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Man's dream to travel into space had a glimmering of reality on a cold March day in 1926. Dr. Robert Goddard, bound up in a heavy muffler and a woolen cap, took his homemade liquid fuel rocket to a field in Worcester, Massachusetts and touched off the new era of space exploration. As the 10 foot rocket lifted off the ground, Dr. Goddard breathlessly said what many Americans have subsequently thought, watching today's giant rockets reach into space—"I think I'll get the hell out of here."

Travel into space still has its aspects of Buck Rogers and unreality, but it isn't just the awe inspiring takeoff of great rockets that is bringing the moon and beyond within man's reach. Dr. Goddard developed the rockets that could propel a payload into orbit, but it has taken the computer, with all of its own aspects of the future, to make current space flight a reality.

In a National Aeronautics and Space Administration report to Congress, NASA said, "Operating in space would not be possible at all without computers." Space flight, in every phase of a mission—concept, design, development, test, preflight checkout, launch, injection into orbit, stabilization and control, guidance, navigation, reentry, recovery, subsequent evaluation of data—is dependent on the power of the computer to process data.

There are two different classifications of computers used for space exploration: the groundbased, or "downstairs" computer and the onboard, "flying" computer. From launch through recovery the two computers must operate as a team, with the smaller onboard computer relaying flight information for immediate analysis to its bigger brother downstairs.

THE COMPUTER "UPSTAIRS"

Since, with today's chemical propellents, about 1000 pounds of thrust is required to orbit one pound of payload, the spaceborne computer must be light and compact. Therefore, the capacity of the "flying" computer is far less than the groundbased installation. Besides, the flying system must be rugged enough to withstand the environment of space—wide varieties of temperature, "hard" radiation, meteorite impact, vacuum, and the stresses of launch and reentry. Through all this, the computer must be reliable.

Downstairs, if some of the components in a computer breakdown, a service engineer can quickly repair or replace them. But service engineers don't travel into space. If an onboard computer has a component failure, the machine should still be able to operate at some level of efficiency. That has been the biggest problem with spaceborne computers—to build a machine that is reliable and yet, allowing for the fact that some components might fail, to maximize the efficiency of remaining components.

Spaceborne, the computer has the added burden of operating in "real-time." In order to perform accurate control operations or be an effective partner with an astronaut in space, computer processed input is required every few milliseconds. Real-time operation imposes greater performance demands on both hardware and software and places tight constraints on the flexibility of the system.

Programming, for example, must be exact in a real-time system since the price of failure is so high. Recently, a rocket launched toward space headed straight from its launching pad toward Brazil because a hyphen had been left out of the control program. The rocket was destroyed and the mission set back a few months. And the consequences of a miniscule error in an upstairs computer program can be even more serious.

During one of the Mercury flights, U. S. ships circled the projected landing area. But the astronaut was bobbing around in his spacecraft some 50 miles downrange. The calculations in the reentry program included a figure of 365 days in a year (the actual number is close to 365¼). That miscalculation accounted for the 50 mile mistake.

To get an idea of the requirements for "flying" computers, the designs of MIT's Apollo, IBM's Saturn computers and IBM's new 4-Pi System provide some sort of guide. These systems are among the most complex "flying" computers being worked on today. An important aspect of these machines is the large amount of storage used for programs and the relatively small amount of memory used for data. This reflects the types of problems the machines are solving, such as navigation, guidance, and control.

But the memory size requirements have been boosted substantially in the past few years. Apollo has gone through two overall system changes. Early in the project, Apollo had only 12,000 words of program storage. Its new design holds 36,000 words, and more can be used if necessary. The

Saturn and middle-size 4-Pi computers have roughly equivalent memory sizes, and all of these systems are about the same in speed and power.

FUTURE SYSTEMS

Recently NASA outlined its future systems needs as space missions are measured, not in days in orbit, but in years of travel. Gene G. Mannella of NASA's Electronics Research Center in Cambridge, Massachusetts, says, "Techniques must be developed which will permit elementary decision functions aboard unmanned vehicles for alternation of mission profiles without continuous recourse to human intervention and, ultimately, a more sophisticated type of integrated experiments package in which the instrumentation comprises a laboratory which is controlled continuously by an onboard computer."

The computer, according to Mr. Mannella, should be a multiprocessor system with a "pool of identical memory and processing elements switched into appropriate combinations as one or more tasks demand service." The multiprocessor organization has the advantage of being able to serve many different functions on a mission without being subject to the failure of the single processor. Two key hardware advances that are paving the way for multiprocessing are microelectric and batch fabrication techniques. "Software," according to Mr. Mannella, "particularly computer languages and programming concepts, must advance correspondingly."

At present, most spaceborne computer programming is accomplished using a machine language specifically designed for the individual computer. But projects are now underway to develop a formal language specification for a procedure-oriented space programming language.

And, according to three IBM scientists, Mr. Mannella's projected unmanned, computer-directed space laboratory is a valid possibility by the early 1970's. Donald G. Bourke, Lloyd Nalaboff, and Dr. Paul Tobias, of IBM Federal Systems Division's West Coast Operations made the prediction last month at a meeting of the American Institute of Aeronautics and Astronautics. Bourke, who addressed the meeting, said, "The key to the Computer-Managed Laboratory concept is the use of programmable logic, which uses computer logic and laboratory elements that can be automatically recombined while in space to conduct difficult experiments." If the result of one experiment suggests that a second would be impractical, the onboard computer would bypass it and combine elements to select a more logical follow-on experiment.

COMMUNICATIONS

Better communication between the orbiting satellite and the ground installation has also taken a forward step recently. The present Manned Space Flight Network system consists of 14 ground stations, five ships and eight aircraft. Yet, there are long periods when spacecraft are not in contact with any station.

The communications gaps were a problem during the Gemini 8 flight when the spacecraft was in trouble and out of contact with ground control. A few weeks ago, Motorola demonstrated a new communications system, developed under a NASA contract, which would provide continuous coverage between ground control and low-orbiting spacecraft.

According to Robert Hunting, Director of the Lunar Module Relay experiment study, "The system employs three synchronous relay satellites and permits simultaneous two-way voice, telemetry data, television, and range rate transmission." In addition to continuous communication between orbiting astronauts and the ground, this new system may also increase the efficiency of all our satellites, allowing ground installations to receive data more quickly.

THE "DOWNSTAIRS" COMPUTER

Groundbased computers are being used for aerospace applications in several thousand Government, industrial, research, and university facilities throughout the world. They are most widely used for post-flight analysis, but one of the most important jobs of the "downstairs" computer is design.

"The scarcest resource in the aerospace field is the creativity of the human mind," says Dr. Barry Boehm who manages engineering computing services for the RAND Corporation. "One solution is to relieve the aerospace engineer or manager of some of his 'rotework.'" Dr. Boehm says, "This is where the computer comes in. . . . Properly programmed, it can take care of the rotework involved in solving a problem and leave one free to concentrate on the creative aspects. Furthermore, its tremendous symbol manipulating power affords new dimensions to creativity which man alone could never attain."

For example, in the Apollo program, CUC has been developing programs using information gathered in testing human reactions to simulated space flight. The data from the tests is programmed to provide parameters for the astronaut's flight gear.

Design problems involving the transient motion of a boundary or interface are a considerable challenge to the aerospace scientist. Usually, these "moving boundary" problems don't have an analytic solution, so it has been important to develop accurate numerical methods for treating the problem.

An example of this kind of problem is in the ablation which occurs in the nose cone of a spacecraft reentering the earth's atmosphere. CUC numerical analysts developed a program and the numerical procedures for solving this ablation problem.

To calculate the temperature rise inside the space vehicle, CUC analysts determined the amount of surface material ablated and the temperature distribution through the successive layers beneath the surface. A moving finite difference mesh, close-packed near the surface was necessary to solve the problem accurately. In the CUC program, meshpoints are chosen with an exponential variation of spacing near the surface. Using a proper finite difference analog of one of two equations, accurate surface temperature profiles and surface velocities are determined.

POST-FLIGHT ANALYSIS

Once computers have defined the concept, been used to design the components of the mission, controlled the craft and gathered the data to be transmitted, the biggest job begins.

This job is the reduction of the observations taken by the onboard equipment. Massive amounts of data are received and must be reduced to usable form.

For instance, CUC has written the world's largest program, for the Navy, to reduce data received from geodetic satellites. It's currently estimated that these programs will run about 2,000 hours per year on the STRETCH computer. The program has more than 200,000 instructions. A typical run will process 60,000 observations and have 500 parameters to be calculated.

Using a combination of 30 such runs—well over a million observations—the surface geometry of the Earth can now be found to closer than 10 meters, wherever a receiving station can be set. This has given rise to a new technique in geodesy involving mobile stations. The stations are dropped off on remote islands to record satellite observations for six to eight weeks, then they are moved on. The data they produce serves to pinpoint locations far better than any previous method. The most abundant and accurate data are Doppler shifts which define line-of-sight velocities.

As is very common in space projects, even post-flight reduction of data from the onboard computer often takes place during the flight and within strict time limits. During the flight of the first Lunar Orbiter, CUC programs took the data as it came from the vehicle to calculate an improved orbit, and the first detailed analysis of the gravitational field of the moon. The program processed the data from the first four days of orbit, as the data was received, to decide if the spacecraft could be safely taken to a lower orbit above the moon. The data had to be processed as soon as it was received, practically in real-time, as the gravitational field of the moon was unknown and errors in the field estimate could substantially shorten the useful life of the Lunar Orbiter.

On this and all the subsequent Lunar Orbiter flights the programs have performed more than just one operation. But the prime mission of Lunar Orbiter is photography. As the spacecraft moves in its orbit, a high-speed camera takes 8 or 16 frames successively over a short interval. These frames, taken from slightly different points in the orbit, produce photographs of a piece of the lunar surface. A number of the photographs will overlap and contain common points. CUC programs use a fitting procedure to produce a three-dimensional view of the lunar surface that corresponds to a particular sequence of photographs. Additionally, the program calculates corrections to the attitude of the spacecraft to get a more accurate fix on where it points in space.

THE MAN IN THE MOON—AND BEYOND

Within the next couple of years the man in the moon will look a lot like the boy next door. And after the projected manned lunar landing, space experts predict far more challenging and complex tasks. "By the year 2000 we will undoubtedly have a sizeable operation on the moon, we will have achieved a manned Mars landing and it's entirely possible we will have flown with men to the outer planets," forecasts Dr. Werner von Braun.

The biggest obstacle will be money. Since recent budgets haven't expanded in line with costs, there won't be enough money to pursue planetary and scientific work at a rate of which the United States is technologically capable. Also, a driving force behind the U. S. space program is national prestige—the space race with Russia—which may be satisfied by a manned lunar landing. In effect, the near future will be an exciting, but economy-ridden period of space exploration, according to Robert H. Gray, Director of Unmanned Launch Operations at NASA's Kennedy Space Center. Mr. Gray says, "The goal will be to use proven hardware we have fought for years to make reliable and cheap."

Much of the slack will be taken up by industry and special interest groups. In coming decades, civilian satellites will do more and more to help man live, work, and learn on Earth. Besides communications satellites, there will be improved weather satellites to help meteorologists extend the accuracy of their 24 and 48 hour forecasts to as long as two weeks.

Ultimately, a constant weather watch will be provided by four high altitude synchronous satellites. These satellites, revolving at the same rate as the Earth, will photograph the entire globe every 20 minutes. As a result, meteorologists will be able to detect the embryonic development of storms and warn people well in advance of weather dangers.

Civilian navigation and traffic-control satellites will guide planes and help them land at crowded terminals. Ships will use a similar system. A three satellite complex will enable aircraft and ships to determine their positions within about 1.5 miles.

Orbiting satellites will also be used to help make surface maps, detect forest fires, measure crop yields, and survey other natural resources on earth. According to NASA expert Peter Badgley, "A well-organized system could be operating by the mid-1970's." The satellites will effect savings of $3 million for timber surveys and $32 million for forest fire prevention. Besides the economies of these satellite systems, speed will be an advantage. Ships can take years to survey one sea; a satellite could do important elements of the job in only days. It would receive and record measurements of ocean depths, currents, fish movements, etc. from instrumented buoys in the water and then transmit the information to groundbased computer installations.

Other possible Earth-satellite services: population estimates (made from photographs of cities and rural regions); animal migration studies; and orbiting telescopes, freed from the blurring affect of the Earth's atmosphere, will transmit better pictures of outer space to earthbound astronomers. The Orbiting Astronomical Observatory, planned for launch in mid-1968, can carry a 36 inch reflecting telescope and may revolutionize our knowledge of stellar U-V and X-ray spectra.

One exciting new area of the computer-aerospace partnership lies in projected flights to the outer planets—a feat that would be impossible without the use of computers. A spacecraft can start from Earth, fly by Mars at a close distance and keep on going to Jupiter. The effect of the gravitational field of Jupiter, as the spacecraft does the fly-by, gives added velocity, speeding it on to Saturn and Uranus with the same effect; out to the edges of our solar system and beyond by 1990.

It's only recently been emphasized that the gravitational swing-by can be used for an increase in speed. And it's such a complex problem that doing the parametric studies would be inconceivable without computers.

But then, the entire space program as it exists today would be inconceivable without computers—as inconceivable as Dr. Goddard's homemade rocket reaching the moon.

Charles Sheffield is CUC Corporate Technical Director in charge of Scientific Computing. He joined Computer Usage in 1962 and was named Manager of the company's Washington Scientific Office in 1966 — a position he still holds.

Mr. Sheffield holds an M.A. degree with first-class honors in Mathematics and Theoretical Physics from St. John's College of Cambridge University. At Cambridge he was a Hoare Exhibitioner in 1955 and a Wrangler in 1957. Mr. Sheffield is a Fellow of the British Interplanetary Society and a member of the American Institute of Aeronautics and Astronautics, the British Computer Society and the Association for Computing Machinery.

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