Apollo GUIDANCE AND NAVIGATION NEWS

AC ELECTRONICS
DIVISION OF GENERAL MOTORS CORPORATION
MILWAUKEE, WISCONSIN 53201

GM

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AC ELECTRONICS DIVISION OF GENERAL MOTORS CORPORATION MILWAUKEE, WISCONSIN 53201
NEWS
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FOR YOUR INFORMATION

For nearly two decades, AC Electronics Division of General Motors has been closely involved in the development of inertial guidance technology for the nation's defense and space programs.

From this base of knowledge and through its own independent research, AC designed, developed and manufactured the Carousel IV inertial navigation system for commercial transoceanic jetliners. This space-age system probably will see its first commercial passenger service late this year -- aboard the Boeing 747.

Attached is some general information about the all-new Carousel IV system.

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CAROUSEL IV INERTIAL NAVIGATION SYSTEM; GENERAL INFORMATION

MILWAUKEE, Wis. -- Carousel IV is the first inertial navigation system designed as an integral part of a commercial aircraft -- the giant new Boeing 747. It was conceived and built by the AC Electronics Division of General Motors in Milwaukee.

Inspired by AC Electronics' inertial system work for Apollo, Titan III-C, missiles and by AC's own research efforts, Carousel IV will provide operators of the 360-passenger 747 with high precision, fully automatic navigation between any points on earth.

Most present aircraft rely upon celestial, long-range radio or radar systems, but the self-contained Carousel IV needs no outside radio or radar contact and cannot be affected by weather or communications interference. One major airline said its flight tests showed Carousel to be five times more accurate than the standard form of navigation.

When connected to the autopilot, the Carousel IV actually steers the plane, while the pilot monitors flight progress through the continuously updated control and display unit.

Boeing made the initial transoceanic crossing with the 747 on June 2-3, from Seattle, Wash., non-stop to Le Bourget Airport and the Paris Air Show. The giant airliner returned to Seattle June 7, with a stop at Dulles International Airport, Washington, D. C.

On both flights, the 747's three Carousel IV systems operated flawlessly, with navigational accuracies well within Federal Aviation Administration (FAA) specifications. On the 9 hour and 8 minute eastbound leg, one Carousel IV was coupled with the autopilot

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near Edmonton, Alberta, Canada, and actually "flew" the aircraft until just off the English coast, a distance of some 4000 nautical miles. Most of the 3400 nautical mile, 8 hour and 12 minute return trip also was under Carousel IV autopilot control. During press conferences after the flights, Boeing test pilots praised the operation of the AC Electronics systems.

FAA specifications for inertial navigation systems call for accuracy within $\pm$ 20 miles cross-track and $\pm$ 25 miles along track on 95% of flights of 1,000 nautical miles or longer, with mean time between failure of 544 hours.

The Carousel IV is one of the first navigators to tell the pilot where he is at any given moment, as well as the time and distance to his next waypoint. He needs only to give the system his starting point and destination. He may also insert as many as eight waypoints enroute and during flight may change these waypoints or insert additional ones. The system's computer calculates the shortest course from waypoint to waypoint, and finally to the destination. The pilot can readily call for display of information on true heading, wind direction and speed, ground track, ground speed and other navigation data.

The great accuracy of Carousel IV inertial navigation, especially on long, over-water flights, provides a number of benefits to the world's airlines, such as fuel and time savings and ease of operation.

In addition, this improved long-range accuracy someday may allow narrowing of air corridors to overseas points, so that twice as many planes could fly in the same airspace. Aircraft now must stay within assigned corridors fixed by international agreement at 120 mile spacing in areas with heavily used routes, such as the North Atlantic. With inertial navigation in general use, airline officials estimate that it should be possible to safely narrow the lanes to about 60 miles.

Navigation hours on the system will be accumulated in Boeing's five-aircraft 747 flight test program, and in testing by a number of airlines in current model jets.

Several testing programs will give the Carousel IV a total of more than 100,000 flight test hours before the 747 goes into service.

The compact Carousel IV system includes four basic components or "black boxes", which are designed to meet ARINC 561 requirements. Heart of the system is the navigation unit which includes a precision inertial reference unit, a digital computer, other electronic and heat control elements, and a power supply. Fitted in a standard Air Transport Rating (ATR) case, and mounted in the aircraft's electronics bay, the unit weighs about 50 pounds -- nearly as light as an office model electric typewriter -- and is less than one cubic foot in volume -- smaller than an office file drawer.

In the Carousel IV inertial reference unit, small, but highly sensitive gyroscopes and accelerometers, also built by AC, are mounted on a platform set within gimbals which isolate the platform from airframe motion and allow it to turn in any direction. In flight, spinning at 24,000 rpm, the gyros sense aircraft rotations. Any movement of the aircraft which moves the platform causes one or more of the gyros to give off an error signal. The signal is amplified through a servo assembly to drive gimbal motors, which torque the platform back to its fixed inertial orientation. The platform thus remains in this orientation regardless of aircraft movement in any direction and therefore provides an attitude and heading reference.

The stable orientation allows the accelerometers on the platform to measure changes in speed very accurately. Accumulating speed and heading data, and keeping its own accurate time internally, the Carousel IV computer provides the human pilot or the autopilot with precise, timely navigation information.

A major contributor to the great accuracy of the AC Electronics system is the technique from which it draws its name, whereby the inertial platform is slowly rotated at a constant rate. This tends to nullify drift rates in the horizontal gyros, which are key to the system's precision navigation measurements in flight. During pre-flight alignment, the rotational technique permits completely automatic inertial instrument calibration, and helps improve alignment accuracy.

A second major component of Carousel IV is the pilot's link with the system -- the control and display unit. The pilot receives navigation data from it via lighted numerical displays and uses push buttons on the unit's keyboard to feed information into the system and request information from it. One of these units is mounted in the airplane's cockpit in front of the pilot, another in front of the copilot.

Mounted in the panel above the crew are two Carousel mode selector units, which are used to turn the system on and off and establish the basic operating condition, such as aligning the inertial reference unit before takeoff, or navigating during flight. The fourth component is a battery unit for backup power.

The Carousel IV navigation unit and other key components are designed to be easily replaced. Other maintainability features include: pre-aligned gyros and accelerometers which can be replaced in an airline's own maintenance shop; numerous built-in self-check features, so that the system can be monitored and tested while installed in the aircraft; and functionally grouped electronic components on quickly replaceable circuit cards.

The General Motors division is prime contractor to the National Aeronautics and Space Administration for guidance and navigation on Apollo Command and Lunar Modules, and associate contractor to the Air Force for the all-inertial guidance system aboard the mighty Titan III-C standard space launch vehicle.

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NEWS
FOR RELEASE Wednesday, June 25, 1969

PAN AMERICAN FIRST TO CERTIFY CAROUSEL IV

MILWAUKEE -- Pan American World Airways has received the first Federal Aviation Administration (FAA) engineering certification of the Carousel IV inertial navigation system, conceived and built by AC Electronics Division of General Motors for the giant new Boeing 747.

Pan Am said its flight tests with the long-range all-weather Carousel IV system showed it to be five times more accurate than the standard form of navigation. Its Carousel units easily satisfied FAA specifications for accuracy and reliability.

Ultimately Pan Am will use the standard equipment Carousel systems in the 33 B-747 jets it has on order for delivery between September, 1969 and June, 1971. Carousel IV was designed by AC Electronics to be an integral part of the 362-passenger jetliner.

Inspired by AC Electronics' inertial system work for Apollo, Titan III-C, missiles and by AC's own research efforts, the Carousel system will provide Pan American and other operators of the 747 with high-precision, fully automatic navigation between any points on earth.

The globe-spanning airline received its FAA engineering supplemental type certificate (STC) using the Carousel IV in three Boeing 707 aircraft, all in scheduled passenger service. Under FAA monitoring, Pan Am conducted the

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required flight test program, amassing 1,222 system navigation hours on 84 flights. Each 707 was equipped with two production Carousel systems, though most 747 jetliners, including Pan Am's, will carry three Carousels, which operate simultaneously and independently while the plane is flying.

Pan American made the certification flights over its regular routes, such as New York to Rome nonstop and return, and San Francisco-Anchorage-Tokyo and return. A unique demonstration of the Carousel IV's high latitude capability came late in March when a London-Seattle nonstop flight was diverted 850 miles north to fly over the North Pole. The Carousel display units read out the 90 degrees latitude and zero degrees longitude, pinpointing for the Pan Am crew their exact position over the Pole.

The FAA specifies accuracy of inertial navigation systems must be within ± 20 miles cross-track and ± 25 miles along track on 95% of flights of 1,000 nautical miles or longer, with mean time between failure of 544 hours. In order to obtain the STC, Pan Am's test flights had to meet these requirements. In addition, Carousel systems had to pass several environmental tests not directly connected with the flights such as temperature, humidity, and vibration.

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SHE KNOWS WHERE SHE IS .... This pretty secretary at AC Electronics Division of General Motors is holding the control and display unit for AC's Carousel IV inertial navigation system. The compact, lightweight Carousel IV will be "standard equipment" aboard the giant new Boeing 747 commercial jet airliner.

The Carousel IV, an outgrowth of AC Electronics' inertial guidance work for spacecraft, missiles and military aircraft, will provide the 747 with high-precision, fully automatic, all-weather navigation between any points on earth.

The young lady knows precisely where she is -- at 87^{o} 54.8' West, 42^{o} 54.1' North, the exact latitude and longitude of the Carousel IV test department within AC's Milwaukee area plant.

Photo No. 5-20-276 062769

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These black boxes make up the new AC Electronics Carousel IV inertial navigation system for present and future jetliners, like the huge new Boeing 747 silhouetted in the background.

The Carousel IV system is one of the first navigators to tell the pilot where he is at all times -- especially valuable on long over-water routes where conventional navigation aids are not available.

At left are the pilot's links with the all-weather system, the mode selector in foreground, and the display unit at center is the heart of the system, the navigation unit, which contains the inertial platform, a high-speed digital computer, and other electronics. At right is the backup battery unit.

Photo No. 3-52-A157 062769

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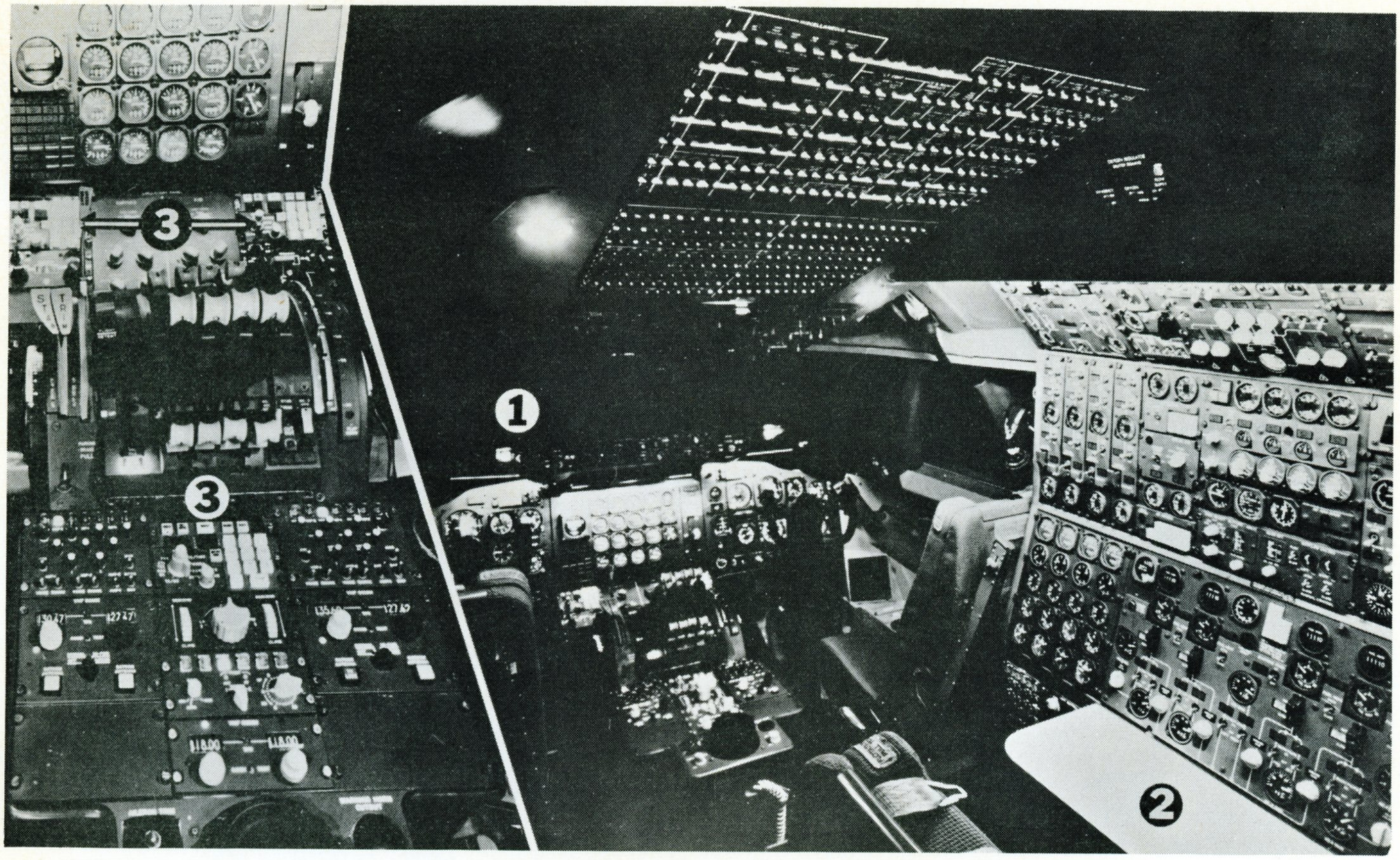

FLIGHT DECK . . . on Pan American World Airways' Boeing 747 has the same general layout as that in Boeing 707 Jet Clipper.

Close-up at left of the instrument console positioned between seats of pilot and co-pilot shows the location of the 747's Carousel IV inertial navigation system (3) which will guide the 362-passenger aircraft. The Carousel IV was designed and built by AC Electronics Division of General Motors, based on in-house research efforts and experience in several defense and space programs for which AC provided inertial systems, including Apollo guidance and navigation.

Three separate Carousel IV systems each constantly provide accurate aircraft position and other navigational essentials, thus minimizing the risk of error due to equipment malfunction. Instruments at the top of the insert measure engine temperature, fuel flow and other performance data. Engine throttles and fuel cut-off levers are shown in middle of insert. Audio controls, very high frequency radio controls and autopilot controls are located on the panel behind the throttles, in the foreground. In full view, front instrument panel (1) faces pilot and co-pilot, while flight engineer panel (2) contains the numerous dials, gauges, switches and indicator lights to monitor the aircraft's vital systems.

Photo No. 3-52-D51 062769 (Pan American World Airways photograph)

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GM'S APOLLO G&N SYSTEM COMPARISON AND OPERATION

MILWAUKEE, Wis. -- AC Electronics Division of General Motors is prime contractor to the National Aeronautics and Space Administration (NASA) for Guidance and Navigation (G&N) systems on both the Command and Lunar Modules. The nearly identical G&N systems aboard the two Apollo spacecraft have proven themselves consistently accurate space performers on all Apollo missions -- especially on the manned flights beginning last October.

Mission control center in Houston, and NASA's world tracking network are in primary control when the spacecraft are visible to the earth. But both systems are self-sufficient in that they can perform all guidance and navigation functions of their respective missions including possible abort maneuvers without aid from the ground.

Behind the moon the G&N systems assume primary control. In addition, each system "remembers" where the other is when the two spacecraft are separated. The astronauts use the G&N systems to accurately pinpoint their position in space, control engine burns, and maintain attitude automatically. In addition, should communications fail, an AC Electronics system would provide the astronauts their only on-board position reference, essential for their safe return to earth.

The Apollo G&N systems achieve an optimum balance between the complex, high-speed measurement and data processing capability of the automatic equipment

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and the adaptable sense and judgment of a man in accomplishing a tremendously complex task - the guidance and navigation for a trip to the moon, a moon landing, and a safe return to earth.

For instance, when a major engine firing is planned in either the LM or the CSM, data to accomplish the burn is inserted into the computer, which then prepares to control the burn automatically. Shortly before the computer commands the engine to fire, it flashes "proceed" on the display for one final okay from the human pilot. The commander must tell the computer to go ahead with the burn by pressing the proceed button.

Primary differences between the two guidance and navigation systems appear in the optical subsystems, the navigation base and in the computer programs. Spacecraft locations of the G&N components also differ.

INERTIAL MEASUREMENT UNITS

The inertial measurement units - heart of the CSM and LM G&N systems, are identical in both spacecraft. The IMU contains in a spherical case, precision gyros mounted on a platform set within gimbals, so that the platform is free to rotate in any direction. Spinning at 24,000 rpm, the gyros stabilize the platform to a known, fixed reference, such as the center of the earth, or certain stars. Any movement of the spacecraft which results in motion of the platform causes one or more of the gyros to give an error signal. The signal is amplified through a servo assembly to drive gimbal motors, which torque the platform back to its fixed inertial orientation. The attitude of the spacecraft also is measured from this stable reference.

Accelerometers also mounted in the platform can measure accurately any changes in the spacecraft's velocity. Accumulating position, speed, and keeping its own accurate time internally, the Apollo guidance computer can tell the astronauts at a given time where they are in space, their present speed, how far they have travelled, the distance to their destination, and what course changes might be necessary to get them there.

OPTICS

The Command Module and Lunar Module optical subsystems are manufactured under subcontract to AC Electronics by Kollsman Instrument Co., Syosset, N. Y., a division of Standard Kollsman Industries. The optical equipment is used to make star sightings to verify or change alignment of the IMU, and to perform celestial navigation through sightings on stars and planets.

The optical units are attached to each spacecraft on an AC-built navigation base, which has a precise, known relationship to each system's IMU. The more complete CSM system requires a larger, more complex navigation base than is needed in the LM.

The CSM optical system consists of two instruments -- a one power, one line-of-sight 60 degree field of view scanning telescope, and a 28 power, dual line-of-sight, 1.8 degree field of view space sextant.

The telescope and sextant are slaved together electronically, such that the telescope moves with the sextant when the latter is positioned by the astronaut or the computer. The telescope is used mainly for coarse acquisition and identification of stars, with the much more accurate sextant reserved to pinpoint an identified star precisely. The astronauts also can change the CSM's attitude, as in the LM, to orient the spacecraft in the proper direction for desired sightings.

In a space navigation exercise the G&N system's computer can automatically drive the CSM optics to point to a known star and, for instance, to the earth's horizon.

The astronaut should be able to look through the telescope and see what he asked the computer to show him. Moving to the sextant, he adjusts the reticle so that one line-of-sight is pinpointed on the horizon. He then optically superimposes, on the horizon's edge in the center of the reticle, the star appearing in the other line-of-sight, and presses a mark button to tell the computer he is on target. Resolvers measure the star-horizon angle. Since this angle changes as the spacecraft moves to or from the plant, two such sightings allow the computer to determine position. These "cislunar" navigation sightings also can be made using a star-moon horizon, star-landmark or moonmark, or with a star and another planet.

Periodically the optics are used to realign the IMU to compensate for accumulation of tiny errors by the inertial instruments since the last alignment. Alignment is always done before thrusting maneuvers, in order to properly position the accelerometers for the burn, and usually a star check also is made to verify proper spacecraft attitude. At other times, the IMU alignment may be changed to new, more convenient or accurate reference coordinates, such as the launch pad or a lunar landing site.

The procedure for alignment is similar to the navigation procedure, except that only stars are used. To perform alignment with the Command Module system, the astronaut/navigator acquires a star with the telescope. Then, using the sextant, he "marks" on two different known stars. Since the stars' position in space appears never to change, they are always in the same place no matter what the position of the spacecraft is on a lunar mission.

The telescope is also used to track earth and moon landmarks in orbit. By "marking" on landmarks several times, the astronaut can determine his orbital velocity and altitude from computer calculations which utilize memorized data about the size and shape of the earth or the moon.

The simpler and lighter LM alignment optical telescope (AOT) is like a periscope. It performs the functions of both the telescope and the sextant on the CSM. In coasting flight, star sightings with the LM AOT normally are made by changing the attitude of the spacecraft -- rocking back and forth, while the astronaut marks on a star each time it crosses the vertical and horizontal lines in the telescope reticle.

The LM instrument has an "Archimedes spiral" reticle along with the cross hairs. When the LM is on the surface of the moon and not maneuverable, the spiral allows star sightings with two degrees of freedom in trunnion and shaft.

After marking the inertial attitude of two stars in platform coordinates, the computer processes this sighting information to calculate the platform drift. From this data, the inertial platform can be realigned.

COMPUTERS

The identical guidance computers built for AC by the Equipment Division of Raytheon Company, are the brains of the G&N systems. The computers are high-speed digital machines capable of up to nine simultaneous parallel computations. They hold in their fixed memories the exact physical relationship between the navigation base, the optics and the IMU, the relative position of major stars and planets, and considerable information about other spacecraft systems. Raytheon also supplies display and keyboard assemblies (DSKY), which permit the astronauts to communicate with each computer, and it with them. There are two DSKY's in the CSM and one in the LM.

The computer programs in the two systems are somewhat different, because each is tailored to control its spacecraft in a different way. While both have capability to control attitude through a digital autopilot routine, for instance, the LM program (Luminary 99 for Apollo 11) must be able to provide steering signals during thrusting of two main engines -- the descent and ascent propulsion systems. The CSM program (Colossus 2, Commanche 55) however, needs only to control one main engine, the service propulsion system, but can handle more exotic optical navigation data than the LM program. Each computer continuously calculates the position and velocity of its companion spacecraft when the two are separated.

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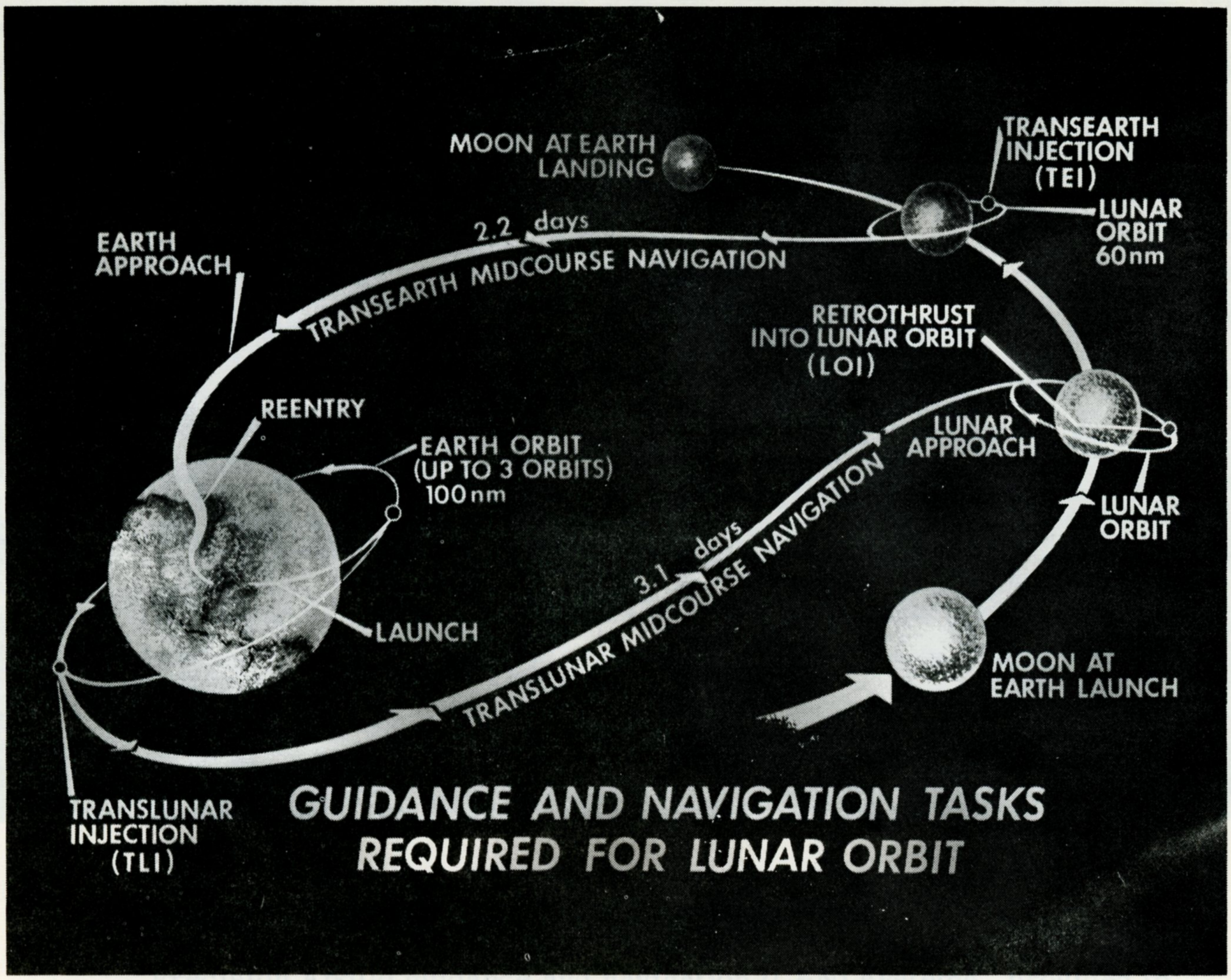

On an Apollo lunar mission AC Electronics' guidance and navigation (G&N) systems control firings of the main engines on both the Command and Service Module (CSM) and the Lunar Module (LM), after the S-IVB firing for translunar injection (TLI). The system controls four critical engine firings behind the moon, out of touch with mission control in Houston. These are: the two lunar orbit insertion burns (LOI-1 and LOI-2), and transearth injection (TEI) with the CSM's service propulsion system, and the descent orbit insertion firing (DOI) with the LM descent propulsion system.

The AC system in the Lunar Module is programmed to control the moon landing automatically, but the astronauts can provide manual control if they wish.

On the way to and from the moon, the astronauts use the G&N system's optical subsystem to navigate in space, sighting on stars and earth or moon horizon. The Command Module system also provides precise, automatic control of the spacecraft during entry into the earth's atmosphere.

Photo No. 3-43-E75B 062769

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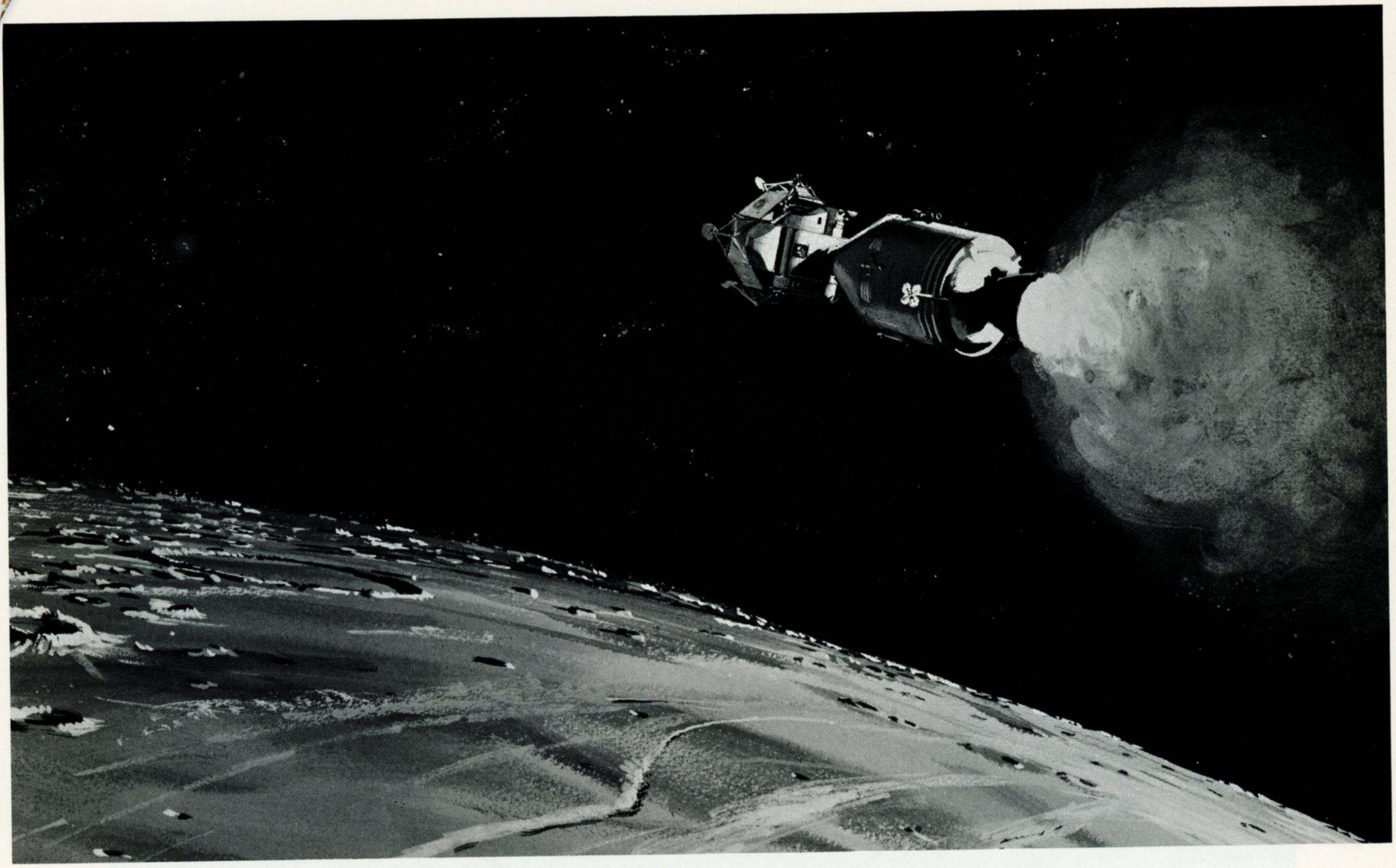

GM'S APOLLO GUIDANCE "ON ITS OWN" BEHIND THE MOON

Precision Apollo guidance and navigation (G&N) systems, provided to NASA by AC Electronics Division of General Motors, control four critical engine firings behind the moon, out of contact with radio or radar signals from earth.

These firings are: the two lunar orbit insertion burns (LOI-1 and LOI-2), like the one depicted here with the command and service module's (CSM) service propulsion system (SPS); the descent orbit insertion firing (DOI) with the lunar module's (LM) descent propulsion system; and transearth injection (TEI), the SPS firing that sends the astronauts home.

The AC systems in both the CSM and the LM normally control all major engine firings during a lunar mission, including the descent engine burn which lowers the LM gently to the lunar surface and the ascent engine firing for liftoff toward rendezvous with the CSM in moon orbit.

Photo 3-43-E186   071069

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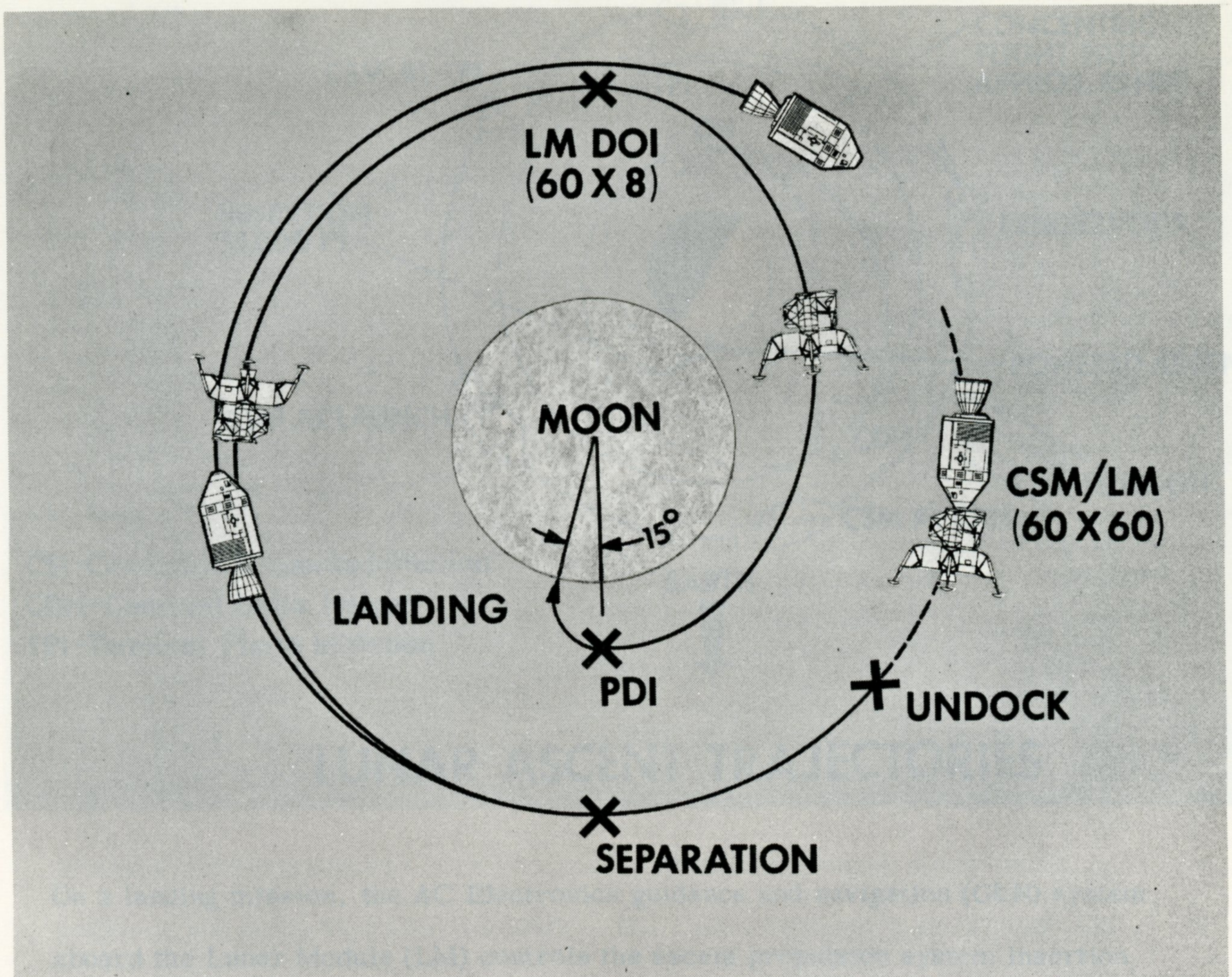

LUNAR DESCENT TRAJECTORIES

On a moon landing mission, the AC Electronics guidance and navigation (G&N) system in the Lunar Module (LM) is programmed to control the landing sequence automatically. If the astronauts desire, they can hand-throttle the descent propulsion system (DPS) during powered descent to a gentle touchdown.

The G&N's system controls the descent orbit insertion (DOI) burn of the DPS engine which heads the spidery craft toward the lunar landing site. This engine firing is performed behind the moon, out of touch with NASA mission control. During DOI, the astronaut orbiting in the Command and Service Module (CSM) tracks the LM with the sextant in that spacecraft's G&N system, and with a VHF radio ranging device. The CSM system computer thus knows the position of the LM at all times, and can monitor its actual descent trajectory.

Photo No. 3-43-E303   062769

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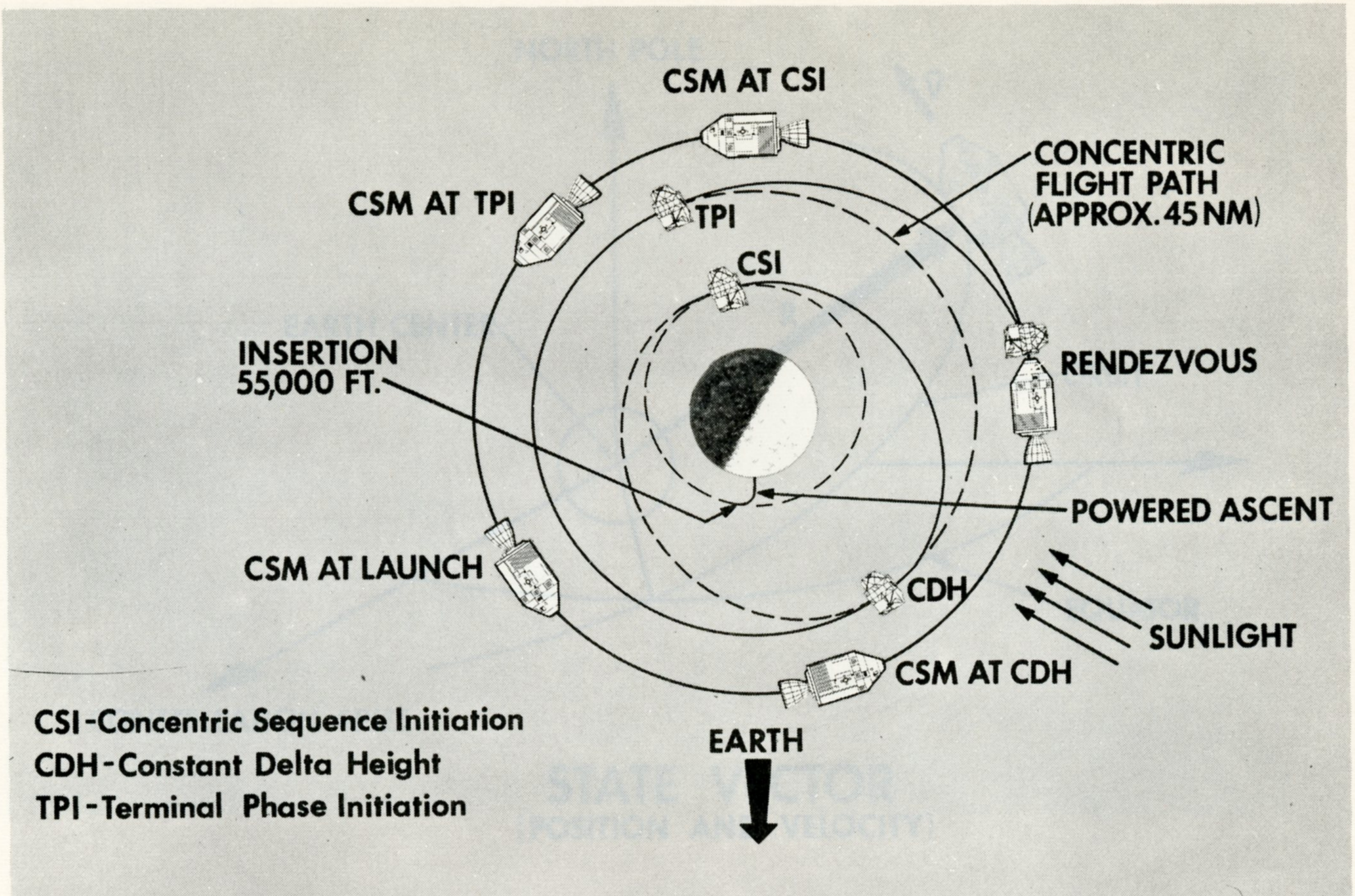
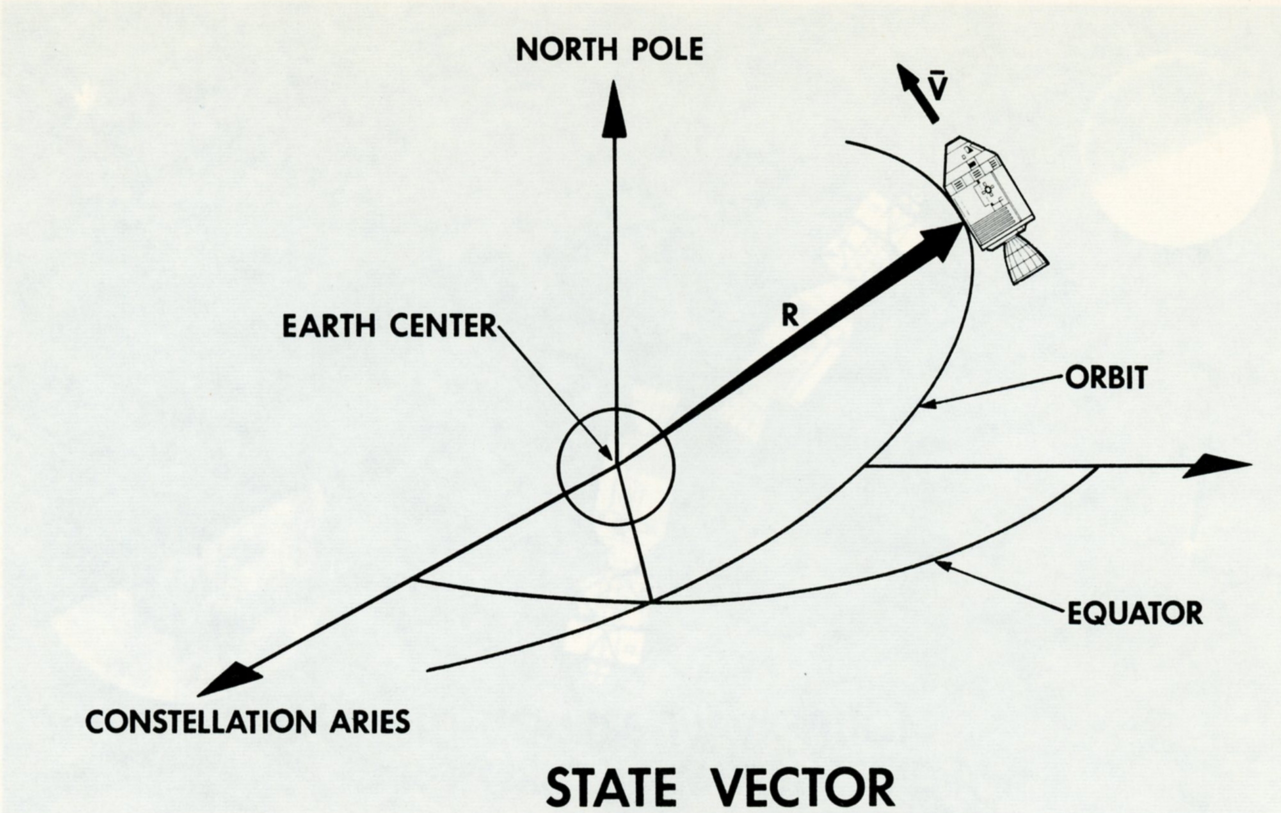


LUNAR ASCENT TRAJECTORIES

On a landing mission, the AC Electronics guidance and navigation (G&N) system aboard the Lunar Module (LM) controls the ascent propulsion system insertion firing to lift the spacecraft from the surface of the moon and guide it to rendezvous with the Command and Service Module (CSM) in orbit. The other rendezvous firings utilize the smaller-thrust reaction control system rockets, and normally are under G&N control. On Apollo 10 the CDH burn will be controlled by the backup abort guidance system (AGS).

While the LM is on its way to the rendezvous, the astronaut in the CSM tracks it with the G&N system's sextant and a VHF radio ranging device. Between rendezvous engine firings, the G&N system in the LM displays rendezvous radar ranging information for the LM astronauts. Thus, each AC G&N system always knows the position of its companion spacecraft.



STATE VECTOR
(POSITION AND VELOCITY)

The "state vector" of an Apollo spacecraft -- simply its position and velocity in space at any given time -- is continually updated by the AC Electronics guidance and navigation (G&N) system. The G&N computer "remembers" the exact position at launch, based on an earth-centered alignment reference (like the one shown here) of the gyroscopically stabilized platform in the system's inertial measurement unit (IMU). During engine firings, accelerometers on the stable platform measure velocity changes, which the computer accumulates, along with time, to arrive at current position and speed.

The astronauts can improve this onboard position and speed estimate by taking several star-horizon measurements with the G&N optical subsystem. This navigation capability would be essential if communications failed, since NASA's radar tracking normally is used to update the state vector by radio from mission control.

Order No. 3-43-E298

AC ELECTRONICS
DIVISION OF GENERAL MOTORS CORPORATION
MILWAUKEE, WISCONSIN 53201

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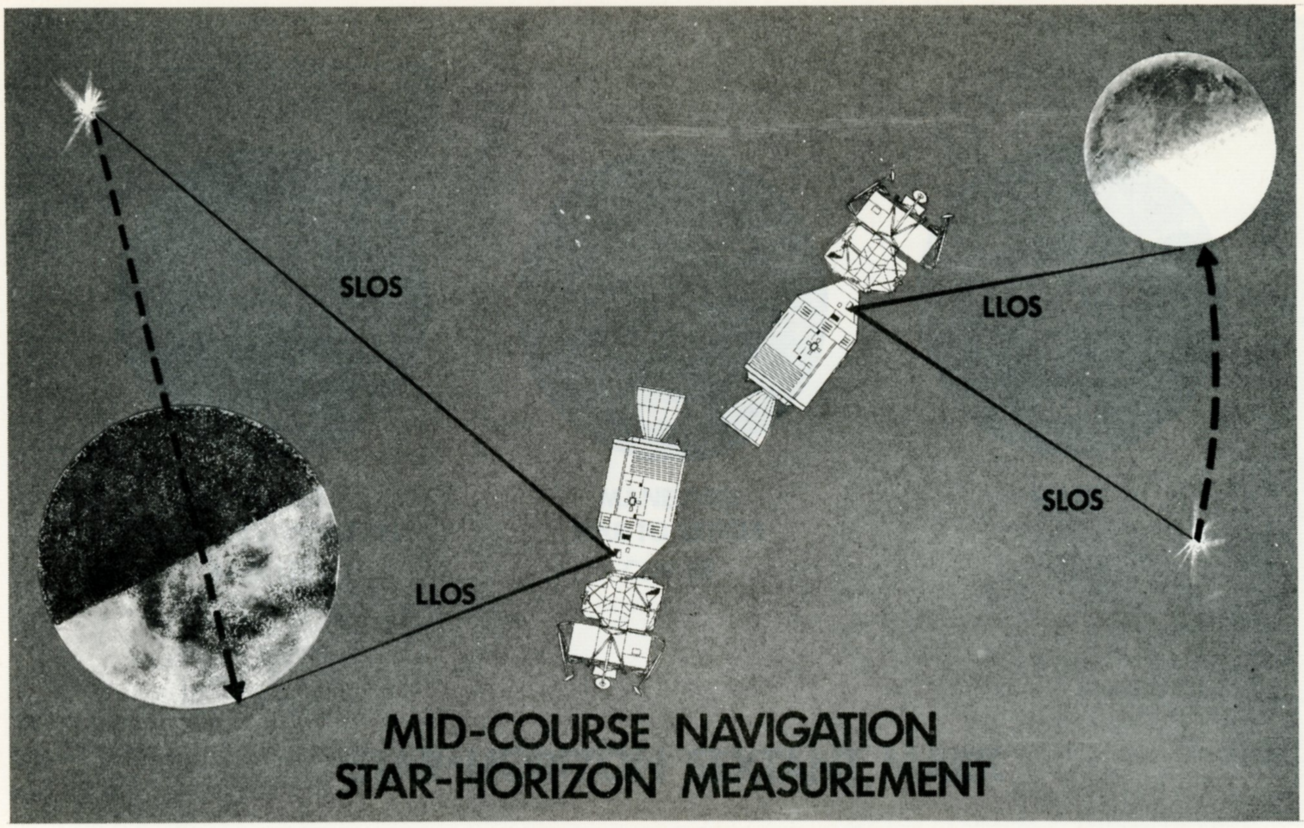
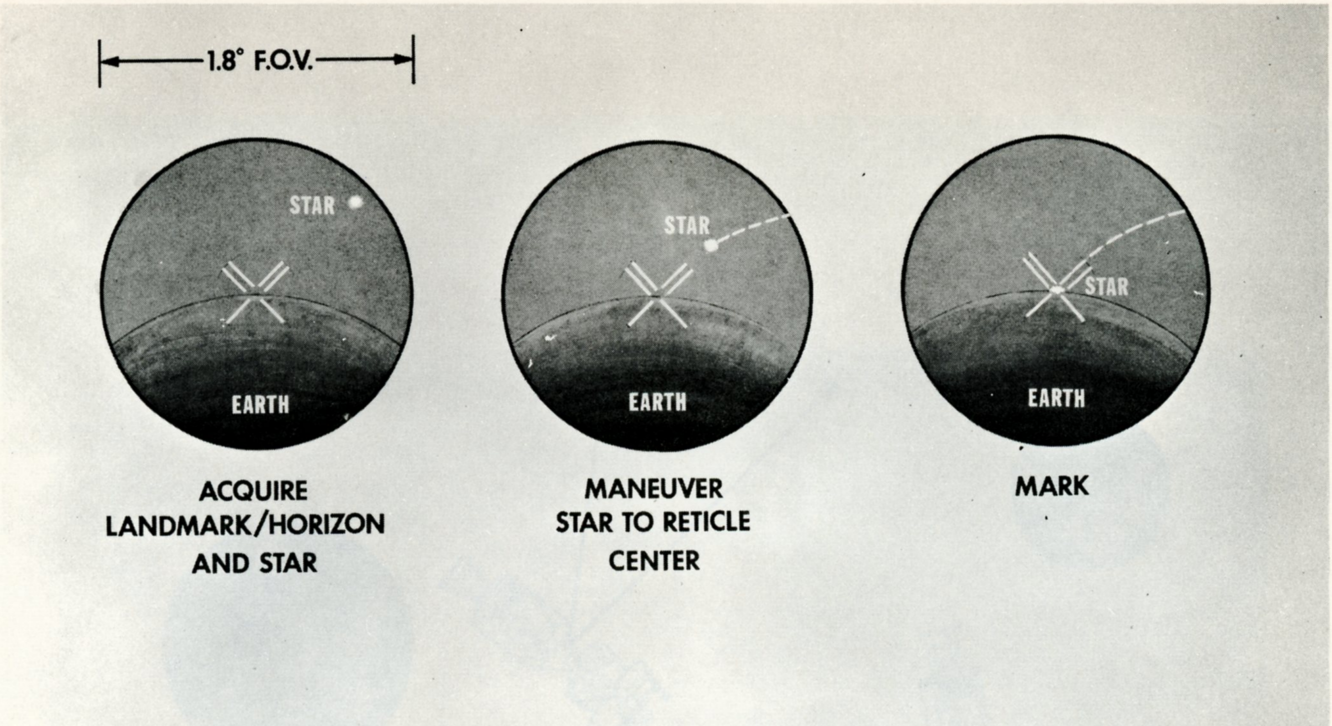


The state vector (position and velocity at a given time) of the Apollo spacecraft is continuously updated by the AC Electronics guidance and navigation (G&N) system. But the astronauts can improve this onboard estimate by taking star-horizon sightings with the G&N optical unit.

The system's 28-power, two line-of-sight sextant is used to measure several times the ever-changing angle between identified, fixed stars and the earth or moon horizon. An astronaut maneuvers the sextant until the horizon and a star appear in the two lines of sight of the reticle, optically superimposes the star on the horizon's edge in the reticle center, then presses a "mark" button on the control panel to enter the sighting angle into the system's computer. The computer calculates the relationship of the measurements to position and speed.

Since the onboard state vector is normally updated via radio, based on NASA's radar tracking, this navigation capability would become essential if communications failed.



STAR-HORIZON SEXTANT MARK

Navigation between the earth and the moon from the Apollo Command and Service Module is performed by taking star-horizon (or star-landmark) sightings with the sextant in the optical unit of the AC Electronics guidance and navigation (G&N) system. The 28-power sextant is a dual line-of-sight device with a 1.8 degree field of view.

The astronaut positions the sextant's landmark line-of-sight on the horizon, moves the star line-of-sight to superimpose the star on the horizon in the center of the reticle, then presses a mark button on the control panel. The mark tells the G&N computer the angle between the two lines of sight. Since the angle changes between the fixed star and the horizon as the spacecraft moves along, such sightings allow the computer to calculate and update the G&N system's state vector (position and velocity at a given time). This onboard capability would become essential should a communications failure shut off radar-based state vector updates from NASA mission control.

Order No. 3-43-E310

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MILWAUKEE, WISCONSIN 53201

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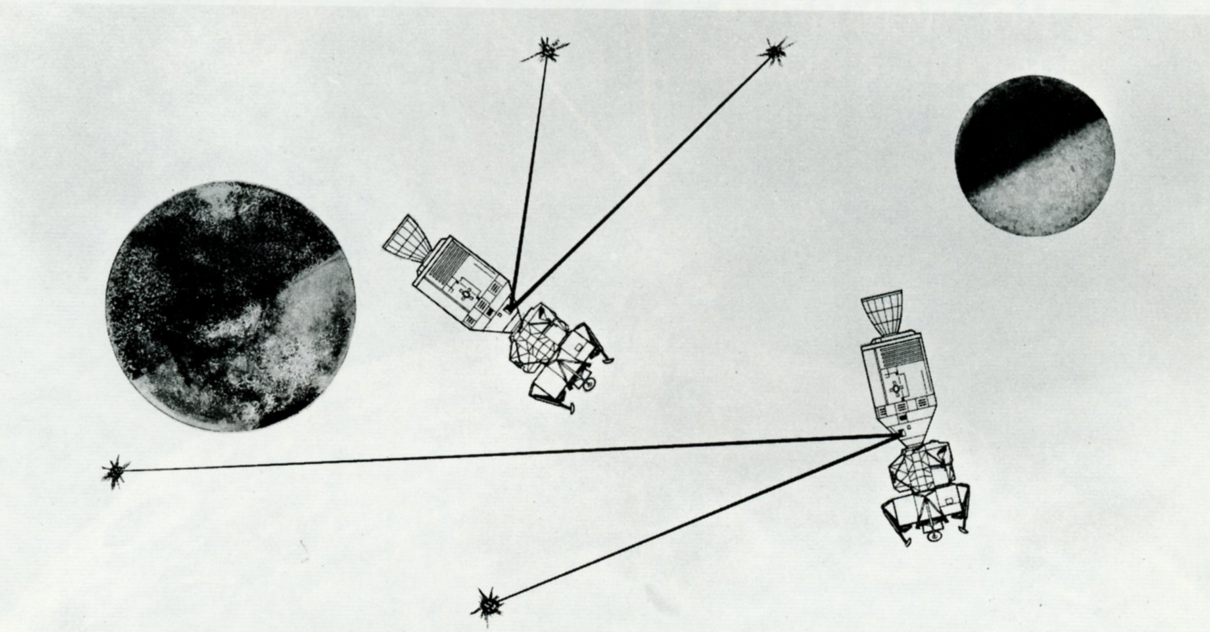

MID-COURSE INERTIAL PLATFORM ALIGNMENT

Apollo astronauts use at least two star sightings to realign the inertial measurement unit (IMU in the AC Electronics guidance and navigation (G&N) system for Apollo spacecraft. The IMU contains in a spherical case a gyroscopically stabilized platform set within gimbals, so that the platform can sense any movement of the spacecraft about it. Before launch the platform is aligned to a pre-launch attitude, which is referenced to an earth-centered inertial coordinate system, and isheld to that attitude by signals from the gyros. During a mission the platform is realigned several times, especially before major engine firings. Since the stars appear not to move in translunar space, they are an excellent inertial reference, and the G&N computer is pre-programmed with exact inertial positions of 37 of them.

The astronauts first aim at an identified star with the Command Module system's one-power telescope, pinpoint it precisely with the 28-power sextant, then mark on it with a control panel button. The mark tells the G&N computer to note the attitude of the IMU in relation to the star. Two such star marks provide a precise realignment reference, as well as a verification of spacecraft attitude.

Photo #3-42-E299A 062769

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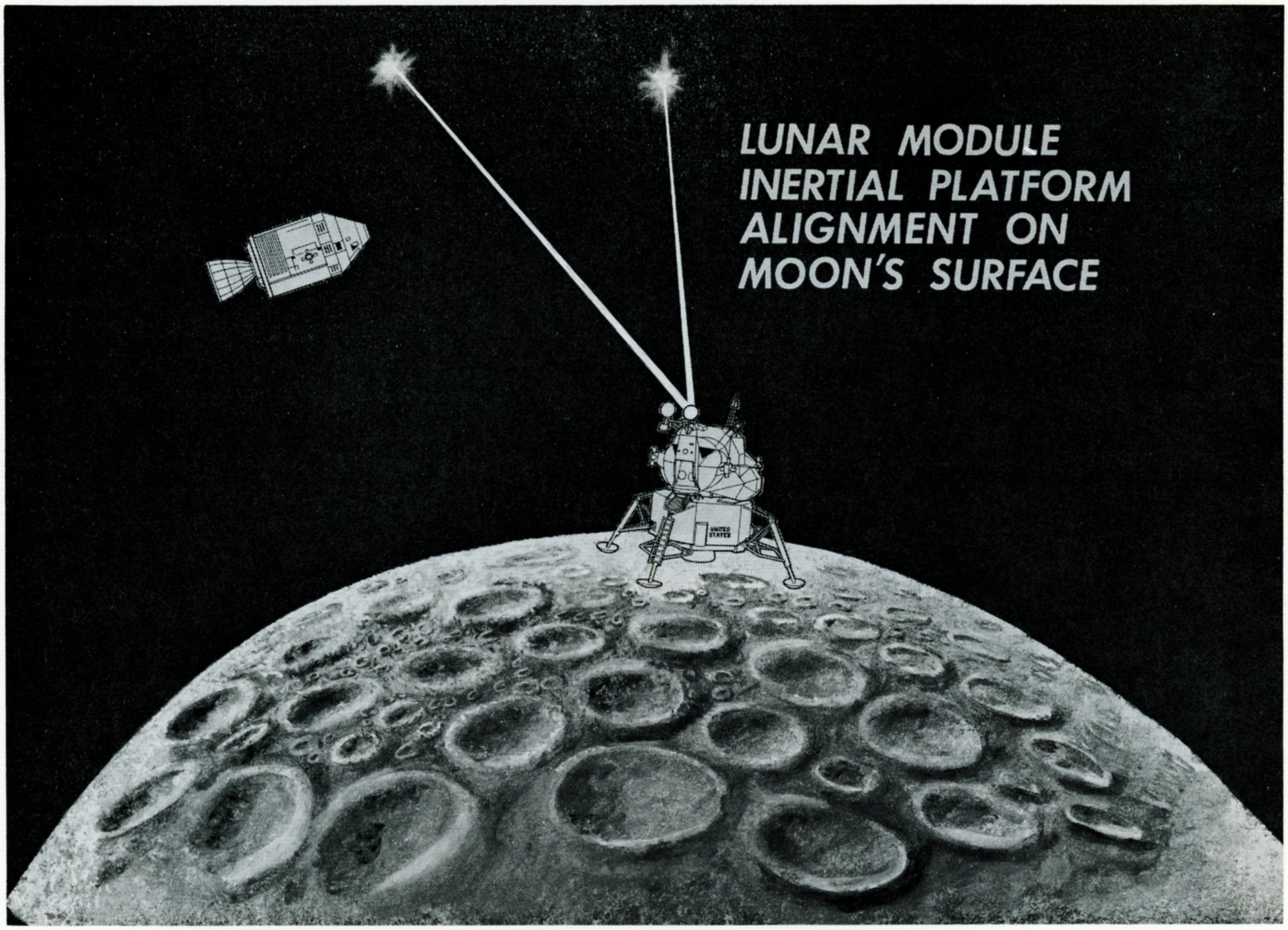

Before their ascent from the lunar surface, the LM astronauts make star sightings with the telescope in the LM guidance and navigation (G&N) system to align the G&N's inertial measurement unit (IMU). Precise IMU alignment is required since the G&N system is programmed to automatically control the liftoff engine firing, using attitude and velocity change information from the IMU.

Normally, IMU alignment would be accomplished using one or two star sightings. However, a backup-abort mode permits alignment by calling up IMU orientation data stored in the G&N computer shortly after touchdown.

AC Electronics Division of General Motors is prime contractor to NASA for G&N systems in both the Command Module and the LM. Kollsman Instrument Corp. supplies AC with the optical instruments for both systems; Equipment Division of Raytheon Co., provides the two computers.

Photo No. 3-43-E305 070969

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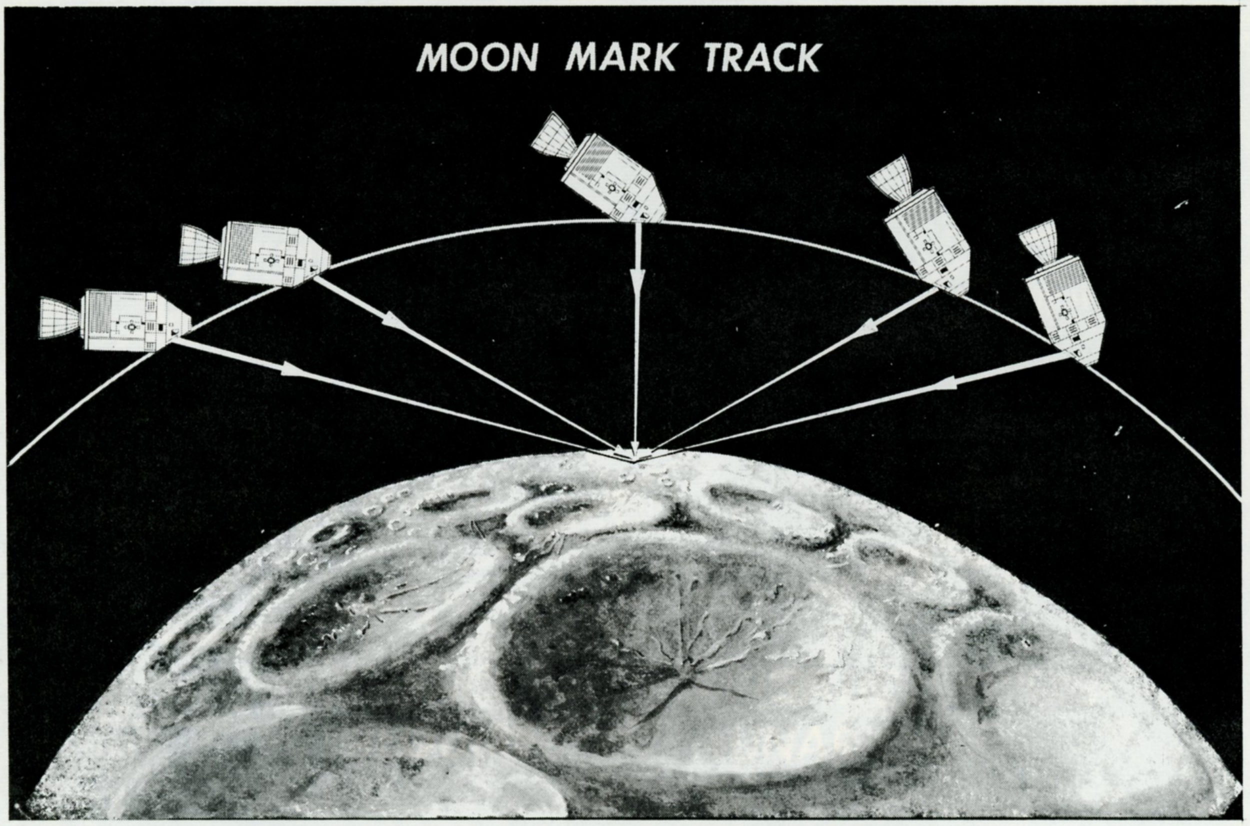

Apollo astronauts will use the optical unit (OUA) in the AC Electronics guidance and navigation (G&N) system in the Command Module to help determine the precise location of lunar landing sites and the altitude of the spacecraft's orbit. The OUA consists of a one-power telescope and a 28-power sextant, both of which can be used for tracking.

As the spacecraft begins a tracking pass, an astronaut will line up in the instrument's reticle a desired point on the lunar surface, and press a mark button on the control panel to tell the G&N computer he is on target. Knowing the exact time of each in a series of marks, the computer is able to calculate the location in inertial space of the specific mark point. Further calculation by either NASA mission control or the onboard computer can help determine the altitude of the spacecraft in its orbit above the mark point.

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NEWS
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GM GUIDANCE PROGRAMMED TO CONTROL FIRST MOON LANDING

MILWAUKEE -- The first manned landing on the moon and liftoff from it are programmed to be controlled by the space-proven Guidance and Navigation (G&N) system in the Apollo Lunar Module (LM).

To begin the dramatic landing sequence, the General Motors-AC Electronics system controls the Descent Orbit Insertion (DOI) firing of the LM descent engine behind the moon, out of touch with Mission Control in Houston. DOI lowers the orbit of the LM, so that its eight mile low point comes some 15 degrees and about 260 nautical miles before landing site two.

As the low point approaches, Apollo 11 Commander Neil A. Armstrong and LM pilot Edwin E. Aldrin will enter Program 63 (P-63) into the G&N computer, calling for the Power Descent Initiation (PDI) firing of the throttleable descent engine, to start the LM down toward the landing site.

Seconds before planned PDI ignition, the computer's display and keyboard (DSKY) will flash its "proceed" button, asking the astronauts if they agree the engine should be fired as planned.

The push of that button will permit a completely automatic descent and landing under G&N control, which incorporates landing radar readouts. Meanwhile the astronauts monitor G&N and double check to be sure they are headed

- more -

for a reasonably smooth, flat area. Thrusting in program 63 reduces relative ground speed to some 350 mph before the program switches automatically to P-64 and at 150 feet altitude to P-65 for the gentle, two-mile-per-hour final approach and touchdown.

Though it is planned that Armstrong and Aldrin will leave the G&N in its automatic mode until the final portion of the descent, they still can use hand controllers to make minor corrections of spacecraft attitude, basing their corrections on instruments driven by the G&N system. Rate of descent and total attitude are regulated automatically.

During the final portion of the descent, the crew can exert more direct control over the final touchdown point and velocities by selecting from two other programs: P-66 (semiautomatic) or P-67 (manual), though once they choose either of these programs -- via DSKY entry -- they cannot return to the automatic sequence. In P-66, total attitude is handled manually. The G&N system controls the rate of descent, though a flip of an instrument panel switch provides a one-foot-per-second variation in the descent rate. Complete manual control is provided by P-67.

The AC Electronics G&N systems in both the Command and Lunar Modules will be put to the test throughout the Apollo 11 lunar landing mission -- from launch to splashdown.

- - - During launch the AC Electronics Command Module (CM) system backstops the launch vehicle guidance package, and is able to turn over manual control of the rocket to the astronauts if the primary unit should fail.

- - - In addition to the ascent and descent burns, AC Electronics systems control all other major firings of main engines in both spacecraft -- the big service propulsion system (SPS) of the Command and Service Modules (CSM) combination, and the descent and ascent propulsion systems (DPS and APS) in the LM.

- - - Four of the most critical of these firings, -- two lunar orbit insertion burns (LOI-1 and 2), DOI and transearth injection (TEI) -- are controlled by G&N behind the moon -- out of "sight" of NASA radar tracking and radio communication.

- - - The astronauts will use the Command Module G&N system to determine their position in space and in lunar orbit, as a correlation with NASA's radar tracking. Should communications fail, the G&N would become the only position reference for the trip home.

- - - While Armstrong and Aldrin are performing separate maneuvers with the LM, Command Module pilot Michael Collins uses the G&N optics to track the landing vehicle, during descent and ascent should a rescue rendezvous of the landing vehicle be necessary.

- - - Each G&N system also maintains the attitude of its spacecraft when the two vehicles are separated. When they are docked, one of the systems (usually in the Command Module) will control attitude. Thus, the systems will be in control of both spacecraft virtually at all times during the mission.

- - - Finally, the AC Electronics G&N system guides the spacecraft through the critical entry corridor at the edge of the earth's atmosphere, to a point just before drogue parachute deployment.

Heart of the G&N system is the inertial measurement unit (IMU), which consists of a gyroscopically stabilized platform mounted within gimbals which allow the spacecraft to move in any direction while the platform remains fixed in inertial space. Accelerometers, which measure changes in velocity, also are mounted on this platform. From the stable platform, all changes in the spacecraft's attitude, speed, and direction are measured and accumulated by the system's guidance computer. The computer controls the overall G&N operation, and issues guidance commands based in part on information from the IMU.

The optical subsystem, consisting of a one-power telescope and 28-power sextant in the CSM, is a very precise refinement of seafaring navigational instruments. In the LM, only a one-power alignment optical telescope (AOT) is provided. The CSM optical subsystem permits the astronauts to find their position in space relative to the moon and the planets, and to realign their stabilized inertial platform to star references. In addition, spacecraft attitude is verified periodically by sextant star sightings.

During the mission the astronauts will use the optics in both spacecraft to realign the stable platform several times, because:

- - Even the most precise gyroscopes accumulate minor errors or "drift" over a period of time, but alignment can correct for this drift.

- - For the most precise measurement of velocity change during a major thrusting maneuver, it is best to have the accelerometers properly aligned for the burn. Usually alignment is performed before every engine firing to accomplish this.

- - Normally the platform is aligned to its most convenient reference. For example, at launch, alignment is to a launch pad reference;

in mid-course, to the stars; at the moon, to the landing site; and near entry, to certain entry coordinates.

Accelerometers also can develop some minor errors, or inherent bias. But as is the case with gyros, the bias usually is a known quantity, a definite signature developed through exhaustive testing of the instrument from the day it was built right up to mission time. The bias factors are programmed into the computer, which compensates for them when computing velocity change.

On their way to and from the moon, the astronauts correlate their position with the ground's radar tracking estimate by using the G&N system's sextant to make star-horizon or star-landmark fixes. The sightings are used to update their onboard state vector - position and velocity estimate - which would become critical if communications failed.

When the LM guidance and navigation system is powered up, the LM's IMU will be aligned initially using coordinates voiced from the CSM. After the two spacecraft separate the astronauts in the LM will take star sightings to perform IMU alignments. One of their first duties after landing on the moon is to perform optical alignment.

LAUNCH AND ORBITAL INSERTION

The CSM guidance and navigation system will be turned on and aligned to a launch pad reference at T-48 hours, and will not be powered down during the mission -- until just before splashdown some 240 hours later. Here is a G&N mission sketch:

During launch and earth parking orbit insertion by the Saturn V rocket, guidance and control normally are the responsibility of the system in the instrument unit (IU) of the S-IVB third stage, while the AC Electronics system monitors

IU guidance performance and displays for the astronauts the spacecraft's attitude and velocity.

If the launch vehicle inertial platform should fail, the AC system can provide the astronauts with a means to assume steering control and either continue or abort the mission as required.

TRANSLUNAR INJECTION (TLI)

During the second revolution of the 100 nautical-mile high circular parking orbit, the instrument unit will control a restart of the S-IVB to place the combined vehicles in a free return trajectory to the moon (so that if no lunar orbit were attempted, the spacecraft would merely circle the moon and return to earth). The AC system monitors this maneuver, and again provides takeover capability should trouble develop in the launch vehicle inertial platform.

TRANSPOSITION, DOCKING AND LM EXTRACTION

Soon after TLI, the astronauts will control separation, transposition and docking with the LM, then ease the moon vehicle from its S-IVB adapter. After the docked spacecraft makes a short evasive burn using the Service Propulsion System (SPS), the S-IVB's remaining fuel will be vented, accelerating it into a solar orbit.

TRANSLUNAR COAST (TLC)

On the 73-hour coasting flight to the moon, the AC G&N system will control up to four mid-course corrections, though on past missions most of these adjustments have not been required.

LUNAR ORBIT INSERTION (LOI-I and LOI-2)

At the moon the G&N system will control insertion of the two Apollo spacecraft into a 60 by 170 nautical mile lunar orbit. Two revolutions later, it will direct the SPS engine to fire again to circularize the orbit at approximately 60 nautical miles. Both burns will be behind the moon with no coverage by NASA's Manned Space Flight Network (MSFN). LM pilot Aldrin will enter the LM for the first time toward the end of the third lunar orbit for a two hour check of communications systems and general housekeeping chores, while CM pilot Collins performs orbital navigation, tracking landmarks with the G&N optical subsystem.

DESCENT ORBIT INSERTION (DOI)

In the eleventh orbit, after a rest period in the Command Module, spacecraft commander Armstrong and LM pilot Aldrin will occupy the LM. This time they will power up and check all LM systems and align its IMU for the first time. Collins will perform more landmark tracking from the CSM. In the 13th lunar revolution the two spacecraft will separate and the LM descent will begin, under G&N control and without MSFN coverage. The DOI - descent propulsion system (DPS) burn will lower the LM altitude to 8 nautical miles at its closest point. During the LM coasting descent, Collins will track it from the CSM with the G&N optics.

POWERED DESCENT AND LANDING

With the astronauts again in contact with earth, the G&N system initiates the key PDI burn which begins the vehicle's powered descent toward a gentle landing on the surface. If the astronauts wish, the guidance system can control the entire landing sequence automatically, while they monitor the progress of the descent. The G&N system processes and displays range and range rate information from the landing radar and attitude data from the IMU. In the latter phase of descent the astronauts can take over manual control and fly the LM to touchdown.

Soon after landing, the G&N's IMU is realigned using AOT star sightings, so that a G&N-controlled liftoff can be performed right away if necessary. Alignment is repeated again before the actual liftoff.

ASCENT AND RENDEZVOUS

When the lunar stay is concluded, the G&N system will automatically control the firing of the LM's ascent engine. The descent stage will be used as a launch pad for liftoff, to start Armstrong and Aldrin toward a rendezvous in orbit with the Command Module.

After the LM is safely in orbit, the G&N system controls the three firings of the small LM reaction control system rockets to enable the spacecraft to rendezvous and dock with the CSM. Further braking burns are under manual control as the LM G&N system displays rendezvous radar data during the rendezvous sequence. Between rendezvous burns, the Command Module pilot again will use the G&N system's sextant to track it. Rendezvous maneuvers are calculated by the G&N computers aboard the CSM and LM.

After the two LM astronauts finish their tasks in that spacecraft and crawl back into the CM with their lunar samples, the LM will be jettisoned and left in orbit around the moon.

TRANSEARTH INJECTION (TEI)

In the 30th revolution, the G&N system will control the SPS burn behind the moon which propels the CSM out of lunar orbit and back toward earth.

TRANSEARTH COAST (TEC)

During the two-and-a-half day trip home, the astronauts may make up to three mid-course corrections, though on Apollo 8 and again on Apollo 10, the transearth injection was so accurate that only one minor correction was needed.

ENTRY

The AC Electronics guidance and navigation system will control the 25,000 mile per hour entry into the earth's atmosphere automatically. The system will continue spacecraft guidance until just before drogue parachute deployment, as it did with such great accuracy on previous Apollo missions. On Apollo 9 and 10, the world watched as the spacecraft drifted down within range of television cameras aboard the recovery aircraft carrier.

The system controls speed and attitude during entry by rotating the spacecraft about its offset center of gravity, thus changing the direction of the aerodynamic lift. The system calculates how much and in which direction the spacecraft should be rolled to achieve the desired parachute deployment point. The system also calculates and shows the astronauts their anticipated splashdown point, the only variable being surface winds in the landing area.

AC is prime contractor to NASA for manufacture, assembly, subsystem integration and testing of the Apollo G&N systems. Major subcontractors are the Equipment Division of Raytheon Co., Sudbury, Mass., for the digital computer and associated displays and keyboards; and Kollsman Instrument Corp., Syosset, N.Y., a division of Standard Kollsman Industries, for the optical subsystem.

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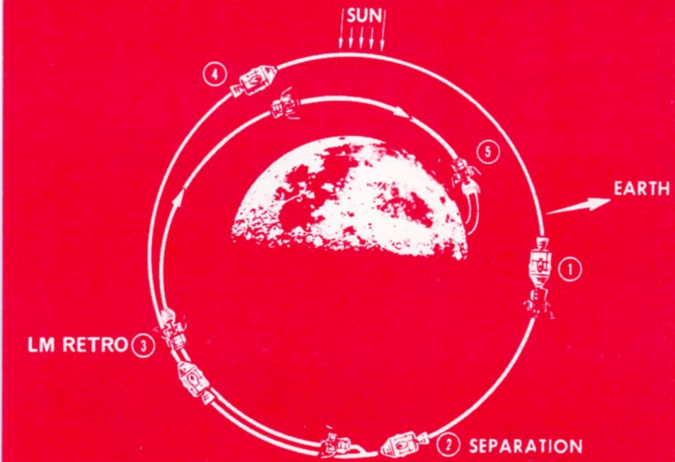
LM SEPARATION & DESCENT

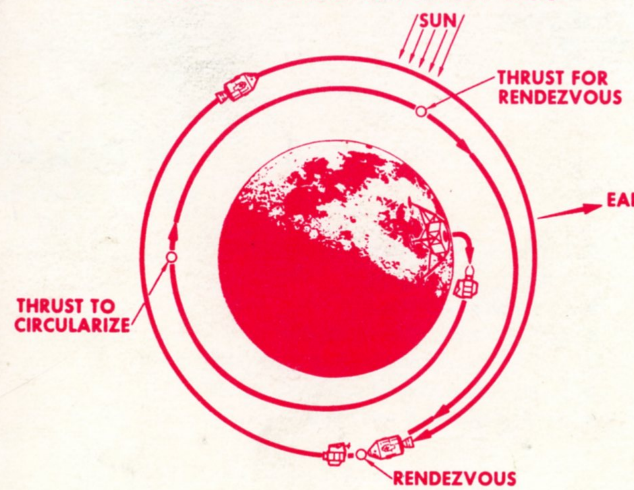


LANDING CONFIGURATION

ASCENT CONFIGURATION

LM ASCENT

LUNAR ORBITAL RENDEZVOUS



APOLLO 11

Guidance & Navigation Information

Apollo GUIDANCE AND NAVIGATION

AC ELECTRONICS
DIVISION OF GENERAL MOTORS CORPORATION
MILWAUKEE, WISCONSIN 53201

GM MARK OF EXCELLENCE

APOLLO 11

MISSION DESCRIPTION

1. EQUIPMENT
   - CM 107 — LM 5
   - G&N 210 — G&N 609

2. DURATION
   - MANNED LUNAR LANDING 8 DAYS

3. LAUNCH
   - 16 JULY 1969, 09:32 EDT,
   - 4 HOURS 24 MINUTES LAUNCH WINDOW

4. BOOSTER
   - SATURN V BOOSTER NO. 506

5. MISSION OBJECTIVES
   - LM DESCENT
   - LOCATE LANDED LM
   - EVALUATE SUPPORT EQUIPMENT
   - LUNAR SURFACE EVA
   - SURFACE SAMPLE COLLECTION
   - EXTERNAL LM OBSERVATIONS
   - LUNAR SURFACE OBSERVATIONS
   - EXPERIMENT DEPLOYMENT/CONDUCT
   - CONTAMINATION PREVENTION

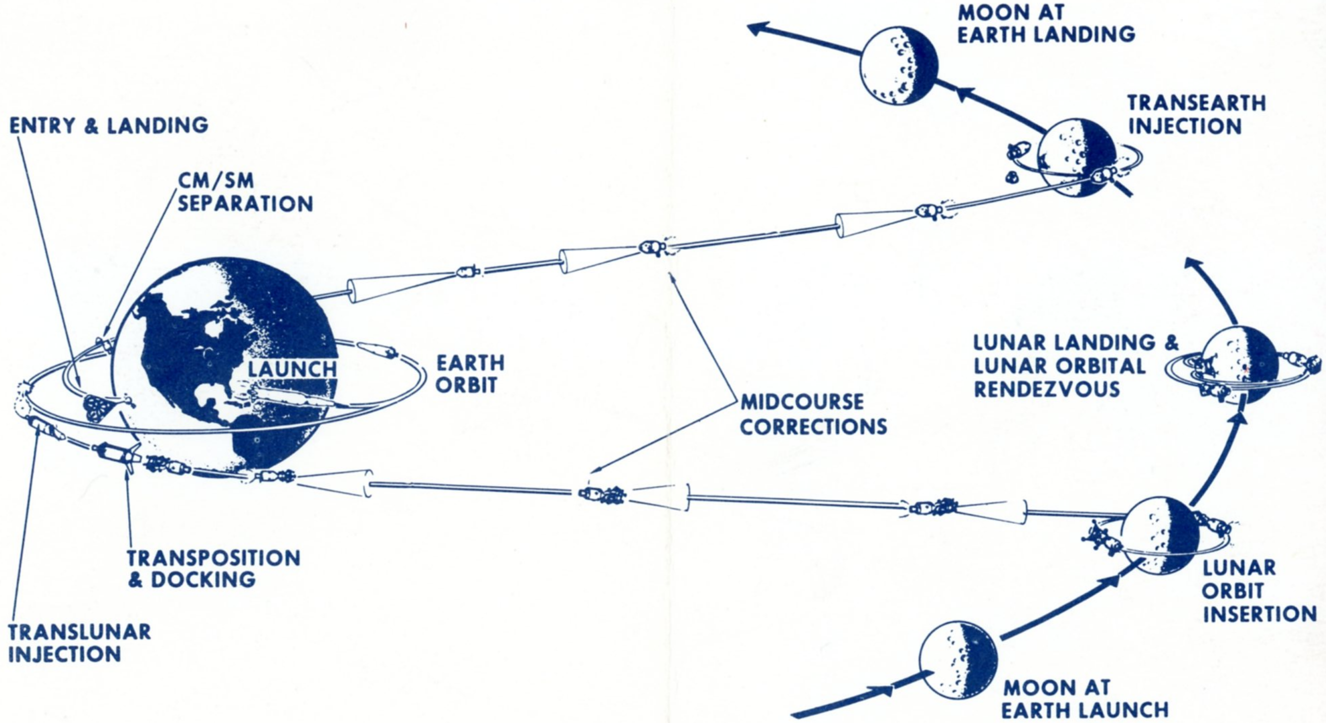
6. CREWS:

POSITION	PRIME CREW	BACKUP CREW
COMMANDER	ARMSTRONG	LOVELL
CM PILOT	COLLINS	ANDERS
LM PILOT	ALDRIN	HAISE

MATERIAL FOR REFERENCE ONLY

TIME NOTATIONS ARE SUBJECT TO CHANGE AS MISSION PROGRESSES.

APOLLO MISSION PLAN



THE DAY ON THE MOON

WITH 16 JULY 1969 LAUNCH - LANDING SITE 2

- SLEEP PERIOD ENDS 6:30 AM EDT 7/20
- UNDOCK 11:48 AM EDT
- TOUCHDOWN 2:22 PM EDT
- EAT AND REST TO 10:00 PM EDT
- ARMSTRONG STEPS ON LS 12:10 AM EDT 7/21
- ALDRIN JOINS ARMSTRONG 12:37 AM EDT
- GATHER SURFACE MATERIAL
- DEPLOY: PASSIVE SEISMIC EXPERIMENT PACKAGE
  LASER RANGING RETRO-REFLECTOR
  SOLAR WIND COMPOSITION EXPERIMENT PACKAGE
  ERECTABLE COMMUNICATIONS ANTENNA
- ALDRIN INGRESSES LM 2:47 AM EDT
- HAUL UP LUNAR SAMPLES
- ARMSTRONG INGRESSES LM 2:57 AM EDT
- JETTISON SUPERFLUOUS MATERIAL
- EAT AND SLEEP UNTIL 8:07 AM EDT
- LAUNCH APS 12:00 PM EDT

TOTAL TIME ON MOON 21 HOURS, 38 MINUTES