproduced directly from the Apollo Operations Handbook for spacecraft SC 012--better known as Apollo 1.

After the fire on 27 January 1967 which killed astronauts Gus Grissom,

Ed White, and Roger Chaffee, NASA began a massive investigation into the accident. Its 3-volume report, "Investigation into the Apollo 204 Accident", published 10 April 1967, contains not only the accident report, but also a wealth of supplementary data documenting the Apollo Command and Service Modules. Included is the complete Apollo Operations Handbook, which gives blueprints, block diagrams, schematics, theory of operations, how-to-fly-it instructions, you name it--including the computer system.

I have broken Section 2, Subsection 2 (Guidance and Navigation System (G&N)) into 4 parts for ease of posting. This is pages 2.2-1 to 2.2-48 of the Apollo Operations Handbook SM2A-03-SC012, or pages 443-488 of Volume II, Part 1 of the Apollo 204 Accident Report. Two of the four figures in this section I reproduce as ASCII art; I've tried to keep it to 80 columns, but in a couple places it spills over, so don't read this with your word wrap on. Of the other two figures, one is a beautiful line drawing, and the other is a 4-page foldout block diagram. If I get around to it, I'll put the text up on my WWW home page and make .GIFs of the artwork.

This description of the Apollo Guidance Computer is only absolutely correct for SC 012. A sister ship, SC 014, was completely dismantled during the accident investigation, and some changes were made in the ship design. Also, SC 012 was never intended to dock with a lunar module--it had no docking probe and tunnel--so any computer programs dealing with translunar injection and lunar orbit rendezvous are absent. As for hardware changes, I don't know if it was due to the fire, but at some point before the manned lunar missions, the Bus A and B voltages were increased from +28 VDC to +65 VDC. This had grave implications for Apollo 13: the thermostatic switch for the heater in the oxygen tanks was never upgraded from +28 VDC, it shorted out during a manufacturing test using +65 VDC, causing the heater to fail on for 8 hours, baking the inside at 1000 degrees F and exposing the bare wires which shorted out so explosively in space. Other changes from the state of SC 012 include the main hatch (changed after Apollo 1) and the plumbing for the oxygen tanks (changed after Apollo 13).

The lunar module computer was evidently similar to the AGC. At least it shared the 1201 and 1202 error codes (which occurred during the lunar descent on Apollo 11, nearly causing the landing to be aborted). I have not found documentation similar to the Apollo Operations Handbook for the LM.

I've tried to catch all the typos, but some may remain. If you find any, please let me know.

Enjoy! I did when I read it; that's why I was motivated to type it all in :-)

Rich

```
--
Richard F. Drushel, B.A., Ph.D.| ColecoVision  AA     DDDDD     AA     M     M
===============================|    Family    A  A    D    D   A  A    MM   MM
      Come to ADAMcon VIII     |   Computer  AAAAAA   D    D  AAAAAA   M M M M
     Cleveland, Ohio U.S.A.    |    System  A      A  DDDDD  A      A  M  M  M
        5-8 September 1996     |=============================================
See the ADAMcon VIII Home Page |  http://junior.apk.net/~drushel/adamcon8.html
```



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Article 95106 of alt.folklore.computers:
Path: fc.hp.com!col.hp.com!sdd.hp.com!usc!math.ohio-state.edu!magnus.acs.ohio-state.edu!usenet.ins.c
From: drushel@junior.wariat.org (Richard Drushel)
Newsgroups: alt.folklore.computers
Subject: Apollo Guidance Computer [1/4]
Date: 19 Dec 1995 05:15:36 GMT
Organization: Akademia Pana Kleksa, Public Access Uni* Site
Lines: 639
Message-ID: <4b5hpo$827@wariat.wariat.org>
NNTP-Posting-Host: junior.wariat.org
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SM2A-03-SC012
APOLLO OPERATIONS HANDBOOK

SYSTEMS DATA

SECTION 2
SUBSECTION 2.2

GUIDANCE AND NAVIGATION SYSTEM (G&N)

Basic Date: 12 November 1966

2.2.1. INTRODUCTION.

The guidance and navigation (G&N) system measures spacecraft attitude and velocity, determines trajectory, controls spacecraft attitude, controls the thrust vector of the service propulsion engine, and provides abort information and display data. Primary determination of the spacecraft velocity and position, and computation of the trajectory parameters is accomplished by the manned space flight network (MSFN).

The G&N system consists of three subsystems as follows:

* Inertial subsystem (ISS)
* Computer subsystem (CSS)
* Optics subsystem (OSS)

The inertial subsystem is composed of an inertial measurement unit (IMU), part of the power and servo assembly (PSA), part of the controls and displays, and three inertial coupling display units (CDUs). The IMU provides an inertial reference with a gimbaled, three-degree-of-freedom, gyro stabilized stable platform.

The computer subsystem is composed of an Apollo guidance computer (AGC), and two display and keyboard panels (DSKYs), which are part of the controls and displays. The AGC is a digital computer which processes and controls information to and from the IMU and optics, and stores programs and reference data.

The optics subsystem is composed of a scanning telescope (SCT), a sextant (SXT), drive motors for positioning the SCT and SXT, parts of the PSA, part of the controls and displays, and two optics CDUs. The SCT and

SXT are used to determine the spacecraft position and attitude with relation to stars and/or landmarks.

The three G&N subsystems are configured such that the CSS and OSS may be operated independently. This allows continued use of the CSS and/or OSS in the event of a malfunction in one of these subsystems or the ISS. System power requirements and reference signals are provided by the power and servo assembly (PSA). Major components of the system are located in the command module lower equipment bay (figure 2.2-1). System circuit breakers, caution and warning indicators, and one of the DSKYs are located on the main display console.

[Figure 2.2-1. G&N Equipment Location] [omitted]

2.2.2. FUNCTIONAL DESCRIPTION.

The guidance and navigation system provides capabilities for the following:

* Inertial velocity and position (state vector) computation
* Optical and inertial navigation measurements
* Spacecraft attitude measurement and control
* Generation of guidance commands during CSM-powered flight and C/M atmospheric entry.

The G&N system is initially activated and aligned during the prelaunch phase. During the ascent phase, the system measures velocity and attitude, computes position, compares the actual spacecraft trajectory with a predetermined trajectory, and displays pertinent data. The flight crew uses the displayed information as an aid for decision to abort or continue the mission. However, spacecraft control is maintained by the S-IVB guidance until CSM/S-IVB separation. Upon separation, the G&N system assumes the guidance and navigation functions using the data acquired during ascent.

During periods when onboard velocity and/or attitude change sensing is not required, the IMU is placed in standby operation to conserve electrical power. The AGC is used more extensively than the IMU; however, it will also be placed in standby operation to conserve electrical power. When the guidance and navigation function is to be restored, the IMU and AGC are reactivated, with the AGC using the last computed velocity as the basis for further velocity computations. New positional data must be acquired from optical sightings or MSFN through telemetry or voice communications.

Initial position and attitude information as well as periodic updating of this information is made through the use of the optics. This is accomplished by the navigator making two or more landmark and/or star sightings. The sightings are made by acquiring the star-landmark with the SCT and/or SXT. When the viewed object is centered, a mark command is initiated. The AGC reads the optics angles, IMU angles, and time, in conjunction with internal programs to determine the spacecraft position. This position information and the spacecraft velocity are used to compute and estimated trajectory. The actual trajectory is compared with previous trajectory data to generate the trajectory error, if any, for further reference. Optical measurements are also used in aligning the IMU to a specific reference orientation.

The IMU (figure 2.2-2) contains three inertial rate integrating gyros (IRIGs), three angular differentiating accelerometers (ADAs), and three pulsed integrating pendulous accelerometers (PIPAs). The IRIGs, PIPAs, and one ADA are mounted on the stable platform which is gimbaled to provide three degrees of freedom. The two remaining ADAs are mounted on the middle gimbal. The stable platform inertial reference is maintained by the IRIGs and ADAs in conjunction with electronic stabilization loops. Any displacement of the platform is sensed by the IRIGs which produce output signals representative of the magnitude and direction of displacement. The ADAs sense the displacement rate and produce output rate control signals to maintain correct stabilization loop control response. The IRIG and ADA signals are applied to servo amplifiers, which condition the signals to drive gimbal torque motors. The gimbal torque motors then restore the initial platform orientation by driving the gimbals until the IRIG signals are nulled.

The PIPAs are orthogonally mounted and sense changes in spacecraft velocity. An acceleration or deceleration results in output signals which are representative of the magnitude and direction of the velocity change. The output signals are applied to the AGC which uses the information to update spacecraft velocity data. Continual updating of velocity information, with respect to the initial spacecraft position and trajectory, enables the AGC to provide current velocity, position, and trajectory information.

The IMU also provides a space stabilized reference for spacecraft attitude sensing and control. Attitude change sensing is accomplished by monitoring the spacecraft attitude with reference to the stable platform. Resolvers are mounted at the gimbal axes to provide signals representative of the gimbal angles. Inertial CDUs contain resolvers which repeat the platform attitude. Attitude monitoring is afforded by comparing the IMU resolver output signals with the CDU resolver signals. If the angles differ, error signals are generated and applied to the stabilization and control system. If the attitude error is larger than the selected deadband limits, the SCS fires the appropriate RCS engines. The spacecraft is rotated back to the initial reference attitude and the error signals are nulled (within deadband limits).

The AGC provides automatic execution of computer programs, automatic control of ISS and OSS modes, and, in conjunction with the DSKYs, manual control of ISS and OSS modes and computer displays. The AGC contains a two-part memory which consists of a large non-erasable section and a smaller erasable section. Non-erasable memory contains mission and system programs and other predetermined data which are wired in during assembly. Data readout from this section is non-destructive and cannot be changed during operation. The erasable section of memory provides for data storage, retrieval, and operations upon measured data and telemetered information. Data readout from this section is destructive, permitting changes in stored data to be made as desired. Information within the memory may be called up for display on the two DSKYs. The DSKYs enable the flight crew to enter data or instructions into the AGC, request display of data from AGC memory, and offer an interrupt control of AGC operation. The AGC timing section provides timing signals of various frequencies for internal use and to other onboard

systems which require accurate or synchronized timing. Data within the AGC is transmitted to MSFN through a "downlink" telemetry function. Telemetered data is transmitted as a function of an AGC program or by request from MSFN. Data within the AGC may be updated through an "uplink" telemetry function controlled by MSFN. The AGC performs guidance functions by executing internal programs using predetermined trajectory parameters, attitude angles from the inertial CDUs, velocity changes from the PIPAs, and commands from the DSKYs (crew) to generate control commands. The navigation function is performed by using stored star-landmark data, optics angles from the optics CDUs, and velocity changes from the PIPAs in the execution of navigation programs.

The optics provide accurate star and landmark angular measurements. Sightings are accomplished by the navigator using the SXT and SCT. The optics are positioned by drive motors commanded by the optics hand controller or manually using a universal tool, as desired. The shaft axes are parallel. Trunnion axes may be operated in parallel or offset, as desired. The SCT is a unity power instrument providing an approximate 60-degree field of view. It is used to make landmark sightings and to acquire and center stars or landmarks prior to SXT use. The SXT provides 28-power magnification with a 1.8-degree field of view. The SXT has two lines of sight, enabling it to measure the included angle between two objects. This requires two lines of sight which enable the two viewed objects to be superimposed. For a star-landmark sighting, the landmark line of sight is centered along the SXT shaft axis. The star image is moved toward the landmark by rotating the shaft and trunnion axes until the two viewed objects are superimposed. The shaft and trunnion angles are repeated by the optic CDUs. When the navigator is satisfied with image positions, he issues a mark command to the AGC. The AGC reads the optics CDU angles, IMU CDU angles, and time, and computes the position of the spacecraft. The AGC bases the computation on stored star and landmark data which may also be used by the AGC to request specific stars or landmarks for navigational sightings. Two or more sightings, on two or more different starts, must be taken to perform a complete position determination.

2.2.2.1. Operational Modes.

The G&N system is operated in six basic operational modes. Selection of any one mode is accomplished manually by the flight crew or automatically by the AGC. The basic modes are as follows:

* Monitor (initiated by SCS mode selection)
* Zero encode
* Coarse align
* Fine align
* Attitude control
* Entry

The system configuration necessary to operate in any of the modes is established by relay switching.

The monitor mode is used at launch, ascent, and during orbit until CSM/S-IVB separation, to provide flight path data for crew displays. The

coarse align, fine align, and zero encode modes are used to align the IMU after standby periods or to acquire a new stable platform orientation. The attitude control mode provides for spacecraft attitude control and navigation computations to measure position and velocity. The entry mode provides control of the spacecraft lift vector during entry phase.

The ISS and CSS will be operated in on-standby cycles to conserve electrical power. During standby operation, the ISS maintains IMU temperature, and the CSS maintains AGC timing functions. The OSS is shut off when not in use. Since standby operation time varies for each of the subsystems, standby is not considered as a basic mode.

2.2.2.1.1. Monitor Mode.

During prelaunch operations, the G&N system is aligned to the desired launch reference attitude and gyro compasses to maintain this attitude. Approximately 3 minutes prior to launch, the gyro compassing is stopped and the system becomes inertially referenced. Upon lift-off the AGC begins monitoring the flight path angles by driving the Inertial Coupling Display Units (ICDUs) through programmed attitude changes. The ICDU angles are compared with the IMU gimbal angles to produce flight path error signals which are displayed by the FDAI error needles. Total spacecraft attitude, with respect to the IMU orientation, is displayed by the FDAI ball. (Prelaunch FDAI readings are 164.76-degree roll, 58.30-degree pitch, and 9.69-degree yaw, with respect to the navigation axis symbol. Display at orbit insertion is 0-degree roll, 310.5-degree pitch, and 0-degree yaw, assuming a 180-degree roll has been performed and launch pad 37 is used.) During boost prior to launch escape tower (LET) jettison, the AGC displays the following:

REGISTER 1 - Inertial flight path angle; inertial velocity with respect to local horizontal in degrees.

REGISTER 2 - Inertial velocity in ft per sec.

REGISTER 3 - Altitude above launch pad in nautical miles (NMs).

Upon receipt of LET jettison signals the displays change to the following:

REGISTER 1 - Predicted Gs for free-fall and entry at 60-degree bank angle.

REGISTER 2 - Altitude of perigee above the mean equatorial radius in NMs.

REGISTER 3 - Time of free-fall to 300,000 ft above mean equatorial radius in minutes and seconds.

This displayed data provides the flight crew with sufficient information to make abort or continue decisions ; however, if time is not critical, the decision is made by the flight crew and MSFN jointly.

2.2.2.1.2. Zero Encode Mode.

The zero encode mode enables correction of the CDU data stored in the AGC. This mode is used to ensure that the reference angles contained in the

CDU registers of the AGC correspond with the actual CDU angles. This is accomplished by driving the CDUs to zero, then clearing the AGC CDU registers. This starts the AGC CDU registers at zero and enables the registers to maintain correct CDU angles by counting pulses from the CDU digital encoders.

2.2.2.1.3. Coarse Align Mode.

The coarse align mode enables stable platform alignment to within approximately 2 degrees of a desired platform orientation. Prerequisite information to accomplish a coarse alignment consists of the desired platform orientation and present spacecraft attitude.

The desired platform orientation angles are computed by an alignment program executed by the AGC. The navigator determines the spacecraft attitude immediately prior to coarse alignment by making two or more sightings on stars or landmarks. Upon completion of the sightings, the AGC reads the optic angles and computes the gimbal angles necessary to attain the desired platform orientation. The AGC generates drive signals to position the CDU resolvers to the required gimbal angles. The IMU-CDU resolver error signals, generated by repositioning the CDUs, are applied to the gimbal torque servo amps which drive the gimbal torque motors to position the platform to the desired orientation.

The stable platform orientation will normally be such that the X-axis lies along the spacecraft thrust vector during all powered phases, except ascent, and along the spacecraft stability axis during entry.

2.2.2.1.4. Fine Align Mode.

The fine align mode completes stable platform orientation to the required degree of accuracy. The navigator makes two or more star sightings, using on-board data and the optics to acquire the desired stars. Upon receipt of the optic angles the AGC computes the IMU angles necessary to complete the alignment. In the fine align mode, the IMU angles are repeated by the inertial CDUs which are monitored by the AGC to determine the actual IMU orientation. The AGC generates torquing signals to cancel any error between the actual IMU orientation and the desired orientation. These torquing pulses are applied to the IRIG torquing coils. The IRIGs, in conjunction with the stabilization loops, reposition the stable platform until the desired orientation is attained. Upon completion of fine alignment, the IMU/CDU resolver signals and the stabilization loop signals are at null.

The system configuration required for fine align mode also applies IMU resolver signals to the SCS as apparent attitude error signals. To prevent these signals from appearing as actual spacecraft attitude errors, the SCS must be operated in an SCS mode which rejects G&N derived signals.

2.2.2.1.5. Attitude Control Mode.

The attitude control mode provides spacecraft attitude change sensing, generates error signals for spacecraft attitude control, velocity change signals for updating AGC velocity information, and signals for timing SPS engine thrust termination commands.

During spacecraft attitude control, the IMU gimbal resolvers sense any displacement of the spacecraft with respect to the stable platform orientation and produce corresponding error signals. The error signals are applied directly to the SCS-FDAI ball for error display and to the inertial CDU resolvers. The IMU-CDU error signals are displayed on the IMU control panel, resolved into spacecraft axes, and applied to the SCS. If the error signals indicate an attitude error larger than the selected deadband, appropriate RCS engines are fired and the desired spacecraft attitude is restored.

For delta V maneuvers, the G&N system provides attitude control, velocity change sensing, and total velocity change control by generating thrust termination commands. Prior to thrusting, the IMU is aligned so that the stable platform X-axis is parallel to the thrust vector. The AGC determines time-to-ignition and total velocity change desired, and performs mode verification routines. At ignition time the AGC flashes the DSKY displays to the crew for initiation of ignition (manual DSKY entry is required). During thrusting, the CDU applies attitude error signals to the SCS. Roll error signals are applied to the RCS engines; however, pitch and yaw error signals are applied to the SPS engine gimbals rather than the RCS engines. This ensures alignment of the thrust vector through the spacecraft center-of-gravity and along the correct trajectory. The PIPAs on the stable platform sense the velocity changes and apply proportional output signals to the AGC. The AGC computes and updates spacecraft velocity, and counts down a preset counter with the PIPA signals. When the counter reaches zero, a thrust termination signal is generated and applied through the SCS electronics to the SPS engine.

2.2.2.1.6. Entry.

The entry mode provides for generation of attitude error and steering signals, sensing of deceleration, and computation of velocity changes during the entry phase of the mission. The steering signals provide for control of the spacecraft lift vector through the SCS, to inhibit excessive G-loadings and heat buildup, and to control the flight path to enable landing at a pre-selected site. Attitude error signals are applied to the FDAI attitude error needles.

Entry configuration is similar to attitude control with the exceptions that the roll response time is reduced, one step of axis resolution is not needed, and the AGC will produce steering signals to the SCS by driving the roll CDU. From initiation of entry mode until 0.05G switching, roll, pitch, and yaw error signals provide attitude control. Upon 0.05G switching, the pitch and yaw error signals provide display only. Prior to entry, the IMU X-axis is aligned along the spacecraft entry velocity vector. This alignment eliminates the need for navigation base-to-spacecraft body axis resolution. Deceleration is sensed primarily by the IMU X-axis PIPA, although changes in lift vector orientation cause some lateral movement which is sensed by the Y and/or Z PIPAs. The outer gimbal, or roll, 1X resolver is connected to the 16x resolver in the ROLL CDU, giving a 16:1 increase in attitude error signal and reducing the response time of the roll channel. The AGC will produce steering signals by executing a programmed lift vector down entry (to ensure capture), 180-degree roll to lift vector up, then generate further steering signals with respect to G forces, heat buildup, and range needed. These steering signals are routed to the roll CDU where an IMU-CDU resolver error is generated and routed to the SCS for FDAI display and/or RCS engine control. The entry may be performed manually with the pilot flying to the steering signals as displayed on the FDAI, or automatically with the AGC steering signals routed to the roll RCS engines for spacecraft control.

2.2.3. MAJOR COMPONENT/SUBSYSTEM DESCRIPTION.

2.2.3.1. Inertial Subsystem.

The function of the inertial subsystem is to provide a space-stabilized inertial reference from which velocity changes and attitude changes can be sensed. It is composed of the inertial measurement unit (IMU), the navigation base (NB), parts of the power and servo assembly (PSA), parts of the control and display panels, and three coupling display units (CDUs).

2.2.3.1.1. Navigation Base.

The navigation base (NB) is the rigid, supporting structure which mounts the IMU and optical instruments. The NB is manufactured and installed to close tolerances to provide accurate alignment of the equipment mounted on it. It also provides shock mounting for the IMU and optics.

2.2.3.1.2. Inertial Measurement Unit.

The inertial measurement unit (IMU) is the main unit of the inertial subsystem. It is a three-degree-of-freedom stabilized platform assembly, containing three inertial reference integrating gyros (IRIGs), three pulsed integrating pendulous accelerometers (PIPAs), and three angular differentiating accelerometers (ADAs). The stable member itself is machined from a solid block of beryllium with holes bored for mounting the PIPAs, IRIGs, and one of the three ADAs. Three gimbal and six intergimbal assemblies, which house torque motors and resolvers, are also part of the IMU assembly, together with preamplifiers and gimbal-mounted electronics. Figure 2.2-2 shows how the IRIGs and the PIPAs are mounted relative to each other on the stable member (or inner gimbal). The three gimbal axes, about which each of the gimbals rotate, are also shown.

[Figure 2.2-2. G&N System Functional Block Diagram] [omitted]

The stable platform attitude is maintained by the IRIGs, ADAs, stabilization loop electronics, and gimbal torque motors. Any displacement of the stable platform or gimbal angles is sensed by the IRIGs and ADAs, which generate error signals. IRIG error signals are resolved and amplified at the IMU and applied to stabilization loop electronics. ADA-produced error signals are summed with the IRIG error signals. The resultant signal is conditioned and applied to the gimbal torque motors, which restore the desired attitude.

The stable platform provides a space-referenced mount for three PIPAs, which sense velocity changes. The PIPAs are mounted orthogonally to sense the velocity changes along all three axes. Any translational force experienced by the spacecraft causes an acceleration or deceleration which is sensed by one or more PIPAs. Each PIPA generates an output signal proportional to the magnitude and direction of velocity change. This signal, in the form of a pulse train, is applied to the AGC. The AGC will use the signal to update the velocity information and also generate signals to torque each PIPA ducosyn back to null.

The temperature of the IRIGs and PIPAs is maintained within required

limits both during standby and operating modes of the IMU. The IMU temperature control system contains circuits to supply normal proportional temperature control with the capability of backup or emergency control in case of a proportional control malfunction. The proportional temperature control circuit is the primary means of maintaining the IRIG and PIPA temperature and provides the most accurate control. This type of control is available when either the proportional or auto-override mode is selected with the IMU TEMP MODE selector switch. The purpose of the auto-override mode is to provide automatic switching from that mode to emergency control if there is a malfunction in the proportional control circuit. If a malfunction occurs in the proportional mode, the switching to emergency control must be performed manually. In the proportional mode, the temperature is controlled by the proportional temperature control bridge and is maintained at 135 +/- 0.5 degrees F. While in the emergency mode, it is controlled by the mercury thermostat and is held within +/- 5 degrees F.

The backup temperature control and indicator circuit is intended for use in the event the proportional control fails. The control sensing elements for this system are three PIPA indicating sensors (connected in series) and six IRIG sensing elements (connected in series) in two separate bridges. This system can maintain the temperature to within +/- 1 degree F. In this mode of operation, an alarm indication is not available to the astronaut because of modifications to the temperature alarm amplifier circuit.

2.2.3.1.3. Coupling and Display Units.

There are five CDUs mounted below the IMU control panel at the lower equipment bay. Three CDUs function as a part of the ISS, while the two remaining CDUs function with the OSS. The optic CDUs (OCDUs) are described in paragraph 2.2.3.2. The three inertial CDUs (ICDUs) are identical and may be interchanged. Display dials on the front panel of each provide a 6-digit readout. Positioning of the ICDUs is accomplished by the AGC. Each ICDU contains a 1/4-speed, 1/2-speed, 1-speed, and 16-speed resolver, the functions of which depend upon the ISS mode of operation. The angular movements of the resolvers are converted into digital signals by a digital encoder, processed by encoder electronics, and routed to AGC registers which maintain current ICDU angles for use as desired. The AGC commands CDU movements by applying digital drive commands to digital-to-analog converters. The drive signals are converted from digital to analog and applied to CDU motor drive amplifiers which position the CDUs. The 1-speed and 16-speed resolvers function as receivers of signals produced by 1-speed and 16-speed resolvers mounted on the IMU. The 1/2-speed resolvers are used to zero the CDUs and the 1/4-speed resolvers are not used. The resolvers provide input signals to selector circuits which provide motor drive signals or spacecraft attitude error signals, depending upon ISS mode of operation. The IMU outer gimbal 1-speed resolver signals are applied to the roll CDU 16-speed resolver to increase roll control rates during entry.

2.2.3.1.4. Power and Servo Assembly.

The power and servo assembly (PSA), located just below the display and control panel in the lower equipment bay, serves as a central mounting point for most of the G&N electronic units such as power supplies and amplifiers. It also contains the backup electronics used to supply timing pulses to the IMU in case of an AGC timing malfunction. It consists of 10 removable trays mounted adjacent to each other and connected to a junction

box. The PSA trays utilize three wiring harnesses to provide electrical connection: one for module-to-module connection, another for module-to-junction box connection, and a third for module connection to a 38-pin female test plug on the front of the PSA tray.

2.2.3.2. Optical Subsystem.

The optical subsystem is used for taking precise optical sightings on celestial bodies and for taking fixes on landmarks. These sightings are used for aligning the IMU and for determining the position of the spacecraft. The system includes the navigational base, two of the five CDUs, parts of the power and servo assembly, controls and displays, and the optics, which include the scanning telescope (SCT) and the sextant (SXT).

2.2.3.2.1. Optics.

The optics consist of the SCT and the SXT mounted in two protruding tubular sections of the optical base assembly. The SCT and SXT shaft axes are aligned parallel to each other and afford a common line-of-sight (LOS) to selected targets. The trunnion axes may be parallel or the SCT axis may be offset depending upon mode of operation.

The sextant is a highly accurate optical instrument capable of measuring the included angle between two targets. Angular sightings of two targets are made through a fixed beam splitter and a movable mirror located in the sextant head. The sextant lens provides 1.8-degree true field of view with 28X magnification. The movable mirror is capable of sighting a target to 57 degrees LOS from the shaft axis. The mechanical accuracy of the trunnion axis is twice that of the LOS requirement due to mirror reflection which doubles any angular displacement in trunnion axis.

The scanning telescope is similar to a theodolite in its ability to accurately measure elevation and azimuth angles of a single target using an established reference. The lenses provide 60-degree true field of view at 1X magnification. The telescope allowable LOS errors are 1 minute of arc rms in elevation with maximum repeatability of 15 arc/seconds and approximately 40 arc/seconds in shaft axis.

2.2.3.2.2. Coupling Display Units.

The function of the OCDUs is to position and repeat angles of the SCT and SXT shaft and trunnion axes. The OCDUs are similar to the ICDUs, but may not be interchanged due to internal mechanical differences allowing higher OCDU rates. Each OCDU has a 6-digit display readout and can be positioned automatically by AGC command. CDU angles are converted to a digital signal by a digital encoder, processed by encoder electronics, and routed to an AGC register. AGC positioning commands are applied to a digital-to-analog converter, converted to a representative analog signal, and applied to a motor drive amplifier in the SXT. Resolvers in the SXT function as transmitters to CDU resolvers which receive the position signals and apply the commanded angles to the CDU motor drive amplifiers to position the CDU motor.

Trunnion CDU 1/4-speed and 16-speed resolvers function as receivers and provide drive signals to the trunnion CDU motor. The SXT trunnion resolvers which drive the CDU resolvers are 1-speed and 64-speed respectively, providing a 1:4 SXT trunnion to CDU trunnion ratio. Visual readouts on the trunnion display dials are thus four times the trunnion angle and two times the start line-of-sight angle from zero position. The 1/2-speed resolver, in conjunction with the cosecant amplifier, provides a variable gain computing resolver which is used in the RESOLVED mode of operation. The 1-speed resolver is not used in the trunnion CDU.

Shaft CDU 1/2-speed and 16-speed resolvers function as receivers and produce drive signals to the shaft CDU motor. SXT resolvers used as transmitters are also 1/2-speed and 16-speed resolvers, affording a 1:1 ratio; thus, the display dials provide direct readouts of the shaft angles. The 1-speed resolver resolves polar coordinates into rectangular coordinates for the RESOLVED mode of operation. The 1/4-speed resolver is not used in the shaft CDU.

2.2.3.2.3. Operational Modes.

Optics positioning is accomplished automatically by the AGC or manually by the crew. Overall mode control is established by crew selection of the ZERO OPTICS, MANUAL, or COMPUTER modes on the OPTICS panel.

ZERO OPTICS mode enables automatic drive of the SXT shaft and trunnion motors to zero. This is accomplished by applying the SXT resolver output signals to the input of the SXT motor drive amplifiers. The drive signals are applied to the CDU and SCT resolvers which follow the SXT shaft and trunnion axes to zero. After 60 seconds, the AGC optics position registers are cleared. This mode may be selected by AGC program or manually.

MANUAL mode enables positioning control of the optics by manual manipulation of the optics hand controller. The hand controller is mechanized such that, right-left movement generates shaft commands, and up-down movement generates trunnion commands. Hand controller drive rates are selected by the position of the CONTROLLER SPEED switch. Positions HI, MED, and LO control the amplitude of the drive signal to the hand controller. Hand controller drive signals are applied to the SXT shaft and trunnion drive amplifiers through the CONTROLLER MODE switch for selection of DIRECT or RESOLVED mode. In DIRECT mode, the image motion is presented in a polar coordinate reference frame; in resolved mode, the image motion is presented in rectangular coordinate reference frame.

In DIRECT mode, shaft commands move the image in a circular path around the center of the field of view. Trunnion commands drive the image in a straight line across the center of the field of view. The angular orientation of the trunnion commanded straight line movement is a function of the shaft angle; therefore, direction of image movement with respect to the direction of hand controller movement is also a function of shaft angle. The rate of image movement, for shaft commands, is a function of trunnion angle, wherein increasing trunnion angle result in increasing image movement rates.

In COMPUTER mode, the AGC positions the optics to a star or landmark determined by AGC programming. This mode is performed by an AGC routine which is called up automatically by various alignment programs. The target star or landmark may be defined by AGC programming or by the crew. If the target star or landmark is not selected by AGC programming, the crew makes a DSKY entry defining either the latitude, longitude, and altitude for a landmark or the star code for a star. The AGC determines the spacecraft attitude by monitoring the ICDUs, and computes the angles necessary to drive the optics to the desired

target. (If the angles necessary to acquire the target are beyond the capabilities of the optics, the AGC flashes the DSKY displays.) When the necessary angles are computed, the AGC displays the desired shaft and trunnion angles on the DSKY and initiates OCDU drive to these angles. When the AGC has completed driving the CDUs, the crew checks the DSKY-displayed angles against the 6-digit CDU displays and the SCT counters. The crew then locates and identifies the target in the SCT, enables manual control, and completes the sighting. The AGC can also perform zero optics functions, if desired, by the AGC program.

The SCT trunnion may be operated in three alternate modes, with respect to the SXT trunnion, as desired. The SLAVE TELESCOPE switch enables crew selection of STAR LOS, LANDMARK LOS 0 DEGREES, or OFFSET 25 DEGREES. The STAR LOS position is normally used. In this position, the SCT trunnion is slaved to the SXT trunnion. The LANDMARK LOS 0 DEGREES position applies a fixed voltage to the SCT trunnion position loop, causing it to null at zero. This holds center of the SCT 60 degree field of view parallel to the SXT landmark line of sight. The OFFSET 25 DEGREES position applies a fixed voltage to the SCT trunnion position loop, causing it to null at 25 degrees off-center. This holds the SCT field of view so that the SXT landmark line of sight remains visible while sweeping the SCT shaft through 360 degrees of rotation, providing an approximate 110-degree total field of view.

2.2.3.3. Computer Subsystem.

The computer subsystem (CSS) consists of the Apollo guidance computer (AGC) and two display and keyboard panels (DSKYs). The AGC and one DSKY are located at the lower equipment bay. The other DSKY is located on the main display console. The AGC mounts one switch on the front panel which applies partial or full power to the computer to enable standby or full operation of the CSS. All other AGC controls and displays are located on the DSKYs. The keyboards on the DSKYs are similar; however, the displays on the DSKY in the lower equipment bay are more extensive.

2.2.3.3.1. Apollo Guidance Computer.

The Apollo guidance computer (AGC) is a digital computer using a two-part rope core memory. (See figure 2.2-3.) The AGC processes various data to provide control and computation functions. Input data is received from the crew, ISS, OSS, MSFN, and other spacecraft systems. This data is processed by various programs to provide outputs to the crew, ISS, OSS, MSFN, and other spacecraft systems in the form of commands and displays. The control functions performed by the AGC consist of the following:

* Align the IMU stable platform.
* Position the optics for navigation sightings.
* Command reaction control system engine firings to maintain specific attitude.
* Request initiation and command termination of service propulsion engine firings.
* Provide synchronization pulses to the central timing equipment.
* Command telemetry transmission to MSFN.
* Command ISS moding.

* Command OSS moding.

The reference data used to generate controls may be acquired externally or generated within the AGC. Initiation of the controls may be accomplished by the crew using the DSKYs, by MSFN via telemetry, or by an AGC program.

```
                                +------------------+
                                |      MEMORY      |
                                |                  |
                                |        |         |
                                | ERASE- |  FIXED  |
                                |  ABLE  |         |
                                |        |         |
                                +------------------+
                                   ^ |       ^ |
                                   | |       | |
                                   | +---+   | |
                 PARITY FAIL       |     |   | |    INHIBIT/ENABLE DOWNLINK
              +----------------+   +---+ |   | |     +-------------------+
              |                |       | v   | v     |                   |
              |   +-------+    |     +-----------+   |       +--------+  |
              +-->|       |    |     |           |   |       |        |--+
SCS MODES-------->|       |    +-----|           |<--+       |        |-->DSKYs
TELEMETRY-------->|       |          |           |           |        |-->ISS MODES & CONTROL
DSKYs (CREW)----->|       | DATA IN  |  CENTRAL  | DATA OUT  |        |-->OSS MODES & CONTROL
ISS MODES-------->| INPUT |--------->| PROCESSOR |---------->| OUTPUT |-->SPS ENGINE
OSS ANGLES------->|       |          |           |           |        |-->TELEMETRY
MESC (EVENTS)---->|       |          |           |           |        |-->CDUs
S-IVB INST UNIT-->|       |          |           |           |        |-->PSA REFERENCE
              +-->|       |          |           |           |        |
              |   +-------+          +-----------+           +--------+
              |
              |  TIMING (REAL TIME)
              +------------------------------+
                                             |
                       TO ALL SECTIONS       | TO ALL SECTIONS
                               ^             |  ^
                               |             |  |
                               |             |  |
                           +--------+    +--------+
                           |        |    |        |
                           |        |    |        |
                +28 VDC,   | POWER  |    | TIMING |
                MAIN DC -->| SUPPLY |    |        |
                 BUSES     |        |    |        |
                           |        |    |        |                SM-2A-827
                           +--------+    +--------+
```

Figure 2.2-3. AGC Functional Block Diagram.

Computations are performed to generate the proper control commands, maintain navigation parameters, and complete various other operations under program control. AGC programs are stored in memory. The memory contains two sections, erasable and non-erasable. The erasable section provides storage for transient data. Readout is destructive; thus, if the data is to be retained,

it must be written back into memory. Otherwise, the location is cleared for further use as desired. Non-erasable memory contains programs, routines, constants, star and landmark coordinates, and other pertinent data. Readout is non-destructive; thus, the data contained in this section is not lost and cannot be altered. AGC programs are performed by controlling the flow of data within the six basic sections listed as follows:

* Power supply
* Input
* Output
* Central processor
* Memory
* Timing

Power supply. The power supply consists of two parts. Input to the power supply is +28 vdc from the spacecraft main d-c bus. The two sections provide +13 vdc and +3 vdc. The +13-vdc output provides power to the DSKYs and, in conjunction with the +3-vdc power, to the logic circuits. The +3-vdc supply provides power to the timing section as well as to the logic circuits. During standby mode of operation, the +3-vdc section only is operated; thus, power consumption is reduced by approximately 100 watts.

Input. The input section consists of four registers which enable inter-communication between the AGC and the other G&N subsystems, the stabilization and control system, the mission sequencer, the S-IVB guidance, and MSFN. The utilization of the registers is such that each bit position in each register is assigned a specific task. For example, bit positions 1, 2, 3, 4, and 5 of input register 0 are assigned to receiving the five bit code generated when a DSKY key is pressed. Data received from the various sources are conditioned by the input registers such that, when it is transferred into the logic circuits, the signal levels and timing are correct. The data received by the four input registers are as follows:

Input 0 Register	Receives 5-bit code from the DSKYs, block uplink signal from the UPTEL switch, control signals from the SCS mode control panel, and mark commands from the MARK pushbutton. Also monitors the signal from the telemetry bit rate detecting circuits.
Input 1 Register	This register is formed by the Scaler A register of the timing section which maintains real time during standby operation, and provides update information to the real time counters when full operation is resumed.
Input 2 Register	Receives 200, 400, 800, and 1600 pps signals from the Scaler A section of the timing section, forming an extension of the real time counters for use by other spacecraft systems which require timing of this order. Also receives discrete event signals from the S-IVB instrument unit, CM/SM separation signals from the master events sequence controller, failure signals from the ISS, mode signals from the SCS, and parity fail

signals.

Input 3 Register	Receives ISS mode signals from the ISS mode relays and mode signals from the OSS, monitors the position of the TRANSFER switch, and provides a logic OR gate for 33 DSKY relays.

Output. The output section consists of four registers which enable the AGC to communicate with the flight crew, ISS, OSS, and other spacecraft systems. The utilization of the registers is similar to that used for the input section (i.e., each bit position, or group of bit positions, is assigned a specific task). The tasks assigned to the various registers and bit positions are as follows:

Output 0 Register	Provides the transmission link from the AGC to the DSKYs by control of 14 banks of relays which provide display of data and routing of control signals to the ISS, OSS, and SCS.
Output 1 Register	Receives internal AGC alarm signals and causes alarm indicators on the DSKYs to illuminate. Receives KEY RLSE request from an AGC program and causes KEY RLSE indicator to flash until the DSKY is released. Receives AGC signal indicating improper DSKY operation and causes the CHECK FAIL indicator to illuminate. Receives SPS engine firing signal from an AGC program, causing the DSKY to flash a request for crew initiation of engine firing. Receives SPS engine off command from an AGC program, removing the engine on signal. Also provides a signal to reset the error interrupt trap circuits, by downlink telemetry, and inhibits further loading of telemetry words when the telemetry word rate exceeds 50 words per second.
Output 2 Register	Controls application of 3200 pps control pulses to the ISS and OSS.
Output 3 Register	Serves as a spare register for the central processor when needed.
Output 4 Register	Contains the next word to be transmitted by downlink telemetry.

Central Processor. The central processor contains the logic circuits and registers which perform the programs. Programs are executed by performing instructions in a sequence controlled by the sequence generator. There are two basic types of instructions. The first is the machine instruction which consists of regular, involuntary, and miscellaneous instructions. Regular instructions are contained within the program and are part of the data words being processed. Involuntary instructions are performed as interrupts to the program and are generated externally to the AGC. Miscellaneous instructions

are used in the computer test only. The second basic type of instruction is the interpretive instructions and are a programmer convenience which are converted under program control to machine instructions. The execution of the instructions is a function of the sequence generator. The sequence generator combines basic timing pulses with the instruction portion of a data word and performs the program in the necessary sequence. Regular machine instructions are processed by the sequence generator initiation of the instruction. The instruction will perform one or more subinstructions, the last of which will be a subinstruction to proceed to the next instruction. Involuntary instructions are initiated by an interrupt from an external source, after which the instruction is performed in the same manner as a regular instruction. After completion of the involuntary instruction, a "resume" command is executed and the sequence generator returns to the program which was interrupted. The central processor performs the data manipulation by adding, subtracting, shifting, etc., within a group of central registers, adder, and parity block. The functions of the registers are as follows:

A Register	Accumulator. Stores the results of arithmetic processing.
LP Register	Stores the least significant portions of the product of a multiply instruction.
B Register	Used to complement (by reading the reset side of the register), as temporary storage, and as a buffer.
Z Register	Program counter. Contains address of next instruction. Incremented by one as each instruction is performed. (Instructions are usually stored in memory sequentially.)
Q Register	If transfer control occurs the contents of Z are read into and stored in Q until interrupt is completed. Enables interrupted program to restart at the proper instruction. Also used in division. Stores remainder in complemented form.
Input 0, 1, 2, 3	Refer to Input section description.
Output 0, 1, 2, 3	Refer to Output section description.
G Register	Provides access to and from memory. Shifting, under program control, takes place in this register. Parity bit is removed and restored in this register.
S Register	Contains address of word to be called from memory. If word is in fixed memory, this selects word in conjunction with BANK register.
BANK Register	Selects bank in fixed memory. Operates in conjunction with S register.
SQ Register	Stores 4-bit order code of instruction word.

X, Y, U Registers	These registers form the adder. Two numbers to be added are placed in X and Y. The result is stored in U.
Parity Circuit	The parity circuit checks the parity of words coming from memory to be odd. If parity is not correct, this circuit generates a parity alarm. Words being transferred to memory are given the proper parity bit by this circuit.

Data flow within the central processor is initiated by an instruction. A data word is brought from memory to the G register. The G register provides temporary storage of the word until it is needed. If the word came from erasable memory, it will usually be written back into the same register. (This is not necessary for words from fixed memory, as readout is not destructive.) The word is then routed to the parity circuits for a parity check and to have the parity bit removed. The sequence generator next controls the transfer of the data word to the other registers for processing. If the result of the processing is to be written back into memory, the word is transferred back into the G register, the parity bit is added, and the word transferred back to memory. If the processing consists of arithmetic functions, it is performed in the adder (X, Y, and U registers). The AGC has the capability to add only; therefore, subtraction, multiplication, and division are performed by complementing and/or shifting, then adding.

Memory. The AGC memory consists of two sections. The largest section is the fixed memory. This is a rope core type having a capability of 24,576 sixteen-bit words. Readout is non-destructive and the data contained cannot be changed. All permanent, pre-determined data, such as programs, tables, constants, star and landmark angles, etc., are contained in this section. Addressing the data contained in the fixed section is accomplished by the S and BANK registers. A smaller erasable section provides temporary storage for transient data. Erasable memory is a coincident-current core array with a capacity of 1024 sixteen-bit words. Readout is destructive, so if data is to be retained, it is necessary to write the data back into the location when it is read out. Addressing the data contained in erasable memory is done by the S register.

Timing. The timing section generates the synchronization pulses for AGC operations and timing pulses for other spacecraft systems. The timing section is divided into the following functional groups:

Clock Divider	This group contains the basic clock oscillator which has a 2.048 mc frequency divided to time various AGC logic functions and certain outputs, clock the time pulse generator, and driver Scaler A.
Scalers A and B	Scaler A contains 17 binary dividers producing signals of various frequencies used within the AGC logic, as reference to the PSA, and to drive Scaler B. Scaler B contains 16 binary dividers producing timing signals to the Input 1 register for maintaining real time when the AGC is in standby. Scalers A and B are used in conjunction with the Input 0 register, TIME 1, and TIME 2 counters to provide real time.

Time Pulse Generator	Produces 12 basic timing pulses which define action times. These pulses are used to control internal sequencing of data processing.
Memory Pulse Generator	This group provides timing pulses to fixed and erasable memory to synchronize read and write operations.
Start-Stop Logic	The start-stop logic generates three commands. A monitor stop command inhibits the time pulse generator and stops AGC data word flow. A monitor start command generates the third signal which is a clear command to the sequence generator.

2.2.3.3.2. Display and Keyboard.

The DSKYs facilitate intercommunication between the flight crew and the AGC. (See Figure 2.2-4.) The DSKYs operate in parallel, with the main display console DSKY providing AGC display and control while the crew are in their couches. The two condition lights provided at the main display console DSKY are COMPUTER FAIL, which is a gross AGC failure indicator, and KEY RLSE, which is a request to the crew to release the DSKY circuits to internal AGC program use. The main display console DSKY also has an UPTEL switch which enables the AGC to accept or block telemetered data from MSFN. The DSKY at the lower equipment bay contains the remainder of the condition lights: PROG ALM, RUPT LOCK, PARITY FAIL, TC TRAP, TM FAIL, COUNTER FAIL, SCALER FAIL, CHECK FAIL, and KEY RLSE. All the condition lights except KEY RLSE are failure indicators. (KEY RLSE is a request for the crew to release the DSKY circuits to internal AGC program use.) This DSKY also has a TEST ALARM pushbutton which is wired to the alarm relays to provide a check of the warning lights. The electroluminescent displays are identical on each DSKY and always display identical data. The intensity of these displays is controlled by the BRIGHTNESS thumbwheels.

The exchange of data between the flight crew and the AGC is usually initiated by crew action; however, it can also be initiated by internal computer programs. The exchanged information is processed by the DSKY program. This program allows the following four different modes of operation:

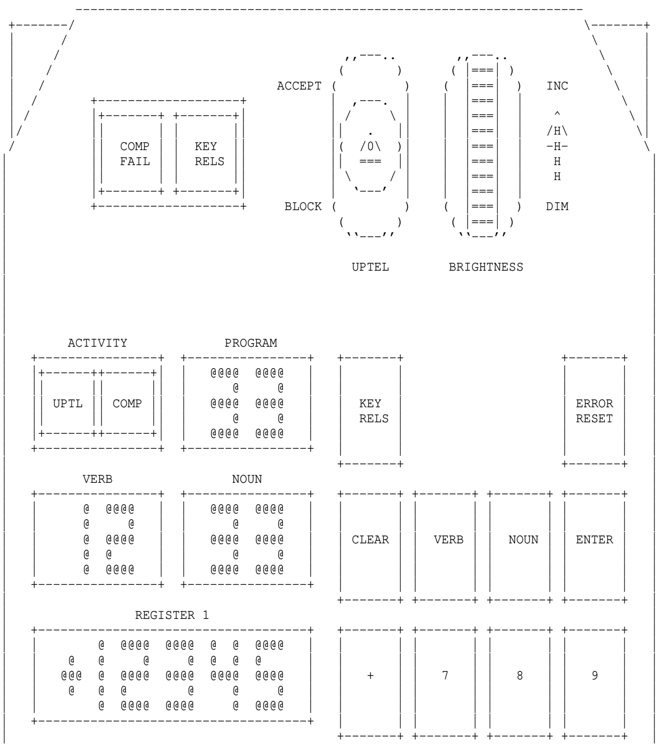
* Display of Internal Data--Both a one-shot display and a periodically updating display (called monitor) are provided.

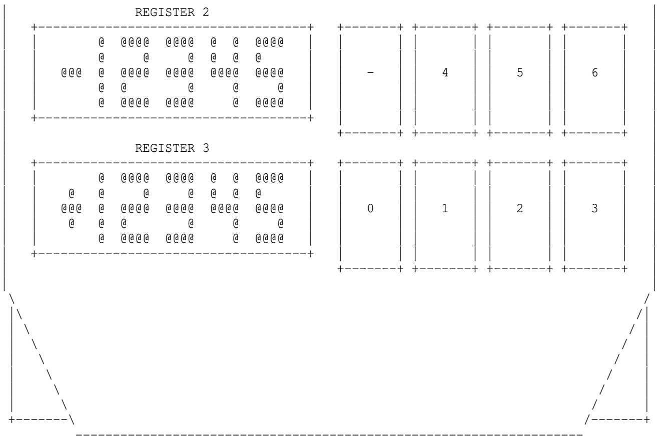
* Loading External Data--As each numerical character is entered, it is displayed in the appropriate display panel location.

* Program Calling and Control--The DSKY is used to initiate a class of routines which are concerned with neither loading nor display. Certain routines require instructions from the operator to determine whether to stop or continue at a given point.

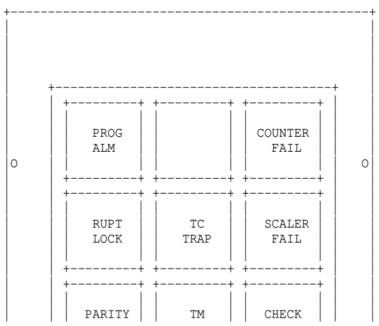
* Changing Major Mode--The initiation of large scale mission phases can be commanded by the operator.

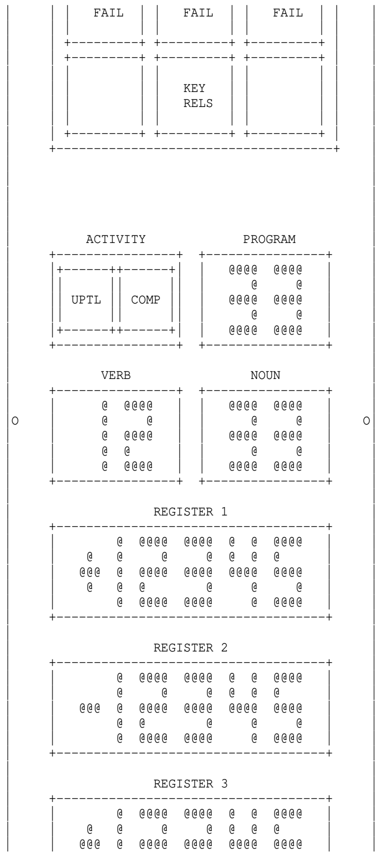
The data involved in both loading and display can be presented in either octal or decimal form as the operator indicates. If decimal form is chosen, the appropriate factors are supplied by the program. Decimals entries are indicated by entering a sign (+, -).

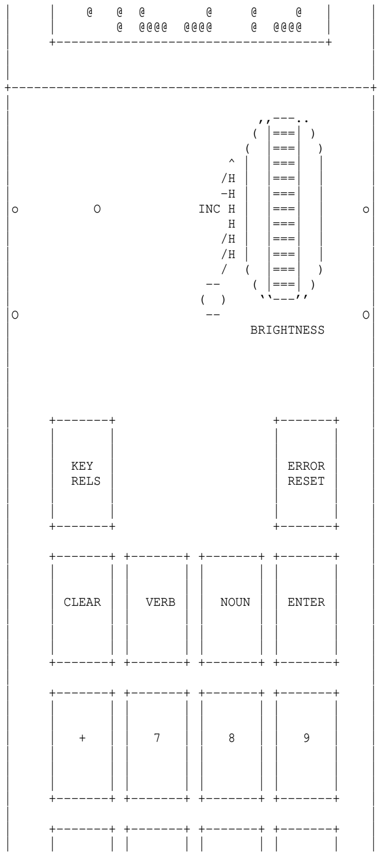




MAIN DISPLAY CONSOLE
DSKY







```
     |      |       | |       | |       | |       |      |
     |      |   -   | |   4   | |   5   | |   6   |      |
     |      |       | |       | |       | |       |      |
     |      |       | |       | |       | |       |      |
     |      +-------+ +-------+ +-------+ +-------+      |
     |                                                   |
     |      +-------+ +-------+ +-------+ +-------+      |
     |O     |       | |       | |       | |       |     O|
     |      |       | |       | |       | |       |      |
     |      |   0   | |   1   | |   2   | |   3   |      |
     |      |       | |       | |       | |       |      |
     |      |       | |       | |       | |       |      |
     |      +-------+ +-------+ +-------+ +-------+      |
     |                                                   |
     +---------------------------------------------------+


                   LOWER EQUIPMENT BAY              SM-2A-894
                          DSKY
```

Figure 2.2-4. Display and Keyboard Panels.

Keyboard Operation. The basic language of communication between the operator and the AGC is a pair of words known as verb and noun. Verb and noun codes are defined in figures 2.2-5 and 2.2-6, respectively. Each of these is represented by a two-character octal number. The verb code indicates what action is to be taken (operation); the noun code indicates to what action is applied (operand). Typical verbs are those for displaying and loading. Nouns usually refer to a group of erasable registers within the computer memory. The PROGRAM, VERB, and NOUN displays provide two digit numbers which are coded octal numbers describing the action being performed. The REGISTER 1, 2, and 3 displays provide display of the contents of registers or memory locations. These displays are numbers which are read as decimal numbers if a sign (+, -) is present and octal numbers if no sign is used. The REGISTER displays operate under program control unless the contents of a specific register or memory location is desired. The crew may request display of the contents of a specific register or memory location by commanding the display from the keyboard. The only other displays are the ACTIVITY lights which indicate whether the computer is computing or accepting telemetry from MSFN.

The keyboard provides 18 keys which, when pressed, generate a five bit signal representative of the key pressed. The +, -, and 0-9 keys are used for numerical entries, while the CLEAR, ENTER, VERB, NOUN, KEY RELEASE, and ERROR RESET keys provide instructions. The TEST ALARM key is wired to the alarm relays and provides a check of the warning indicator lights with the exception of SCALER FAIL. The main display console DSKY UPTEL switch enables or inhibits the acceptance of telemetry from MSFN. The function of each of the keys is as follows:

0-9	Enter numerical data, addresses, and action codes.

VERB	Commands AGC to accept the next two numbers as verb code data. Verb display is blanked until numbers are entered.
NOUN	Commands AGC to accept the next two numbers as noun code data. Noun display is blanked until numbers are entered.
ENTER	Instructs AGC to accept keyed-in data as completed and initiate operation specified by data word.
CLEAR	Enters all zeros in data register being loaded. Each successive pressing of this key clears the next higher register.
KEY RLSE	Release the DSKY circuits and displays for use by the AGC program being executed.
ERROR RESET	Momentarily resets AGC failure lights.
(+) and (-)	Denotes sign of data to follow. Denotes that following data is decimal.
TEST ALARM	Sets relays to illuminate LEB DSKY condition lights (except SCALER FAIL) to ensure proper operation. (LEB DSKY only.)
UPTEL	Sets AGC input registers to accept or inhibit telemetered data from MSFN. (MDC DSKY only.)
BRIGHTNESS	Provides control of intensity of electro-luminescent displays.

The lower equipment bay DSKY provides nine condition lights of which eight are failure indicators and the remaining light a request for action. The function of each is as follows:

PROG ALM	The AGC program being executed has detected an error.
COUNTER FAIL	Detected failure in input timing pulses. Either interrupt or circuitry failed. Interrupt failure is denoted by RUPT LOCK failure indicator illumination.
RUPT LOCK	Interrupt failed to occur or was not completed within specified time.
TC TRAP	Transfer control instruction has not occurred, or has occurred but was not completed within a specified time.
SCALER FAIL	Failure detected in AGC timing section.
PARITY FAIL	Parity failure detected in data read from memory.

TM FAIL	Telemetry word rate to MSFN either too high or too low. Telemetry word rate from MSFN too high or incorrect transmission of data.
CHECK FAIL	Attempted illegal DSKY operation. Normally operator error.
KEY RLSE	Flashes to indicate AGC program in operation requires DSKY circuitry to continue.

The standard procedure for the execution of keyboard operations consists of a sequence of seven key depressions:

VERB V2 V1 NOUN N2 N1 ENTER

Pressing the VERB key blanks the two verb lights on the DSKY and clears the verb code register in the AGC. The next two numerical inputs are interpreted as the verb code, in octal form. Each of these characters is displayed by the verb lights as it is inserted. The NOUN key operates similarly with the DSKY noun lights and AGC noun code register. Pressing the ENTER key initiates the program indicated by the verb-noun combination displayed on the DSKY. Thus, it is not necessary to follow a standard procedure in keying verb-noun codes into the DSKY. It can be done in reverse order, if desired, or a previously inserted verb or noun can be used without rekeying it. No action is taken by the AGC in initiating the verb-noun-defined program until the ENTER key is actuated. If an error is noticed in either the verb code or noun code prior to actuation of the ENTER key, it can be corrected simply by pressing the corresponding VERB or NOUN key and inserting the proper code. The ENTER key should not be actuated until it has been verified that the correct verb and noun codes are displayed.

If the selected verb-noun combination requires data to be loaded by the operator, the VERB and NOUN lights start flashing on and off (about once per second) after the ENTER key is pressed. Data is loaded in five-character words and, as it is keyed in, it is displayed character-by-character in one of the five-position data display registers, REGISTER 1, REGISTER 2, or REGISTER 3. Numerical data is assumed to be octal unless the five-character data word is preceded by a plus or minus sign, in which case it is considered to be decimal. Decimal data must be loaded in full five-numeral character words (no zeros may be left out); octal data may be loaded with high order zeros left out. If decimal is used for any component of a multicomponent load verb, it must be used for all components of that verb. In other words, no mixing of octal and decimal data is permitted for different components of the same load verb. The ENTER key must be pressed after each data word. This tells the program that the numerical word being keyed in is complete. The on-off flashing of the VERB-NOUN lights terminates after the last ENTER key actuation of a loading sequence.

The CLEAR key is used to remove errors in loading data as it is displayed in REGISTER 1, REGISTER 2, or REGISTER 3. It does nothing to the PROGRAM, NOUN, or VERB lights. (The NOUN lights are blanked by the NOUN key, the VERB lights by the VERB key.) For single-component load verbs or "machine address to be specified" nouns, the CLEAR key depression performs the clearing function on the particular register being loaded, provided that the CLEAR key is depressed before the ENTER key. Once the ENTER key is depressed, the CLEAR

key does nothing. The only way to correct an error after the data is entered for a single-component load verb is to begin the load verb again. For two- or three-component load verbs, there is a CLEAR backing-up feature. The first depression of the CLEAR key clears whichever register is being loaded. (The CLEAR key may be pressed after any character, but before its entry.) Consecutive CLEAR key actuations clear the data display register above the current one until REGISTER 1 is cleared. Any attempt to back up (clear) beyond REGISTER 1 is simply ignored. The CLEAR backing up function operates only on data pertinent to the load verb which initiated the loading sequence. For example, if the initiating load verb were a "write second component into" type only, no backing up action would be possible.

The numerical keys, the CLEAR key, and the sign keys are rejected if depressed after completion (final entry) of a data display or data load verb. At such time, only the VERB, NOUN, ENTER, ERROR RESET, or KEY RELEASE inputs are accepted. Thus, the data keys are accepted only after the control keys have instructed the program to accept them. Similarly, the + and - keys are accepted only before the first numerical character of REGISTER 1, REGISTER 2, or REGISTER 3 is keyed in and at no other time. The 8 or 9 key is accepted only while loading a data word which is preceded by a + or - sign.

The DSKY can also be used by internal computer programs for subroutines. However, any operator keyboard action (except ERROR RESET) inhibits DSKY use by internal routines. The operator retains control of the DSKY until he wishes to release it. Thus, he is assured that the data he wishes to observe will not be replaced by internally initiated data displays. In general, it is recommended that the operator release the DSKY for internal use when he has temporarily finished with it. This is done by pressing the KEY RELEASE key.

Verb-Noun Format. The verb-noun codes are defined in figures 2.2-5 and 2.2-6. A noun code may refer to a device, a group of computer registers, or a group of counter registers, or it may simply serve to convey information without referring to any particular computer register. The noun is made up of 1, 2, or 3 components, each component being entered separately as requested by the verb code. As each component is keyed, it is displayed on the display panel,with component 1 displayed in REGISTER 1, component 2 in REGISTER 2, and component 3 in REGISTER 3. There are two classes of nouns: normal and mixed. Normal nouns (codes 01 through 54) are those whose component members refer to computer registers which have consecutive addresses and use the same scale factor when converted to decimal. Mixed nouns (codes 55 through 77) are those whose component members refer to nonconsecutive addresses or whose component members require different scale factors when converted to decimal, or both.

A verb code indicates what action is to be taken. It also determines which component member of the noun group is to be acted upon. For example, there are five different load verbs. Verb 21 is required for loading the first component of the selected noun; verb 22 loads the second component; verb 23 loads the third component; verb 24 loads the first and second component; and verb 25 loads all three components. A similar component format is used in the display and monitor verbs. There are two general classes of verbs: standard and extended. The standard verbs (codes 01 through 37) deal mainly with loading, displaying, and monitoring data. The extended verbs (codes 40 through 77) are principally concerned with calling up internal programs whose function is system testing and operation.

Whenever data is to loaded by the operator, the VERB and NOUN lights flash, the appropriate data display register is blanked, and the internal computer storage register is cleared in anticipation of data loading. As each numerical character is keyed in, it is displayed in the proper display register. Each data display register can handle only five numerical characters at a time (not including the sign). If an attempt is made to key in more than five numerical characters at a time, the sixth and subsequent characters are simply rejected but they do appear in the display register.

The + and - keys are accepted prior to inserting the first numerical character of REGISTER 1, REGISTER 2, or REGISTER 3; if keyed in at any other time, the signs are rejected. If the 8 or 9 key is actuated at any time other than while loading a data word preceded by a + or - sign, it is rejected and the CHECK FAIL light goes on.

The normal use of the flash is with a load verb. However, there are two special cases when the flash is used with verbs other than load verbs.

* Machine Address to be Specified--There is a class of nouns available to allow any machine address to be used; these are called "machine address to be specified" nouns. When the "ENTER", which causes the verb-noun combination to be executed, senses a noun of this type the flash is immediately turned on. The verb code is left unchanged. The operator should load the complete machine address of interest (five-character octal). This is displayed in REGISTER 3 as it is keyed in. If an error is made in loading the address, the CLEAR key may be used to remove it. Pressing the ENTER key causes execution of the verb to continue.
* Change Major Mode--To change major mode, the sequence is VERB 37 ENTER. This causes the noun display register to be blanked and the verb code to be flashed. The two-character octal major mode code should then be loaded. For verification purposes, it is displayed as it is loaded in the noun display register. The entry causes the flash to be turned off, a request for the new major mode to be entered, and a new major mode code to be displayed in the PROGRAM display register.

The flash is turned off by any of the following events:

* Final entry of a load sequence
* Entry of verb "proceed without data" (33)
* Entry of verb "terminate" (34).

It is important to conclude ever load verb by one of the aforementioned three, especially if the load was initiated by program action within the computer. If an internally initiated load is not concluded validly, the program that initiated it may never be recalled. The "proceed without data" verb is used to indicate that the operator is unable to, or does not wish to, supply the data requested, but wants the initiating program to continue as best it can with old data. The "terminate" verb is used to indicate that the operator chooses not to load the requested data and also wants to terminate the requesting routine.

Figure 2.2-5. Verb List.

Verb Code	Description	Remarks
		NOTE Verb codes 01 through 37 denote standard verbs.
01	Display 1st component of	Performs octal display of data on REGISTER 1.
02	Display 2nd component of	Performs octal display of data on REGISTER 1.
03	Display 3rd component of	Performs octal display of data on REGISTER 1.
04	Display 1st and 2nd components of	Performs octal display of data on REGISTER 1 and REGISTER 2
05	Display 1st, 2nd, and 3rd components of	Performs octal display of data on REGISTER 1, REGISTER 2, and REGISTER 3.
06	Display all component(s) of	Performs decimal display of data on appropriate registers. The scale factors, types of scale factor routines, and component information are stored within the machine for each noun which it is required to display in decimal.
07	DP decimal display	Performs a double precision decimal display of data on REGISTER 1 and REGISTER 2. It does no scale factoring. It merely performs a 10-character, fractional decimal conversion of two consecutive, erasable registers, using REGISTER 1 and REGISTER 2. The sign is placed in the REGISTER 1 sign position with the REGISTER 2 sign position remaining blank. It cannot be used with mixed nouns. Its intended use is primarily with "machine address to be specified" nouns.
10	Enter request to waitlist (Used only during ground checkout.)	Enters request to "waitlist routine" for any machine address with delay involved. This verb assumes that the desired number of 10-millisecond units of delay has been loaded into the low order bits of the prio/delay register

		(noun 26). This verb is used with the "machine address to be specified" noun. The complete address of the desired location is then keyed in. (Refer to "Machine address to be specified" in paragraph on Verb/Noun Formats.)
11	Monitor 1st component of	Performs octal display of updated data every 1/2 second on REGISTER 1.
12	Monitor 2nd component of	Performs octal display of updated data every 1/2 second on REGISTER 1.
13	Monitor 3rd component of	Performs octal display of updated data every 1/2 second on REGISTER 1.
14	Monitor 1st and 2nd components of	Performs octal display of updated data every 1/2 second on REGISTER 1 and REGISTER 2.
15	Monitor 1st, 2nd, and 3rd components of	Performs octal display of updated data every 1/2 second on REGISTER 1, REGISTER 2, and REGISTER 3.
16	Monitor all component(s) of	Performs decimal display of updated data every 1/2 second on appropriate registers.
17	Monitor DP decimal	Performs double precision display of decimal data on REGISTER 1 and REGISTER 2. No scale factoring is performed. Provides 10-character, fractional decimal conversion of two consecutive erasable registers. The sign is placed in the sign-bit position of REGISTER 1. REGISTER 2 sign bit is blank.
20	Enter request to executive (Used only during ground checkout.)	Enters request to executive routine for any machine address with priority involved. This verb assumes that the desired priority has been loaded into bits 10-14 of the prio/delay register (noun 26). This verb is used with the noun, "machine address to be specified". The complete address of the desired location is then keyed in. (Refer to "Machine address to be specified" in paragraph on Verb/Noun Formats.)
21	Write 1st component into	Performs data loading. Octal quantities are unsigned. Decimal quantities are preceded by + or - sign. Data is displayed on REGISTER 1.

22	Write 2nd component into	Performs data loading. Octal quantities are unsigned. Decimal quantities are preceded by + or - sign. Data is displayed on REGISTER 2.
23	Write 3rd component into	Performs data loading. Octal quantities are unsigned. Decimal quantities are preceded by + or - sign. Data is displayed on REGISTER 3.
24	Write 1st and 2nd components into	Performs data loading. Octal quantities are unsigned. Decimal quantities are preceded by + or - sign. Data is displayed on REGISTER 1 and REGISTER 2.
25	Write 1st, 2nd, and 3rd components into	Performs data loading. Octal quantities are unsigned. Decimal quantities are preceded by + or - sign. Data is displayed on REGISTER 1, REGISTER 2, and REGISTER 3.
26	(Spare)	
27	(Spare)	
30	(Spare)	
31	Bank display	This verb is included to permit displaying the contents of fixed memory in any bank. Its intended use is for checking program ropes and the BANK positions of program ropes.
32	(Spare)	
33	Proceed without data	Informs routine requesting data that the operator chooses not to load fresh data, but wishes the routine to continue as best it can with old data. Final decision for what action should be taken is left to the requesting routine.
34	Terminate	Informs routine requesting data to be loaded that the operator chooses not to load fresh data and wishes the routine to terminate. Final decision for what action should be taken is left to the requesting routine. If monitor is on, it is turned off.
35	(Spare)	

36	Fresh start	Initializes the program control software and the keyboard and display system program.
37	Change major mode to	Change to new major mode. (Refer to "Change major mode" in paragraph on Verb/Noun Formats.)
		NOTE Verb codes 40 through 77 denote extended verbs.
40	Zero	Must be used with noun 20 (ICDU) or noun 55 (OCDU) only. Sets the CDU registers to zero.
41	Coarse align IMU	Must be used with noun 20 (ICDU) or noun 55 (OCDU) only.
42	Fine align IMU	Calls up programs that perform the indicated G&N system procedures.
43	Lock IMU	Calls up programs that perform the indicated G&N system procedures.
44	Set IMU to ATTITUDE CONTROL	Calls up programs that perform the indicated G&N system procedures.
45	Set IMU ENTRY	Calls up programs that perform the indicated G&N system procedures.
46	Return IMU ENTRY	Calls up programs that perform the indicated G&N system procedures.
47	(Spare)	
50	Please perform	This verb is used only by internal routines that wish the operator to perform a certain task. It should never be keyed in by the operator. It is usually used with noun 25, "checklist". The coded number for the checklist item to be performed is displayed in REGISTER 1 by the requesting routine.
51	Please mark	This verb is used only by internal routines that request the operator to "mark". It should never be keyed in by the operator. It is usually used with noun 30, "star numbers". The numbers of the stars to be marked

		are displayed in REGISTER 1, REGISTER 2, and REGISTER 3 by the requesting routine. The operator should indicate completion of each valid mark by pressing the MARK button. He should never press enter with verb 51.
52	Mark reject	Rejects "mark" and returns to verb 51. Must be entered within 20 seconds of pressing MARK button.
53	Free	Calls up programs that perform the indicated G&N system procedures. Used only with noun 20 (ICDU) or noun 55 (OCDU).
54	Pulse torque gyros	Calls up programs that perform the indicated G&N system procedures.
55	Align time	
56	Perform BANK sum	
57	System test (Used only during ground checkout.)	
60	Prepare for standby	
61	Recover from standby	
62	(Spare)	
63	(Spare)	
64	Calculate orbital parameters	
65	Calculate time of arrival at longitude	
66	Calculate latitude and longitude at specified time	
67	Calculate maximum declination and time of arrival	
70	(Spare)	
71	(Spare)	
72	(Spare)	
73	Return to Earth aim point update	
74	Orbit change aim point update	

75	Manual lift-off for flights	
76	R.V.T. update (state vector)	R.V.T. denotes position, velocity, and time.
77	(Spare)	

Figure 2.2-6. Noun List.

Noun Code	Description	Scale/Units
	NOTE Noun codes 01 through 54 denote normal nouns.	NOTE In Scale/Units column: X=significant digit 0=zero (always) B=blank.
01	Specify machine address	XXXXX
02	Specify machine address	XXXXX.
03	(Spare)	
04	(Spare)	
05	Angular error	XXX.XX degrees
06	Pitch angle	XXX.XX degrees
	Heads up-down	+/- 00001
07	Change of program or major mode (Used only with verb 50, "Please perform".)	
10	(Spare)	
11	Engine on enable (Used only with verb 50, "Please perform".)	
12	Delta V allowable	XXXXX. ft/sec
	Delta V tailoff	XXXXX. ft/sec
13	Delta V measured (Vector magnitude.)	XXXXX. ft/sec

14	Delta V counter setting	XXXXX. ft/sec
15	Increment address (Used only during ground checkout.)	Octal only
16	AGC clock time: REGISTER 1 REGISTER 2 REGISTER 3	 00XXX. hours 000XX. minutes 0XX.XX seconds
17	(Spare)	
20	ICDUs: X-REGISTER 1 Y-REGISTER 2 Z-REGISTER 3	 XXX.XX degrees XXX.XX degrees XXX.XX degrees
21	PIPA counters: X-REGISTER 1 Y-REGISTER 2 Z-REGISTER 3	 XXXXX. pulses XXXXX. pulses XXXXX. pulses
22	New angles I: X-REGISTER 1 Y-REGISTER 2 Z-REGISTER 3	 XXX.XX degrees XXX.XX degrees XXX.XX degrees
23	Delta angles I: X-REGISTER 1 Y-REGISTER 2 Z-REGISTER 3	 XXX.XX degrees XXX.XX degrees XXX.XX degrees
24	Delta time for AGC clock: REGISTER 1 REGISTER 2 REGISTER 3	 00XXX. hours 000XX. minutes 0XX.XX seconds
25	Checklist (Used only with verb 50, "Please perform".)	XXXXX
	Checklist code numbers (Appear in REGISTER 1.) 00001 SCS mode to G&N attitude control 00002 SCS mode to G&N Delta V 00003 SCS mode to G&N entry 00004 SCS mode to monitor 00007 Manual attitude maneuver 00011 Automatic optics positioning 00012 Target data entry 00013 Switch OSS to computer control 00014 Fine align check 00015 Perform star acquisition 00031 Engine on	

	00035 Prepare AGC for thrusting 00036 Thrust terminate 00041 C/M-S/M separation	
26	Prio/delay (Used only during ground checkout.)	XXXXX.
27	Self test ON-OFF switch	XXXXX.
30	Star number	XXXXX.
31	Failure register code	
	NOTE Error codes are defined in paragraph 2.2.2.3.3.	Octal only
	Self-test diagnosis REGISTER 2	Octal only
	Self-test diagnosis REGISTER 3	Octal only
32	Decision time (Used only during ground checkout.)	
33	Ephemeris time (Used only during ground checkout.)	
34	Event time: REGISTER 1 REGISTER 2 REGISTER 3	 00XXX. hours 000XX. minutes 0XX.XX seconds
35	Delta event time: REGISTER 1 REGISTER 2 REGISTER 3	 00XXX. hours 000XX. minutes 0XX.XX seconds
36	Delta event time (Display only.)	XXBXX. minutes, seconds
37	(Spare)	
40	Gamma (Inertial flight path angle.) REGISTER 1	XXX.XX degrees
	Inertial velocity REGISTER 2	XXXXX. ft/sec
	Altitude above launch pad REGISTER 3	XXXX.X nautical miles
41	Maximum acceleration REGISTER 1	XXXX.X g's

	Perigee altitude REGISTER 2	XXXX.X nautical miles
	Free-fall time REGISTER 3	XXBXX. minutes, seconds
42	Miss distance REGISTER 1	XXXX.X nautical miles
	Perigee altitude REGISTER 2	XXXX.X nautical miles
	Free-fall time REGISTER 3	XXBXX. minutes, seconds
43	Perigee altitude REGISTER 1	XXXX.X nautical miles
	Apogee altitude REGISTER 2	XXXX.X nautical miles
	Free-fall time REGISTER 3	XXBXX. minutes, seconds
44	Latitude REGISTER 1	XXX.XX degrees
	Longitude REGISTER 2	XXX.XX degrees
	Altitude (Above mean equatorial radius.) REGISTER 3	XXXX.X nautical miles
45	Perigee altitude REGISTER 1	XXXX.X nautical miles
	Apogee altitude REGISTER 2	XXXX.X nautical miles
	Delta velocity required REGISTER 3	XXXXX. ft/sec
46	Time to event REGISTER 1	XXBXX. minutes, seconds
	Velocity to be gained REGISTER 2	XXXXX. ft/sec
	Perigee altitude REGISTER 3	XXXX.X nautical miles
47	Flight path angle	

	REGISTER 1	XXX.XX degrees
	Miss distance REGISTER 2	XXXX.X nautical miles
50	Time to event REGISTER 1	XXBXX. minutes, seconds
	Delta time of burn REGISTER 2	XXBXX. minutes, seconds
51	Time to event REGISTER 1	XXBXX. minutes, seconds
	Velocity to be gained REGISTER 2	XXXXX. ft/sec
	Measured velocity change along spacecraft X-axis REGISTER 3	XXXXX. ft/sec
52	Time to event REGISTER 1	XXBXX. minutes, seconds
	Velocity to be gained REGISTER 2	XXXXX. ft/sec
	Free-fall time REGISTER 3	XXBXX. minutes, seconds
53	Maximum acceleration REGISTER 1	XXXX.X g's
	Free-fall time REGISTER 2	XXBXX. minutes,
54	Commanded roll angle REGISTER 1	XXX.XX degrees
	Present acceleration REGISTER 2	XXXX.X g's
	NOTE Noun codes 01 through 54 denote mixed nouns.	
55	OCDUs: X (Shaft angles) REGISTER 1	XXX.XX degrees

	Y (Trunnion angles) REGISTER 2	XX.XXX degrees
56	Uncalled mark data: X (Shaft angles) REGISTER 1	XXX.XX degrees
	Y (Trunnion angles) REGISTER 2	XX.XXX degrees
57	New angles-OCDUs: X (Shaft angles) REGISTER 1	XXX.XX degrees
	Y (Trunnion angles) REGISTER 2	XX.XXX degrees
60	IMU mode status (Used only during ground checkout.)	Octal only
61	Target: (Used only during ground checkout.)	
	Azimuth REGISTER 1	XXX.XX degrees
	Elevation REGISTER 2	XX.XXX degrees
62	Delta velocity insertion REGISTER 1	XXXXX. ft/sec
	Miss distance REGISTER 2	XXXX.X nautical miles
	Free-fall time REGISTER 3	XXBXX. minutes, seconds
63	Latitude REGISTER 1	XX.XXX degrees
	Longitude/2 REGISTER 2	XX.XXX degrees
	Altitude REGISTER 3	XXX.XX nautical miles
64	(Spare)	
65	Sampled time (Fetched in interrupt.) REGISTER 1 REGISTER 2 REGISTER 3	 00XXX. hours 000XX. minutes 0XX.XX seconds
66	System test results (Used only during	

	ground checkout.)	
67	Delta gyro angles: (Used only during ground checkout.)	
	X-IRIG REGISTER 1	XX.XXX degrees
	Y-IRIG REGISTER 2	XX.XXX degrees
	Z-IRIG REGISTER 3	XX.XXX degrees
70	Pitch trim REGISTER 1	XXX.XX degrees
	Yaw trim REGISTER 2	XXX.XX degrees
	Delta velocity tailoff REGISTER 3	XXX.XX degrees
71	(Spare)	
72	Delta position (Used only during ground checkout.)	
73	Delta velocity (Used only during ground checkout.)	
74	(Spare)	
75	Delta position magnitude REGISTER 1	XXXX.X nautical miles
	Delta velocity magnitude REGISTER 2	XXXXX. ft/sec
	Measurement angle deviation REGISTER 3	XXX.XX degrees
76	R-position (Used only during ground checkout.)	
77	V-velocity (Used only during ground checkout.)	

2.2.3.3.3. Error Codes.

Error code numbers appear in REGISTER 1 with noun 31.

OSS Errors

00101 Optics mode control switched from ZERO OPTICS before end of 30 seconds.
00102 AGC unable to achieve desired optics mode.
00103 Function not valid for SC 012.
00104 No vacant area available for marks.
00105 Internal mark request while mark system is busy.
00106 Function not valid for SC 012.
00107 Mark reject while mark system is not in use.
00110 Mark reject with all requested marks accepted or no marks since initiating last mark reject.
00120 Too many marks.

ISS Errors

00201 Zero encode ended before end of 30 second wait.
00202 AGC unable to achieve desired ISS mode.
00203 No ISS mode indicated to AGC.
00204 ISS mode changed while TRANSFER switch is in COMPUTER position, but AGC did not command mode change.

Procedural Difficulties

00401 Desired gimbal angles will produce gimbal lock. (Middle gimbal angle greater than 60 degrees.)
00402 Star out of field of view.
00403 Same as 00402.
00404 IMU orientation unknown.
00405 SCS mode monitor failure.
00406 Navigation program busy.
00407 Navigation program needed internally.
00410 AGC update not allowed.

AGC Hardware Malfunctions

01101 Unused interrupt (RUPT 2) occurred.
01102 AGC self-test error.
01103 Unused count, compare, and skip (CSS) branch executed.
01104 C-relay failed during C-relay test.
01105 Star search failure.
01106 IMU orientation no good for entry.

List Overflows

01201 Executive overflow--no vacant areas. *
01202 Executive overflow--no core sets. *
01203 Waitlist overflow--too many tasks. *
01204 Same as 01203. *
01205 Master control overflow--too many jobs waiting. *
01206 DSKY waiting line overflow. *
01207 No vacant area for marks. *
01210 Something already waiting in IMU stall. *

Interpreter Errors

01301 Arccos-arcsin input angle too large. *

01302 Square root called for with a negative argument. *

Display Alarms

01401 VG increasing--loss of control.
01402 Delta V too low--engine not on.

DSKY Program Errors

01501 Check fail alarm during internal use. *

* These alarms are "aborts" and define alarms which initiate a restart of the AGC program which was in progress when the alarm appeared.

2.2.3.3.4. AGC Programs.

The following list of AGC programs defines the programs and routines applicable to SC-012. The AGC programs provide the major modes of G&N system operation. The routines consist of a specific sequence of operations which are performed by more than one program and/or other routine.

Program Number	Title	Contains Routines
00	AGC Idling	
01	Prelaunch Initialization	
02	Gyro Compassing	
03	Optical Azimuth Verification	
04	Inertial Reference	
05	G&N Startup	
06	G&N Power Down	
07	Systems Test (Limited in-flight use.)	
11	Pre-LET Jettison	
12	Post-LET Jettison	R 24, R 34
17	LET Abort	
22	Landmark Tracking	R 27, R 28
23	Star/Landmark Navigation Measurement	
24	Ground Track Determination	
27	AGC Update	

31	Orbit Change (Prethrust)	R 1, R 21, R 35
32	Return to Earth (Prethrust)	R 1, R 21, R 36
33	SPS Minimum Impulse (Prethrust)	R 1, R 21, R 31, R 33
41	Orbit Change	R 2, R 22, R 24, R 31, R 34, R 37
42	Return to Earth	R 2, R 22, R 24, R 31, R 34, R 37
43	SPS Minimum Impulse	R 2, R 31, R 34, R 37
51	IMU Orientation Determination	R 27, R 29
52	S-IVB/IMU Align	R 4, R 25, R 27, R 28, R 29, R 30
53	CSM/IMU Align	R 1, R 4, R 21, R 25, R 27, R 28, R 29, R 30
54	IMU Realignment	R 27, R 29, R 30
61	Maneuver to CSM/SM Separation Attitude	R 1, R 21
62	CM/SM Separation and Pre-Entry Maneuver	R 3, R 21
63	Initialization	
64	Post 0.05G	
67	Final Phase	
71	First Abort Burn	R 24

Routine Number	Title	Contains Routines
1	Attitude Control Mode Check	R 22
2	Thrust Control Mode Check	R 1, R 21, R 22
3	Entry Control Mode Check	R 22
4	Fine Alignment	R 25, R 27, R 28, R 29, R 30
21	Attitude Maneuver	

22	SCS Discrete Monitor	
24	Delta V Monitor	R 38
25	Coarse Alignment	
27	Sighting Mark	
28	Auto Optics Positioning	
29	Star Data Test	
30	Gyro Torquing	
31	Backup Delta V Counter	
33	Prethrust SPS Minimum Impulse Data Load	
34	Orbit Parameter Display	
35	Prethrust Orbit Change Data Load	
36	Prethrust Return to Earth Data Load	
37	SPS Engine Ignition	R 38
38	SOS Engine Thrust Fail	

2.2.4 PERFORMANCE AND DESIGN DATA.

(TBD)

2.2.5. OPERATIONAL LIMITATIONS AND RESTRICTIONS.

2.2.5.1. S/C Attitude.

The S/C should not be maneuvered to an attitude which will align the inner circle of either red area on the FDAI ball under the navigation axis marker. Failure to avoid this condition can result in IMU gimbal lock. Specifically, the following maneuvers should be avoided:

* Yaw maneuver greater than +/- 75 degrees when roll angle is 0 degrees of 180 degrees.

* Pitch maneuver greater than +42 degrees or -108 degrees when roll angle is +/- 90 degrees.

2.2.5.2. IMU Operation.

* The AGC must be ON before the IMU is placed in operation by engaging the IMU circuit breakers.

* The AGC must be ON or in STANDBY before the IMU is placed in standby mode.

* Allow 15 seconds for the stabilization loop to completely stabilize the platform after applying operating power, i.e., after engaging the IMU circuit breakers.

* The IMU must be in full operation for at least 1 hour before valid operation of the inertial components can be assumed.

* The inertial components will suffer a loss of calibration if the temperature falls below 120 degrees F or exceeds 140 degrees F. Damage will occur if the temperature falls below 40 degrees F or exceeds 160 degrees F.

* Do not operate the IMU such that the middle gimbal angles reaches or exceeds 70 degrees.

2.2.5.3. Optics Operation.

* Do not slew the SXT or SCT into the mechanical stops.

* Do not drive the 2X TRUNNION CDU in excess of 180 degrees as read on the CDU display dials. Insure that this display dial indicates less than 180 degrees before engaging the ZERO OPTICS mode of operation.

2.2.6. TELEMETRY MEASUREMENTS.

The following is a complete list of all G&N system telemetry data that is monitored by flight controllers and ground support personnel. The last column contains the name and type of S/C crew display. The display utilizes the same pickoff signal or signal source as telemetry, unless a separate measurement number is included in the display column.

An asterisk (*) by the measurement number denotes information which is not available for recording or telemetry during PCM low bit rate operation.

Measurement Number	Description	Sensor Range	Normal Operating Range	Crew Display
CG 0001 V	Computer digital data	+4/+132 vdc		None
CG 1101 V	-28 VDC supply	-30/0 vdc	-28 vdc	None
CG 1110 V	2.5 VDC TM bias	TBD	-28 vdc	None
CG 1503 X	IMU +28 vdc operate	Event		None
CG 1513 X	IMU +28 vdc standby	Event		None
CG 1523 X	AGC +28 vdc	Event		None

CG 1533 X	Optics +28 vdc	Event		None
CG 2110 V	IGA torque motor input	TBD		None
*CG 2112 V	IGA 1X res output sine in phase	TBD		None
*CG 2113 V	IGA 1X res output cos in phase	TBD		None
*CG 2117 V	IGA servo error in phase	0/0.5 vrms		None
CG 2140 V	MGA torque motor input	TBD		None
*CG 2142 V	MGA 1X res output sine in phase	TBD		None
CG 2143 V	MGA 1X res output cos in phase	TBD		None
*CG 2147 V	MGA servo error in phase	0/0.5 vrms		None
CG 2170 V	OGA torque motor input	TBD		None
*CG 2172 V	OGA 1X res output sine in phase	TBD		None
*CG 2173 V	OGA 1X res output cos in phase	TBD		None
*CG 2177 V	OGA servo error in phase	0/0.5 vrms		None
*CG 2206 V	IGA CDU 1X res error in phase	0/0.2 vrms		None
*CG 2236 V	MGA CDU 1X res error in phase	0/0.2 vrms		None
*CG 2266 V	OGA CDU 1X res error in phase	0/0.2 vrms		None
CG 2300 T	PIPA temp	TBD	+126.0 F/ +134.0 F	None
CG 2301 T	IRIG temp	TBD	+129.5 F/ +137.5 F	None
CG 2302 C	IMU heater current	0/+5 amps	0/+2 amps	None
CG 2303 C	IMU blower current	0/+5 amps	0/+2 amps	None

*CG 3102 V	SXT trun motor drive in phase	TBD		None
*CG 3112 V	SXT shaft motor drive in phase	TBD		None
*CG 3133 V	SCT trun motor drive	TBD		None
*CG 3141 V	Trun CDU 16X res error in phase	TBD		None
*CG 3200 V	Trun CDU motor drive in phase	TBD		None
*CG 3220 V	CDU motor drive RMS	TBD		None
*CG 4300 T	AGC temp monitor	TBD		None
CG 5000 X	PIPA fail	Event		ACCEL FAIL, G&N ACCEL FAIL C&W lights (2).
CG 5001 X	IMU fail	Event		IMU FAIL C&W lights (2).
CG 5002 X	CDU fail	Event		CDU FAIL C&W lights (2).
CG 5003 X	Gimbal lock warning	Event		GIMBAL LOCK, GMBL LOCK C&W lights (2).
CG 5005 X	Error detect	Event		PGNS, G&N ERROR C&W lights (2).
CG 5006 X	IMU temp light	Event		IMU TEMP C&W lights (2).
CG 5007 X	Zero encode light	Event		ZERO ENCODER, ZERO ENC. C&W lights (2).
CG 5008 X	IMU delay light	Event		IMU DELAY C&W light.
CG 5020 X	AGC alarm 1 (Program)	Event		PROG ALM, COMP FAIL (DSKY lights).
CG 5021 X	AGC alarm 2 (AGC activity)	Event		COMP DSKY lights (2).
CG 5022 X	AGC alarm 3 (TM)	Event		TM FAIL, COMP FAIL (DSKY lights).

CG 5023 X	AGC alarm 4 (prog chk fail)	Event		CHECK FAIL, COMP FAIL (DSKY lights).
CG 5024 X	AGC alarm 5 (scaler fail)	Event		SCALER FAIL, COMP FAIL (DSKY lights).
CG 5025 X	AGC alarm 6 (parity fail)	Event		PARITY FAIL, COMP FAIL (DSKY lights).
CG 5026 X	AGC alarm 7 (counter fail)	Event		COUNTER FAIL, COMP FAIL (DSKY lights).
CG 5027 X	AGC alarm 8 (key release)	Event		KEY RLSE (DSKY lights) (2).
CG 5028 X	AGC alarm 9 (rupt lock)	Event		RUPT LOCK, COMP FAIL (DSKY lights).
CG 5029 X	AGC alarm 10 (TC trap)	Event		TC TRAP, COMP FAIL (DSKY lights).
CG 5030 X	Computer power fail light	Event		AGC PWR FAIL (DSKY lights) (2).
*CG 6000 P	IMU pressure	TBD		None
*CG 6020 T	PSA temp 1 tray 3	TBD		None
*CG 6021 T	PSA temp 2 tray 2	TBD		None
*CG 6022 T	PSA temp 3 tray 4	TBD		None

2.2.7. G&N POWER CONSUMPTION.

The optics are only powered up when a star or landmark sighting is required. The subsystems power levels are as follows:

Description	Control	
IMU--operate	CB 59 and 58	325.0 watts (dc)
standby	CB 61 and 60	61.7 watts (dc)
AGC--operate	CB 57 and 56	115.0 watts (dc)
standby	AGC Mode Switch	15.0 watts (dc)
Optics--operate	CB 55 and 54	124.4 watts (dc)
Controls and displays	CB 93 and 62 and Switch No. 7	
AGC only		10.0 watts (dc)
AGC and IMU		10.7 watts (dc)
Full G&N operation		18.7 watts (dc)

Minimum power consumption is 76.7 watts (dc) when AGC and IMU are in the standby mode.

2.2.8. INTERFACE SIGNALS.

The following list provides the signal, source, and description of the interface signals.

Signal Name	Source	Description
Stabilization and Control System (SCS) and G&N System Interface		
Engine on-off	AGC (Apollo) guidance computer)	Provides pulse train that lasts as long as the engine is required to fire. The time at which the signal terminates takes into account electronic delays within the SCS and tail-off characteristics of the engines.
Discrete signal carrier	AGC	Provides continuous pulse train to the SCS to be switched back to the AGC.
G&N system attitude control (or SCS attitude control)	SCS	Provides power to an attitude control switch on the G&N system.
Minimum impulse enable	G&N system	Disables all three attitude channels simultaneously and supplies voltages to an attitude control switch on the G&N system.
Minimum impulse + and - pitch, yaw, and roll	SCS	Provides six signals to the G&N system for hand controller operation.
Minimum impulse pitch, yaw, and roll	G&N system	Provides the capability to initiate remote spacecraft attitude changes in the G&N system attitude control mode or the SCS attitude control mode. These changes will be initiated by discrete minimum impulses.
Pitch error body offset and body axis	G&N system	Provides pitch attitude error signal to the SCS.
Yaw error body offset axis	G&N system	Provides yaw attitude error signal to the SCS during G&N system entry mode.
Yaw error body axis	G&N system	Provides yaw attitude error signal to the SCS during normal G&N system operating modes.
Roll error body offset axis	G&N system	Provides roll attitude error signal to the SCS during G&N system entry mode.
Roll error body axis	G&N system	Provides roll attitude error signal to the SCS during normal G&N system operating modes.
IMU 28V 800 cps (demodulator reference)	G&N system	Provides an 800 cps, synchronous. in-phase voltage from the G&N system.
IMU sin A 1X, IG IMU cos A 1X, IG IMU sin A 1X, MG IMU cos A 1X, MG IMU sin A 1x, and OG IMU cos A 1x OG	G&N system	Provides total attitude signals to the SCS.
Electrical Power System (EPS) and G&N System Interface		
+28 vdc AGC bus A and bus B	EPS	Provides power to the AGC.
+28 vdc optics bus A and bus B	EPS	Provides power to the optics subsystem.
+28 vdc IMU bus A and bus B	EPS	Provides power to the IMU.
+28 vdc standby bus A and bus B	EPS	Provides IMU temperature control power.
115v 400 cps	EPS	Provides power for all G&N system 6-volt lamps.
Communication and Instrumentation System and G&N System Interface		
DLNK sync	AGC	Synchronizes data transferred from the AGC to the communications and instrumentations system.
DLNK end	AGC	Permits two AGC words to be transferred from the AGC to the communications and instrumentation system. Stops the AGC and the transmission of data from the AGC to the communications and instrumentation system.
DLNK start	AGC	Provides pulse signal that occurs at the beginning of every data transmission to the communications and instrumentation system. Sets flip-flop in AGC that enables 5-stage downlink counter.
DLNK data	AGC	Initiated by a DLNK start, stopped by DLNK end, and consists of a 40-bit telemetry word (two AGC words and an 8-bit telemetry word order code).
ULNK 1	AGC	Transmitted to the uplink counter in the AGC. Adds one to uplink counter and shifts the counter one increment.
ULNK 0	AGC	Transmitted to the uplink counter in in AGC. Shifts uplink counter one increment.

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