

APOLLO EXPERIENCE REPORT
GUIDANCE AND CONTROL SYSTEMS:
LUNAR MODULE STABILIZATION AND CONTROL SYSTEM

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SUMMARY

The lunar module stabilization and control system, which is part of the lunar module guidance, navigation, and control system, is designed to control vehicle attitude and translation about or along all axes during a lunar module mission. Vehicle attitude and small translations are controlled by selectively firing the 16 reaction control system jets mounted on the ascent stage. The design concepts used were representative of the state of the art, and six different assemblies constituted the subsystem: (1) attitude and translation control assembly, (2) descent-engine control assembly, (3) rate gyro assembly, (4) attitude controller assembly, (5) thrust and translation controller assembly, and (6) gimbal drive actuator.

Subsystem procurement was at the assembly, or black-box, level, and the lunar module contractor was responsible for black-box integration. Design-feasibility and design-verification tests were performed at the assembly level during developmental phases, using early production equipment.

Subsystem-level testing was accomplished in vehicles and in the lunar module contractor Full Mission Engineering Simulator/Flight Control Integration Laboratory. All detailed test objectives were satisfactorily accomplished before the Apollo 11 (lunar module 5) mission.

INTRODUCTION

The initial concept and configuration of the lunar module (LM) guidance and control (G&C) system evolved during the period from 1963 to 1964. The initial concept included the Government-furnished primary guidance subsystem for the necessary guidance and navigation functions and the contractor-furnished stabilization and control subsystem (SCS) for the vehicle stabilization and control functions.

Additionally, the SCS was to act as a backup guidance system that would permit attainment of a safe lunar orbit if primary guidance were lost.

By mid-1964, the SCS stabilization and control functions had become fairly well defined, the design-control specifications had been completed, and subcontracts had been awarded for most assemblies. During the fall and winter of 1964, NASA and two participating contractors reviewed the LM and G&C requirements and the hardware capabilities of the primary guidance subsystem and the SCS. This review resulted in implementation of the integrated G&C concept. Additionally, the backup or abort guidance requirements were further established as being more complex than originally envisioned (ref. 1).

The LM G&C subsystem provides two paths or subsystems for vehicle G&C. The primary guidance, navigation, and control subsystem (PGNCS) provides the necessary G&C capability for mission completion. The abort guidance subsystem (AGS) provides the necessary G&C capability for mission abort if the PGNCS fails but does not provide the capability to complete a lunar landing mission. The SCS forms an integral part of both the primary and abort subsystems. As part of the primary system, the SCS includes the drivers for reaction control subsystem (RCS) jet operation; the electronic interface for descent-engine thrust and gimbal control; and the hand controllers for manual attitude, descent-thrust, and translational input commands. In the AGS, the SCS includes jet-select logic, signal summing, gain control, and the same hand controllers used for manual commands in the PGNCS. The attitude reference or steering errors are provided to the SCS by the AGS.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Systeme International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

FUNCTIONAL DESCRIPTION

The major features of both the PGNCS and AGS modes are summarized in the following brief functional description of the SCS. The LM SCS is part of the LM guidance, navigation, and control system and is designed to control vehicle attitude and translation about or along all axes during an LM mission. Vehicle attitude and small translations are controlled by firing one or more of the 16 RCS jets mounted on the ascent stage. Major translations are accomplished by means of the ascent or descent propulsion engine. Rotation around the LM X-axis, Y-axis, and Z-axis is termed yaw, pitch, and roll, respectively. Movement along an axis is termed translation. The LM axes form a right-handed orthogonal triad.

The LM guidance, navigation, and control system contains two independent guidance sections. The PGNCS is designed to control the LM during all mission phases. The AGS is designed to guide the LM to the command and service module if the PGNCS fails. A simplified block diagram of the SCS is shown in figure 1. The SCS flight hardware is shown in figure 2.

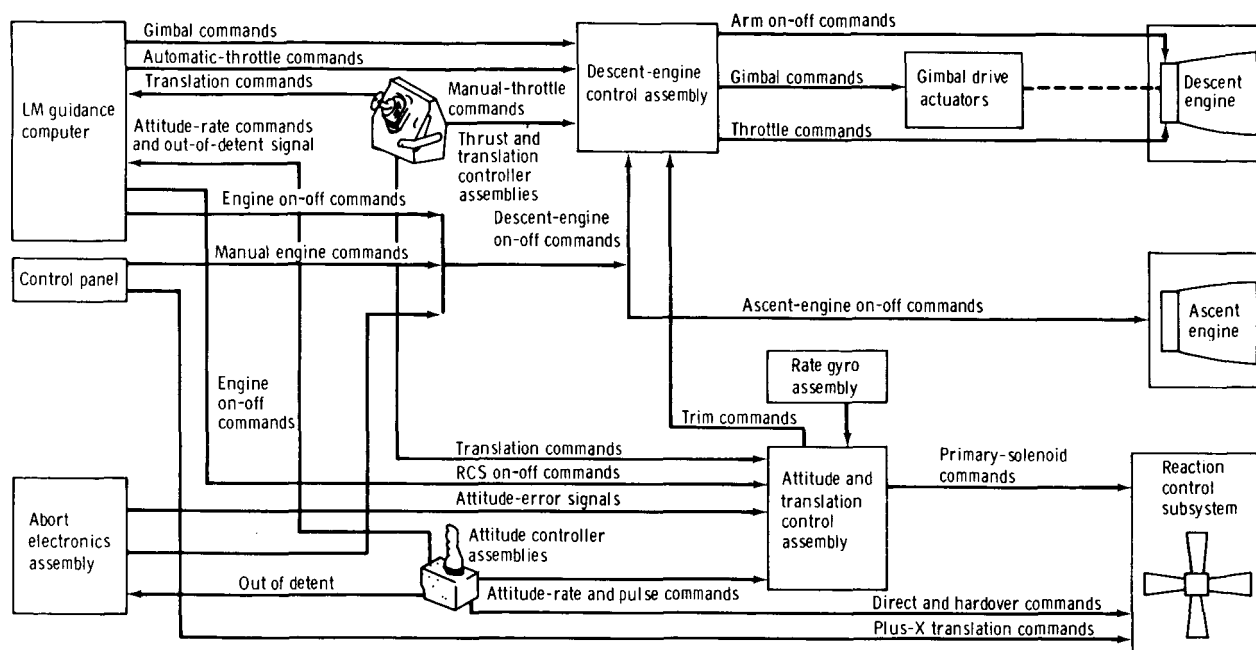


Figure 1.- Block diagram of LM SCS .

Primary Mode

When operating in the PGNCS mode , the SCS performs the following functions.

1. Converts RCS jet commands issued by the LM guidance computer (LGC) to the electrical power required to operate the RCS-jet solenoid valves for attitude and translation control
2. Accepts discrete (on-off) descent-engine gimbal commands from the LGC (Upon receipt of an "on" command , the descent engine is gimballed about its axes at a constant angular rate until the command is removed.)
3. Accepts LGC automatic and manual engine on-off commands and routes them to the propulsion system to start or stop the descent or ascent engine

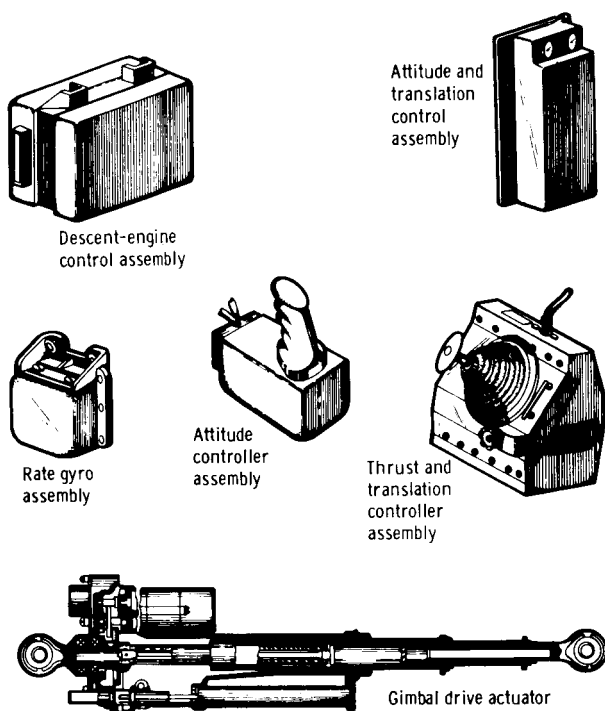


Figure 2.- Lunar module SCS hardware.

4. Accepts LGC automatic thrust commands and thrust and translation controller assembly (TTCA) manual thrust commands to control the thrust of the descent engine

5. Provides manual attitude and translational commands to the LGC

The LM digital autopilot (DAP) has interfaces with 16 RCS solenoid driver preamplifiers in the attitude and translation control assembly (ATCA) and with the pitch- and roll-trim gimbal servomotor drives in the descent-engine control assembly (DECA). During the descent-engine burn, the DAP tries to control the spacecraft attitude with the trim gimbal servomotor drive to save RCS propellants; however, if the rather slow trim gimbal servomotor drive does not keep the attitude error within specified bounds, the RCS jets are used until the error is brought within

the attitude dead band, and control is then returned to the trim gimbal servomotor drive.

The DAP works in conjunction either with a PGNCS guidance loop to provide an automatic G&C system or with the TTCA and the attitude controller assembly (ACA) for manual G&C. In the latter mode of operation, the DAP provides the crewman with an integrated stabilization and control system for performing translational maneuvers and for maintaining rate command/attitude hold.

The DAP monitors the eight RCS thruster-off signals and chooses the best set of jets to use under the combined conditions of rotational commands, translational commands, and disabled jets. Propellant economy, minimization of the number of RCS jet firings, and operation with detected and undetected jet failures are of primary concern. The LGC will issue automatic engine on, engine off, descent-engine thrust magnitude, and descent-engine gimbal position commands, all automatically under program control.

The rate-command/attitude-hold mode is the normal means of astronaut control of the spacecraft. The maximum maneuver rate about any axis of the spacecraft is 20 deg/sec. The ACA acts as an analog device during rate command by producing a voltage proportional to stick deflection. The voltage, which represents

commanded rate, is converted to a binary number (quantized at approximately 0.625 deg/sec/bit) and presented to the DAP. When the stick is out of detent, the DAP tries to match the vehicle rate to the rate commanded by the hand controller. When the rate error is less than the rate dead band (0.4 deg/sec during descent, 1.0 deg/sec during ascent), the jets are no longer commanded on. However, if the rate error exceeds a specified bound (2.0 deg/sec during ascent, 1.4 deg/sec during descent), four jets are used to torque the spacecraft. When the ACA is returned to the detent position, the DAP computes the time of jet firing required to zero the rates of the vehicle. When the rate of the vehicle is brought inside a dead band about zero rate, the contents of the coupling data unit (CDU) registers are transferred to the desired CDU registers, and attitude steering about the newly attained position of the vehicle is begun. If the spacecraft has large pitch- and roll-rate errors, diagonal jets are used; the jets are thus selected efficiently.

The crewman uses the minimum-impulse mode to control the spacecraft with very small rate maneuvers. Each discrete deflection of the ACA 2.5° or more out of detent will cause the DAP to issue commands to the appropriate jets for a minimum impulse. In this mode, an astronaut must anticipate on his own and perform rate damping and attitude steering.

Selection of the minimum-impulse mode enables the crewman to perform an economical low-rate maneuver to a new orientation of the spacecraft. After completing the maneuver, the crewman codes the display and keyboard, and the DAP returns to attitude hold and causes the vehicle to limit cycle, with the normal attitude steering about the new orientation.

Abort Mode

When operating in the abort guidance mode, the SCS performs the following functions.

1. Accepts attitude-error signals from the AGS or manual attitude-rate commands from the ACA and fires the proper RCS jets to achieve attitude control (Rate damping is achieved by summing the error signal or the rate command with the rate gyro feedback signals.)
2. Accepts manual translational commands from the TTCA and fires RCS jets to accelerate the LM in the desired direction
3. Automatically gimbals the descent engine for trim control
4. Accepts AGS automatic and manual engine on-off commands and routes them to the descent or ascent engine

5. Accepts TTCA manual-throttle commands to control the thrust of the descent engine

The abort system provides the same basic autopilot modes provided by the DAP; that is, automatic, rate command/attitude hold, and pulse. In these modes, the ATCA (rather than the LGC) receives signals from the TTCA, the ACA, and the AGS (steering errors or attitude reference) and provides the necessary jet-select logic for jet firing. In the pulse mode, a series of minimum-impulse jet firings is provided when the ACA is deflected 2.5° . This series of pulses contrasts with the single pulse used for this mode in the primary system.

SUBSYSTEM DESIGN AND DEVELOPMENT

The discussion of subsystem design and development includes subsystem requirements definition, assembly design and development, and subsystem verification tests.

Subsystem Requirements Definition

The major elements of the subsystem functional and performance requirements were developed from 1963 to 1965. Periodic meetings were held at the NASA Lyndon B. Johnson Space Center (JSC) (formerly the Manned Spacecraft Center (MSC)) during the requirements definition phase. Interested personnel from MSC, NASA Headquarters, and three contractors participated in the meetings, which were helpful in bringing different viewpoints into focus regarding the establishment of detailed requirements concurrently with hardware design. Before the integrated G&C concept was adopted, the more significant results of these meetings were recorded in the proceedings of the LM SCS meetings for the period from 1963 to early 1964. The implementation of the integrated concept began in September 1964 and is documented in the LM G&C implementation meeting minutes.

Assembly Design and Development

Hardware procurement by the LM contractor was at the black-box or assembly level. Individual design-control specifications were prepared for each assembly by the LM contractor, and competitive bids were used for vendor selection. The task of assembly integration was retained by the contractor. Overall hardware-design and development-test requirements are defined in a Type I contract specification. In this specification, broad subsystem functional and interface requirements are stated; the scope of the developmental and qualification test programs is established; and applicable publications, specifications, and standards are defined.