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FOR A.M. NEWSPAPERS OF
SUNDAY, AUGUST 21, 1966

A critically-important piece of equipment in America's reach for the moon goes up for its first flight test soon.

It is the guidance and navigation system developed for the National Aeronautics and Space Administration's Project APOLLO spacecraft by a team of university and industry engineers and scientists.

In a test scheduled for no sooner than August 25, an unmanned APOLLO spacecraft controlled by an on-board guidance and navigation system will be launched from Cape Kennedy, Fla. The spacecraft will follow a suborbital flight path that will carry it over the southern tip of Africa to a target area in the mid-Pacific Ocean half way around the world from the point of launch.

A test objective will be to measure the accuracy with which the guidance and navigation system controls spacecraft attitude and angle of entry into the earth atmosphere.

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Of the three major sub units of the system--inertial measurement unit (IMU), computer unit and optical unit--only the first two will be involved in the suborbital flight test. The optical unit except for eye pieces will be physically present, but it will not be in operation since this requires the on-board presence of an astronaut-operator.

The guidance and navigation system was designed and developed by engineers and scientists at the Instrumentation Laboratory, Massachusetts Institute of Technology, Cambridge, Mass., under contract from NASA's Manned Spacecraft Center, Houston, Tex.

The industrial team which produces the operational systems is headed by AC Electronics Division of General Motors Corporation, Milwaukee, Wisconsin. As prime contractor to NASA, AC Electronics is responsible for manufacturing, assembly, testing, and sub-system integration.

Sub-contractors to AC Electronics for the major subsystems are Space and Information Systems Division, Raytheon Co., Sudbury, Mass., for the digital computer, and associated display keyboards and Kollsman Instrument Corporation, Syosset, N.Y., a subsidiary of Standard Kollsman Industries, Inc. for the optical subsystem. This same industrial team provided industrial support for the M.I.T. design and development effort.

AC Electronics has continuing responsibility for system field test and check out, along with the other contractors, and M.I.T. has continuing responsibility for programming the various APOLLO missions into the operational guidance and navigation systems.

The same university-industry team is developing the guidance system that will be used aboard the APOLLO lunar excursion module, the vehicle which two APOLLO astronauts will ride from the command module in lunar orbit down to the lunar surface. The LEM system is almost identical to the command module system, except that the optical unit will contain a somewhat different telescope and no space sextant. Programming also will be different.

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The system scheduled for the forthcoming suborbital test is of Block I design. Block I was made final about 18 months ago so complete hardware would be available for the start of testing. Design changes developed later have been incorporated into a Block II design. Both Block I and Block II systems will be used in manned earth orbital development flights, but only Block II systems will be used on flights to the moon and back.

The M.I.T. Instrumentation Laboratory began its studies on manned spacecraft guidance and navigation in early 1961. Later that year, when the late President Kennedy announced the sending of men to the moon in this decade as a major national goal, the Laboratory already had established basic guidance and navigation concepts and was able to initiate a design and development program quickly.

The system that has evolved is self-sufficient, flexible and makes maximum use of both man and machine.

It is self-sufficient in that it can perform all guidance and navigation functions of a complete mission, including all various possible aborts, with no aid from the ground. Nevertheless, there is also provided a redundant operational capability from the ground through tracking networks and radio links.

It is flexible in that it can be used in a variety of alternative ways and modes in accomplishing the complex task of guidance and navigation to the moon and back. For example, modifications in flight plans and trajectories are easily accommodated.

By coupling what men can do best (pattern recognition in sighting stars and landmarks, etc.) with what machines can do best (tedious and repetitive computation, high-speed switching, etc.) the M.I.T. engineers and scientists were able to design a system

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that allows the crew to exercise its various options and carry out human decisions efficiently.

Inside the spacecraft, the guidance and navigation system is mounted on the wall in what is called the lower equipment bay. This is the area immediately at the feet of the middle astronaut at launch when the crew is on couches facing upward toward the apex of the cone-shaped ship. The system occupies a wall area about four feet high and three feet wide.

Virtually all methods of obtaining data for guidance and navigation are used in the APOLLO system--inertial, celestial, radio and radar.

The inertial measurement unit--a spherical structure 14 inches in diameter in Block I and 12.5 inches in Block II--is what establishes and holds a stable on-board frame of reference and then measures spacecraft acceleration against that frame of reference. The IMU consists of three gyroscopes and three accelerometers mounted on a stabilized inner member structure which, in turn, is suspended inside three concentric spherical gimbals connected to each other by drive motors and angle (read out) resolvers.

The gyro design is the M.I.T. 25 IRIG (for 2.5-inch diameter inertial reference integrating gyroscope). Accelerometer design is the M.I.T. 16 PIPA (for 1.6-inch diameter pulsed integrating pendulous accelerometer). They are can shaped.

Gyro signals drive gimbal motors to hold the inner member in a fixed spatial orientation despite spacecraft movements. Accelerometers then measure forces acting on the vehicle and, hence, provide the data for deriving spacecraft velocity changes, or acceleration.

IMU information flows to the guidance computer and is used there in generating appropriate steering signals for the spacecraft rocket system. Likewise, spacecraft position information is fed to the computer from the ground (based on ground tracking) and

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from the optical unit.

The optical unit enables the astronauts periodically to realign the IMU spatial orientation with reference to the stars and to earth and moon landmarks. It consists primarily of a wide angle field of view unity power scanning telescope used to acquire stars and landmarks and a 28 power magnification narrow field of view space sextant to measure angles between two sighting points.

The APOLLO guidance computer is a sophisticated and versatile general purpose digital computer organized for deep space flight. Basic word length in parallel operations is 15 bits with an added bit for parity check and with subroutines for double and triple precision operations as required. Memory cycle time is 11.7 microseconds and single addition time is 23.4 microseconds.

Core ropes are used for fixed memory, and the erasable memory consists of ferrite core planes. The processor portion is formed from integrated circuits, one of the newest forms of miniaturization in electronics.

From the standpoint of design, the largest differences between Block I and Block II guidance systems appear in the computer, principally because of improvements in packaging. Essentially, the new Block II computer is smaller than the Block I, but has greater speed and capacity. Block II erasable memory, for example, has a 2,048-word capacity, which is twice as large as Block I. Block II fixed memory has a 36,864-word capacity, 50 per cent larger than Block I. Block II computers weigh about 65 pounds, compared to 80 pounds for the Block I computers.

Astronaut and computer communicate in a coded numerical language via a 21-digit character display and a 16-button keyboard designated as the DSKY (pronounced "disky") for

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display and keyboard. Two-digit numbers represent programs, verbs and nouns and five-digit numbers stand for data such as position, velocity, etc. The astronaut inserts data and commands to the system by punching numbers on the keyboard that are then displayed to him for verification in electro-luminescent counter-type readout windows. The computer communicates with the astronaut by displaying numbers in the same windows. (When the computer requests the astronaut to take some action the numbers flash in a periodic way to attract attention).

Two other sub units complete the guidance and navigation system. They are the power servo assembly and the coupling and display unit. The PSA accepts power from the spacecraft main power supply, converts it into the various currents and frequencies required by the different parts of the guidance system and also serves as an amplifier for servomechanism signals.

The CDU serves as an interface between the IMU and optical measuring systems and the computer. In Block I, the CDU is basically an electro-mechanical system through which the astronaut can command IMU and optics directly. In Block II, the CDU is fully electronic and the astronaut commands the IMU and optics through the computer.

The M.I.T. Instrumentation Laboratory has pioneered inertial guidance and navigation for airplanes, ships, submarines, missiles, satellites and spacecraft in this country. Founder and director is Dr. Charles Stark Draper, M.I.T. Professor of Aeronautics and Astronautics who is often called the father of inertial guidance in the U.S. The Laboratory has previously developed inertial guidance systems for the Air Force THOR and the Navy POLARIS missiles and components for the Air Force TITAN missile. Under development now at the Laboratory are guidance systems for the Navy POSEIDON missile and an experimental guidance system, called SABRE, being developed for the Air Force. Deputy

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director of the Laboratory for NASA programs is Mr. Ralph R. Ragan, who formerly directed the Laboratory POLARIS work. Director of the APOLLO program itself is Mr. David G. Hoag, who was technical director on the POLARIS program. Mr. Hoag, who formerly was APOLLO technical director, succeeded Mr. Milton B. Trageser as APOLLO director when the latter became director of the Laboratory's advanced planning group.

General manager of AC Electronics Division is Dr. B.P. Blasingame. Director of Engineering is Donald J. Atwood and APOLLO program director is Hugh Brady.

Key Raytheon officials in the APOLLO program include Justin J. Guidi, responsible for all NASA programs within Raytheon's Space and Information Systems Division; William R. Kurtz, APOLLO program manager; and Edwin R. Bradshaw, Jr., APOLLO engineering manager.

At Kollsman Instrument Corp., director of the APOLLO/LEM program is Arthur M. Ferraro and Stanley Millman is program manager for APOLLO optical subsystem while Horatio Dickerson is program manager for LEM optical subsystem.

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