be made. The fourth exploration probably would cover some particular feature noted during previous exploration, such as small craters, a volcanic cone, rock outcrop, or other surface feature. These would be explored, described, photographed and sampled in considerable detail. Should the astronaut decide to descend into a crater or operate behind a terrain feature out of line-of-sight of the LEM, he would emplace a small reflector so as to maintain voice communications with LEM.

Traverses now are considered for a maximum distance of approximately 1,000 ft. from LEM and maintaining line of sight view and communication, with the exceptions just mentioned. With considerable equipment being worn by the astronaut—including pressure suit and helmet, thermal protective overgarment and a meteoroid protective garment on top of this, for a total earth weight of approximately 100 lb.—there probably will be some requirement for mobility assistance.

Among aids being considered is a "Jacob's Staff," which would have fittings for mounting equipment such as a compass, telescope or sextant, would be striped to provide calibrations for later photo interpretation, and perhaps also have a container for carrying small tools or experiments. Another device is a lunar-walker, a collapsible aluminum-legged cage which the astronaut would grasp and which would give wide-legged stability over rough terrain. Such an aid could be fitted with canvas pockets for holding necessary tools, other equipment and sample bags. Although need for such walking aids has not yet been proven, experiments are continuing here with their development. Some medical personnel feel that there are still many unknowns about the metabolic requirements of a suitably garbed and equipment-laden astronaut, limited in his mobility and operating in a strange and harsh environment, that will require giving him as much assistance as is feasible. Other personnel, not so close to the critical medical aspects of such a mission, feel that these handicaps can be overcome by sufficient training prior to the flight.

Considerable research also is being done in areas of sample collection and preservation, since sample gathering and return will be among the high-priority aspects of the lunar landing mission. Exacting procedures for removing the proper samples from the surface, recording their position and environment, and avoiding contamination by organic or inorganic earth materials or contamination from other lunar samples are under study. Improper handling, collecting or packaging could result in destruction of much of the value to be obtained from samples.

Tools for this purpose, for the most part, do not appear to be available as off-the-shelf items and must be designed for size, weight, stowage and ease in handling. Much normal earth-geologist equipment is not suitable for use by the astronauts. A conventional geologist's hand lens, for example, is too small for the astronaut's handicapped dexterity and its field of view would be too limited. Hand-operated lunar terrain-coring devices also would require design for easier operation than earth counterparts, and should provide container shapes compatible with spacecraft storage areas formerly occupied by expendable items. This is necessary for optimum loading at minimum weight of the return vehicle.

Detail studies of sampling procedures embrace such considerations as what possible contamination of the lunar surface or atmosphere might be caused by the astronauts, the LEM spacecraft and its rocket motor exhaust.

More Apollo Guidance Flexibility Sought

Washington—Apollo guidance, navigation and control concepts have undergone a number of evolutionary changes intended to improve mission flexibility and reliability and to save weight and space in the spacecraft.

Some of these changes have resulted from more detailed studies of alternative solutions, while others stem from technical advances and experience gained since the Apollo program was launched several years ago.

For example, while it has always been planned to use both on-board equipment in the spacecraft and earth-based tracking facilities to establish vehicle position for navigation purposes, present plans call for heavier reliance on terrestrial facilities than was expected several years ago.

It was originally planned to carry spare black boxes and plug-in modules in the spacecraft to enable astronauts to perform on-board maintenance, but this concept has been largely abandoned. One reason is that to design avionics equipment for on-board maintenance not only increases its size and weight, but also makes it more susceptible to failure because it can not be hermetically sealed and requires more electrical connectors, according to Dr. Joseph F. Shea, manager of the Apollo Spacecraft Program Office.

Troubles encountered during the 34-hr. Mercury MA-9 flight revealed that in a zero-g environment, tiny droplets of fluid in the spacecraft are attracted to avionics equipments by their electrical fields. Once deposited on the surface, the fluid penetrates tiny openings more easily than on earth because surface tension and capillary forces are not restrained by gravity, Shea points out. To make matters worse, a pure oxygen environment in the spacecraft speeds up corrosion if there are acids or salts present in the fluid droplets.

In the initial Apollo design, the inertial and guidance subsystem being developed by the Massachusetts Institute of Technology's Instrumentation Laboratory (AW&ST Sept. 30, 1963, p. 32) fed its output signals through the Honeywell-developed stabilization and control subsystem to operate the service module propulsion engine and reaction jets. With the two subsystems connected in this "series" configuration, a failure in the Honeywell subsystem could incapacitate the guidance-navigation subsystem.

The series configuration now has been changed to better integrate the two subsystems while making them electrically independent, so that a failure in one does not affect the other. This was achieved by increasing the capability of the guidance-navigation computer so it could handle the stabilization and control tasks, thereby becoming the primary portion of the integrated guidance, navigation and control system. The Honeywell portion becomes the manual and semi-automatic control system and serves as a back-up to the other. The inertial measurement unit (gyro stabilized platform) portion of the MIT-developed system is being built by AC Spark Plug while the computer is being built by Raytheon.

This new independent but integrated design approach, referred to as the Block 2 design, will be used in all lunar flight models. If a malfunction should occur in the spacecraft guidance-navigation portion of the system, the astronauts aboard will be able to perform many of the guidance functions using the Honeywell portion. This illustrates the current philosophy of using two non-identical systems to achieve functional redundancy without actually carrying duplicate equipments on board, according to Paul Schrock, Apollo Test Directorate, NASA Headquarters.

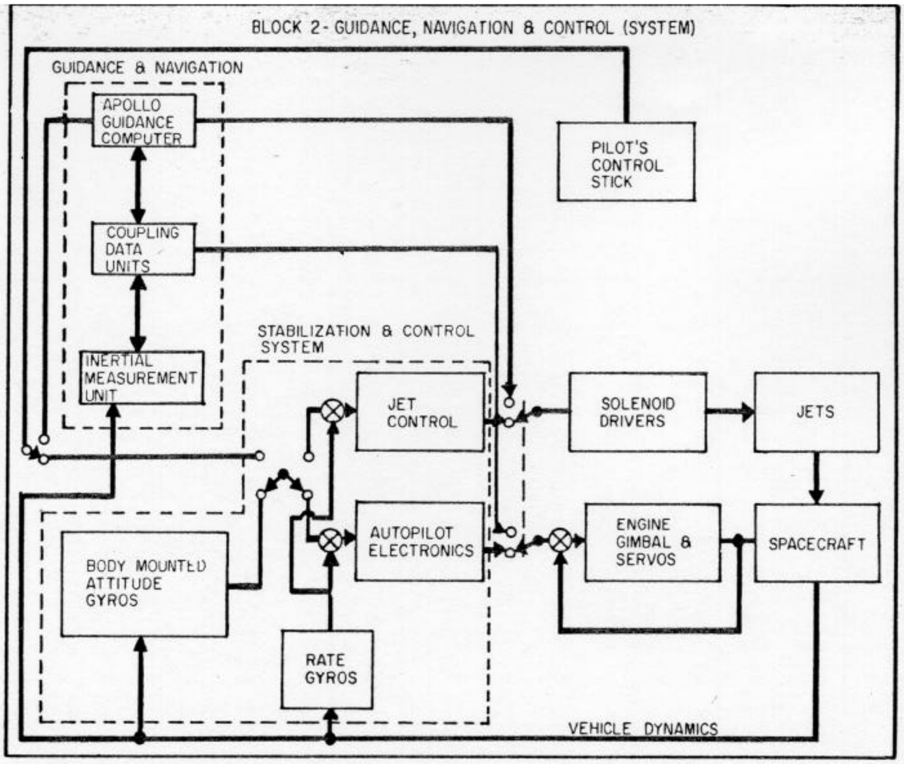
Experience obtained during the last several years also has demonstrated that the Apollo mission can lean more heavily on terrestrial tracking and computing facilities for guidance-navigation, providing still another form of redundancy with essentially no added weight aboard the spacecraft.

Although Schrock emphasizes that

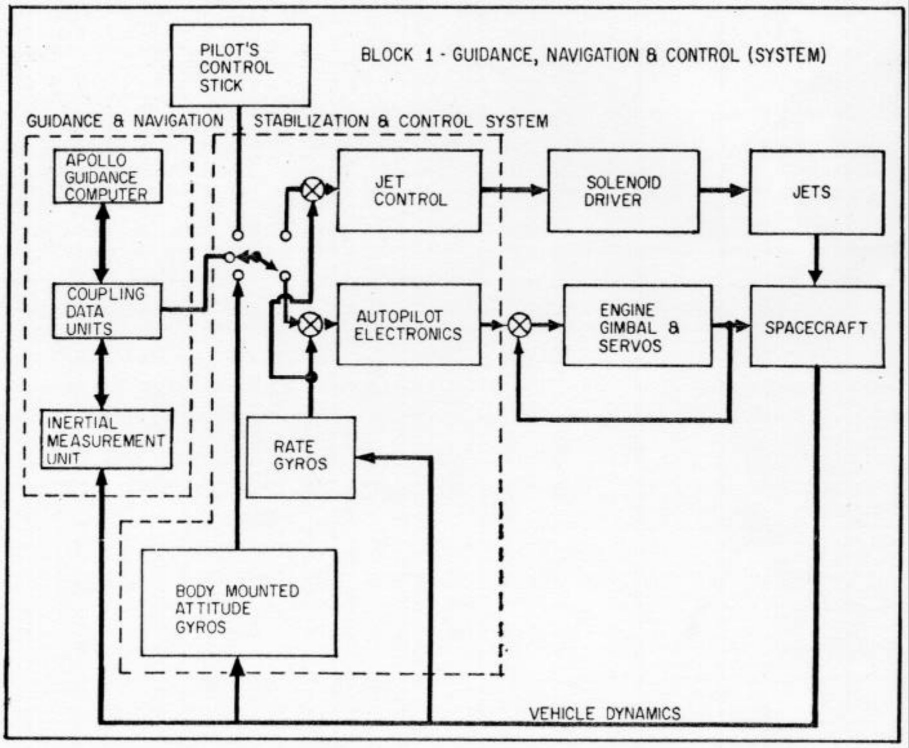
the use of terrestrial facilities had been intended since the inception of the program, "we have gained increased understanding of what terrestrial-based guidance can do," he says. A recent example is the accuracy with which Ranger 7 was guided to impact on the moon without on-board guidance.

Terrestrial-based equipment, having none of the size, weight or power constraints imposed on spacecraft hardware, being able to employ extensive redundancy and to have a team of experts on hand to perform maintenance, is not likely to encounter outages of sufficient duration to affect the mission adversely. On the other hand, terrestrial facilities can not be used when the spacecraft is behind the moon, and they are not as accurate as on-board spacecraft systems for terminal guidance in the vicinity of the moon, Schrock points out.

The two systems are viewed as complementary, with each having the capability of handling the mission in the event of a failure in the other. Schrock acknowledges that present plans call for greater dependence on terrestrial guidance facilities than first envisioned when the Apollo program was launched, but he says this represents only the same type of evolutionary change that has taken place elsewhere in the program.



LATEST DESIGN of Apollo spacecraft guidance, navigation and control system (above) in contrast to earlier version (below) completely separates guidance and control functions.



The digital computer used in the guidance and navigation subsystem provides an interesting example of this design evolution and of NASA's attempt to use innovations in the state-of-the-art once they have demonstrated the required reliability needed for so critical a mission.

The original version used an adaptation of the packaging and construction techniques proven in the Polaris missile guidance computer which MIT had developed earlier. The electrical design was based on "core transistor logic" (CTL) which minimizes the number of transistors required and has relatively low power consumption.

An important characteristic of the core transistor logic computer design is that power consumption is proportional to operating speed, which means the machine could be operated at relatively low speeds during long periods of the mission when there was little work load, with reduced power consumption, according to Dr. Robert C. Duncan, chief of guidance and control division at the Manned Spacecraft Center.

While other computer designs might have been smaller, lighter and faster, for the Apollo application the flexible computing speed and low power consumption seemed overriding considerations, according to Duncan.

At the time the Apollo digital computer design was started in 1961, the semiconductor microcircuit was beginning to emerge from the development laboratories. Its many potential advantages for Apollo made it too attractive to ignore, but it was too new and unproven to be used for the initial computer design. So, in the fall of 1961, MIT initiated studies of a microcircuit computer. This indicated that computer size and weight could be cut at least by half, and that memory cycle time could be reduced nearly as much with a net gain of about 150% in computer speed, according to Duncan. The attendant disadvantage would be an increase in power consumption from 35 w. to 100 w., which in time might be reduced, and the loss of the variable speed/variable power consumption.

As extensive tests by MIT and the microcircuit suppliers showed encouraging gains in reliability, and as predicted reductions in cost materialized, microcircuitry began to be introduced into the computer design, replacing some welded cordwood packages using conventional components.

But to gain the full potential required

a basic computer redesign. About two years ago the commitment was made to proceed with an essentially all-microcircuit computer design. This would use a single universal NOR gate logic element, employing modified direct coupled transistor logic (DCTL), which would permit vendors to concentrate their efforts on producing a reliable microcircuit. The high quantities of the single logic circuit would offer lower costs, provide large quantities of reliability data and could be produced by more than a single supplier. Each NOR gate was to be packaged in a TO-47 can.

Because two microcircuit computers could be accommodated in the size and weight previously allocated to the original computer and because of concern over the reliability of a digital computer, it was decided about a year ago to install two identical microcircuit machines in the Apollo command module, one of which would serve as a standby.

During the past year, life tests conducted by MIT and by vendors have demonstrated increasing microcircuit reliability. In seven test computers, a total of 40 million microcircuit hours have been accumulated with a failure rate of less than 0.05 per million hours, at a 90% confidence level, according to Duncan.

This practical demonstration of microcircuit computer reliability, coupled with the new operational independence of the guidance-navigation and stabilization-control subsystems and increased reliance on terrestrial-based facilities, recently prompted NASA to eliminate the second (back-up) guidance computer from Apollo.

In the Block 2 lunar flight system, the computer will be constructed from microcircuits fabricated by epitaxial rather than diffusion techniques, and two NOR gates will be mounted in a single flat-pack enclosure instead of the single gate in a TO-47 can. The two NOR gates placed in a single flat-pack can share common power and ground leads, saving external connections and improving reliability. The new flat-packs also are expected to shave 20 lb. from the computer's weight, bringing it down to 50 lb. Development of lower-power logic circuits will cut computer consumption to 75 w., about a third less than the original microcircuit model.

The decision to abandon on-board maintenance by means of plug-in modules has made it possible to provide better hermetic sealing of electrical connectors and to improve internal computer cooling, both expected to enhance reliability.

Present plans call for construction of 20 Block 1 computers and 25 sets of Block 2 computers for use in the command module and in the Lunar Excursion Module. The first Block 2 machine is scheduled for delivery next summer.