NASA's new Electronics Research Center

It will stimulate and support a broad national attack on space electronics – guidance, control, communications, instrumentation, data processing, and system reliability

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During the last two years the term *space electronics* has received increasing prominence due in part to the public attention given to NASA's proposal to Congress for a new Electronics Research Center. This new Center, actually established on Sept. 1, 1964, represents part of a long-range NASA effort to upgrade its electronics-research capability, an effort which encompasses all NASA centers, and will draw upon the country's industrial and university resources. This article cites some reasons for increasing electronics research to meet the future needs of the space program and describes the intent and initial form of the center.

What do we mean by *space electronics*? And what is so different about it? The term "electronics" was defined well by the eminent Provost of Stanford Univ., F. E. Terman:

> "Electronics is the science and technology that deals with the devices that sense, collect, process, and transmit information and either control machines or present the information to humans for their direct use. Electronics may encompass both traditional equipment in which conduction of electrons takes place through a vacuum, gas, or semiconductor, or equipment that handles information through some other basic mechanism."

In other words, electronics involves the generation and handling of information and includes instrumentation, communications, guidance and control, and data processing.

The large number of space vehicles launched by this country have obviously contained much electronic equipment. In large measure, however, this has been designed for other applications, and not particularly for space use. Much of it was originally designed for military use in an Earth environment. Although designed for severe conditions, military or commercial equipments are intended to satisfy primarily an environment which is recognized as *different* from the space environment. The term *space electronics* has come to denote equipment and components specifically designed for use in the space environment. Since the space environment itself is continually being redefined as we progress in its exploration, space electronics represents a dynamic technology which requires as much emphasis on research as on development and rapid exploitation of the concept of laboratory experimentation into the flight application.

Taking into account space-flight requirements expected over the next 10-20 yr, we might cite some specific examples of operating environmental conditions in space which are different from those which we normally encounter on Earth.

1. Both high- and low-temperature extremes as spacecraft explore the entire solar system. Spacecraft flying close to the Sun will experience temperatures on the order of thousands of degrees.
2. Severe or hard vacuum.
3. Weightlessness, which may not affect electrons *per se* but can affect mechanical or other physical characteristics of electronic equipment.
4. Radiation, which we know already from experience to be damaging and about which we are continually learning more.
5. Power limitations, since the power sources in a spacecraft are self-contained and conservative limits must be imposed on power drain.
6. Engineering and economic limitations on size and weight.
7. Long, unattended equipment lifetimes, particularly as we probe deeper into space.
8. Emphasis on reliability as opposed to maintainability. Periodic service checks and routine maintenance cannot be made on equipment

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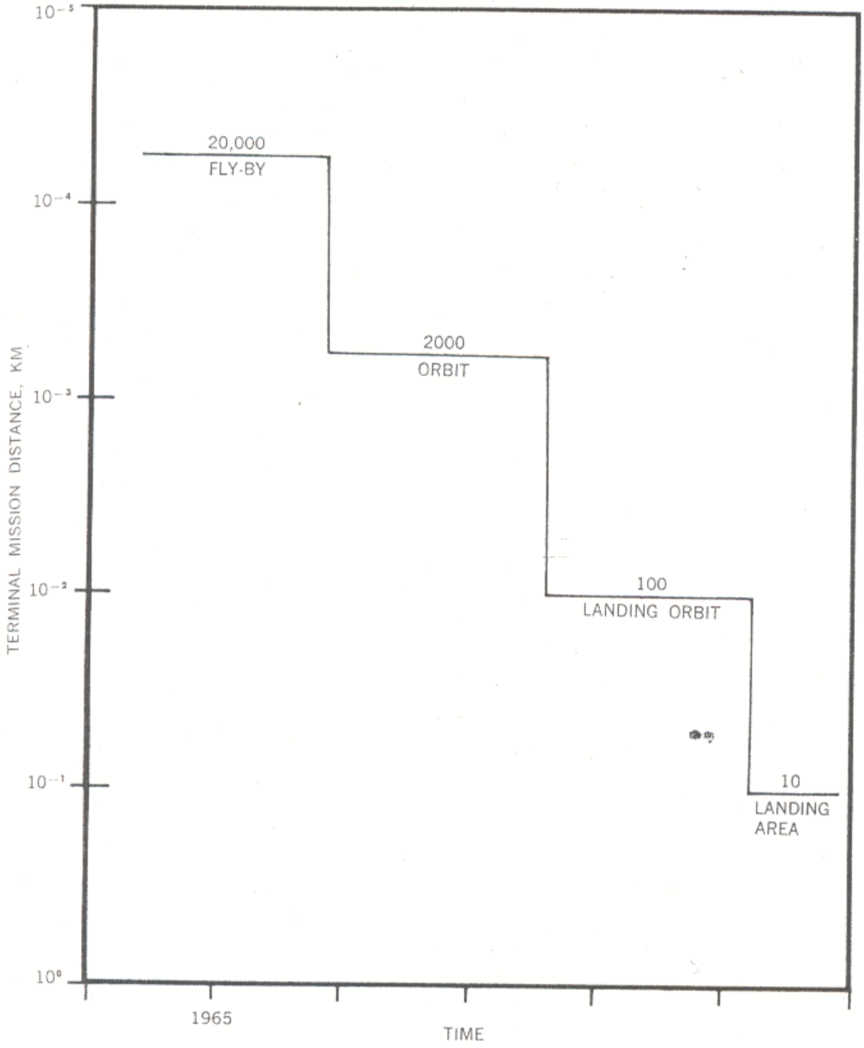
GUIDANCE REQUIREMENTS TO NEAR PLANETS



flying through space. This leads to more-stringent reliability requirements but allows greater flexibility in packaging and mechanical design, since periodic access to equipment is not required.

Performance objectives and requirements for space electronic equipment also differ from those met on Earth, as can be illustrated by the following examples:

1. *Guidance*. Guidance systems must perform during high-g launch, followed by a period of weightlessness, then often by a high-g re-entry. During long flight times, propulsive forces may be very small, as with electric propulsion, and difficult for guidance equipment to separate from disturbing forces.

The graph at the top shows the guidance accuracy required for various planetary missions in terms of tolerable miss distance at the target. (Trends are shown rather than the exact time period when advanced requirements can be met on this and the following figures, since the state of technology at any moment depends on many factors, including effort and resources previously invested.) The stringent angular aiming accuracies for advanced missions will undoubtedly lead to terminal guidance systems for interplanetary missions, as well as to increased demands for midcourse accuracy.

2. *Control*. Self-contained stabilization and control systems must function for long periods of stabilized flight without aerodynamic damping. Typical duty cycles consist of short periods of slewing followed by precise control of vehicle attitude or tracking instruments. Aiming accuracy and repeatability requirements for celestial navigation in space place special demands on the control of tracking instruments because of the slow rates of movement between spacecraft and celestial bodies and resultant small angular deviation rates.

Top graph on page 60 illustrates the precision with which spacecraft instruments must be aimed and controlled in various space missions. Current operational requirements can be met with pointing precision on the order of 1 to 10^{-1} deg. To observe an area on the Sun's surface 20 arc-sec in diameter, a future orbiting solar observatory would require a pointing accuracy on the order of 10^{-3} deg. Future orbiting astronomical observatories will require still greater precision, on the order of 10^{-4} deg. These two requirements represent different conceptual solutions as well as different accuracies; while the OAO can lock on a star and track with a closed-loop control system, a future OSO must be preprogrammed and essentially point in response to a command.

Advanced systems such as large orbiting telescopes, or deep-space laser communication systems will, if they are to realize their full potential, require still higher pointing accuracies, on the order of 10^{-5} deg.

3. *Communications*. Spacecraft-to-Earth communication systems must solve the problem of sheer distance, since the performance of a radio-communications link varies inversely as the square of the transmission distance. The expression for power received on Earth from a spacecraft:

$$P_{RE} = \frac{P_{SC} \cdot G_{SC} \cdot A_{RE}}{4\pi R^2}$$

where P_{RE} = received power at the Earth-based receiving station; R = transmission distance; P_{SC} = spacecraft transmitter power; G_{SC} = gain of spacecraft antenna (proportional to cross-sectional area of the antenna and inversely proportional to the square of the wavelength); and A_{RE} = effective cross-sectional area of Earth-based receiving antenna.

The technical challenges offered in improving the spacecraft factors P_{SC} and G_{SC} to compensate for increased range involve severe constraints on spacecraft size and weight. Despite these, significant future improvements are possible through improved power transmitting devices, judicious choice of frequencies, furlable antennas, and careful spacecraft system tradeoffs.

At the Earth-based receiving station, weight and size are not as critical. While some improvement can be made in receiver design to reduce the detectable level of received power, a large payoff is potentially available by increasing the equivalent cross-sectional area of the receiving antenna, the term A_{RE}.

Straightforward methods of realizing this potential include a large single antenna or a group of smaller antennas phased to approximate the performance of a larger single dish. Cost of construction and installation, as well as technical difficulty, must be taken into consideration for either of these two approaches. The graph at bottom shows the trend of cost versus effective antenna diameter for the two.

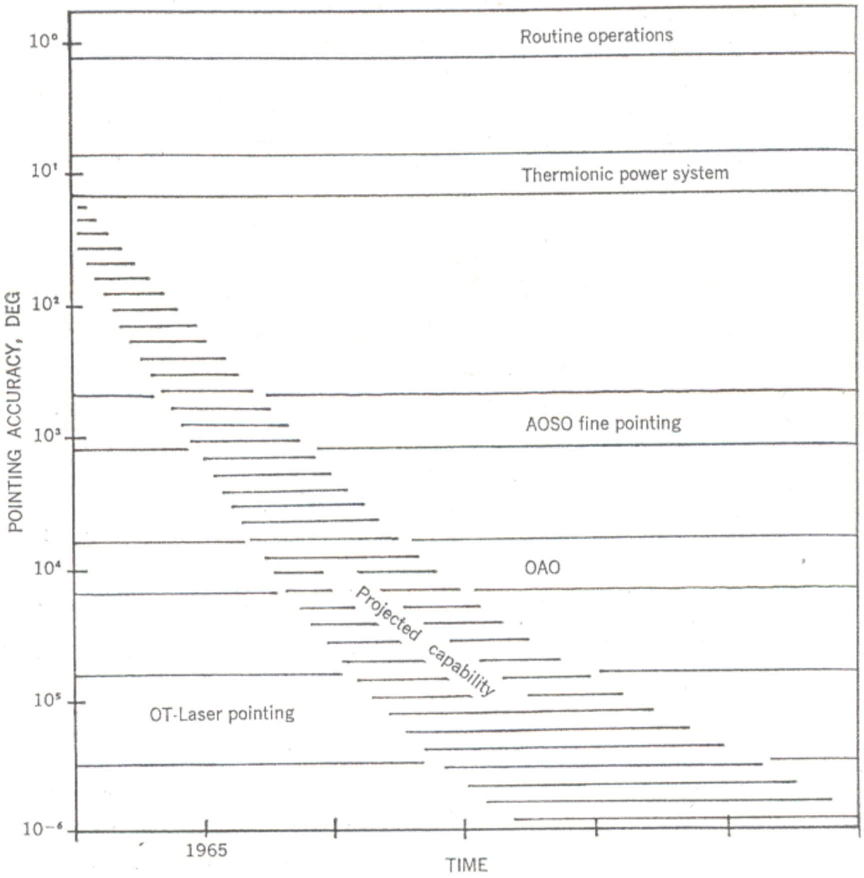
In actual operation, the penalty for increased range is taken in increased message time. For example, it was possible for Ranger to transmit within about 15 min more than 6000 good-quality TV pictures over 230,000 mi. On the other hand, Mariner IV, launched by the same booster Atlas-Agena and now approaching Mars, will transmit its pictures to Earth over a distance of approximately 150-million mi. at planetary encounter. Each pulse will require more than 13 min to reach Earth, and a single TV picture from Mariner will require about 8 1/3 hr of transmission time. The transmission time of radio signals, traveling through space with the speed of light, has often been cited as the critical problem of space communications. This example illustrates that the channel capacity or, correspondingly, the time span from start to finish of a message presents a greater problem in deep space, where real-time communication is not possible.

Unlike signal propagation time, the message time or data rate can be improved by technological advances, as indicated in top graph on page 61. Data rate is shown in bits/sec for a typical planetary distance, together with the mission capabilities represented by various bit rates.

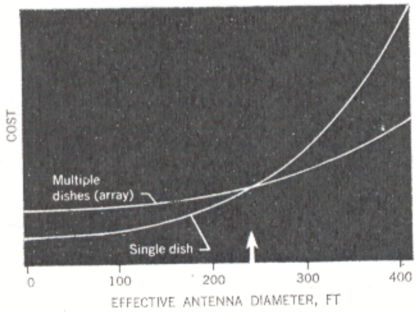
Further improvements require research and advanced technology effort, with great potential gains available from use of optical or sub-millimeter frequencies. Relay stations and application of new technologies to over-all communication systems offer potential improvements by optimizing potential system tradeoffs between weight, power, message structure, and frequency selection.

4. *Instrumentation.* Instruments familiar in concept often must be designed differently for space use. The name of the instrument may even be the same, for example, a particle counter; yet the number and velocity of particles it counts and its principle of detection may be quite different from on Earth. The magnetometer on Earth will be designed to measure small variations in a large magnetic field. For space applications, however, it may be configured to measure the absolute value of a small magnetic field.

POINTING SENSOR REQUIREMENTS



ONE VS. MULTIPLE ANTENNA COSTS



In keeping with ground-based digital computers and digital Pulse Code Modulated telemetry, a natural space application trend is towards direct digital readout instruments. By eliminating the analog-to-digital conversion steps, this trend will lead to simpler, more reliable, and possibly more accurate instrumentation.

5. *Data Processing.* While some applications of data processing require extremely high speed and others require very large memory, space requirements usually fall between the two extremes. For onboard spacecraft computation, the resistance to radiation of pneumatic and hydraulic components present an attractive potential. They may, as a consequence, find application in space computers earlier than in Earth-based ones.

As already shown, the communications data rate is a limiting parameter in deep-space exploration. Moreover, as our large boosters come into operation and larger payloads with more instruments are launched, it can be expected that saturation of communication channels could become a problem even in near-space exploration. We can expect increasing amounts of data to be competing for a limited number of telemetry channels, ground-based computers, and human interpreters. Whether exploring deep or near space, making scientific or engineering measurements, we will find it important to make every data bit transmitted back to Earth contain the maximum amount of *information.* Reducing the required channel capacity for a TV video picture can be done by sending only information that differs from the last picture, rather than transmitting a completely new picture each time.

Onboard data processing will become increasingly important to separate out and interpret meaningful information before transmission over the communications channel. As numbers of spacecraft in operation increase, as well as the data rate from each, onboard data reduction by techniques such as pattern recognition, statistical moment generation and logical analysis will become a performance requirement of increasing importance.

6. *Reliability.* The economic, practical use of space will necessitate vehi-

cles operating in a very hostile environment for as long as several years without attention or maintenance, as indicated by mission lifetime requirements for planetary exploration in bottom graph here. If the performance of the entire system depends on each and every part functioning, the desired cumulative reliability may never be achieved. *System* reliability is the important parameter, and it necessitates investigation of such approaches as self-checking and self-organizing concepts of design.

Most space systems for many years will be few-of-a-kind items. Lack of production follow-on rules out the normal opportunity to isolate and correct faults as operational experience grows. Besides statistical analysis, intensive investigation will therefore be required into the basic mechanisms of failure, together with quick feedback of results into component and system design.

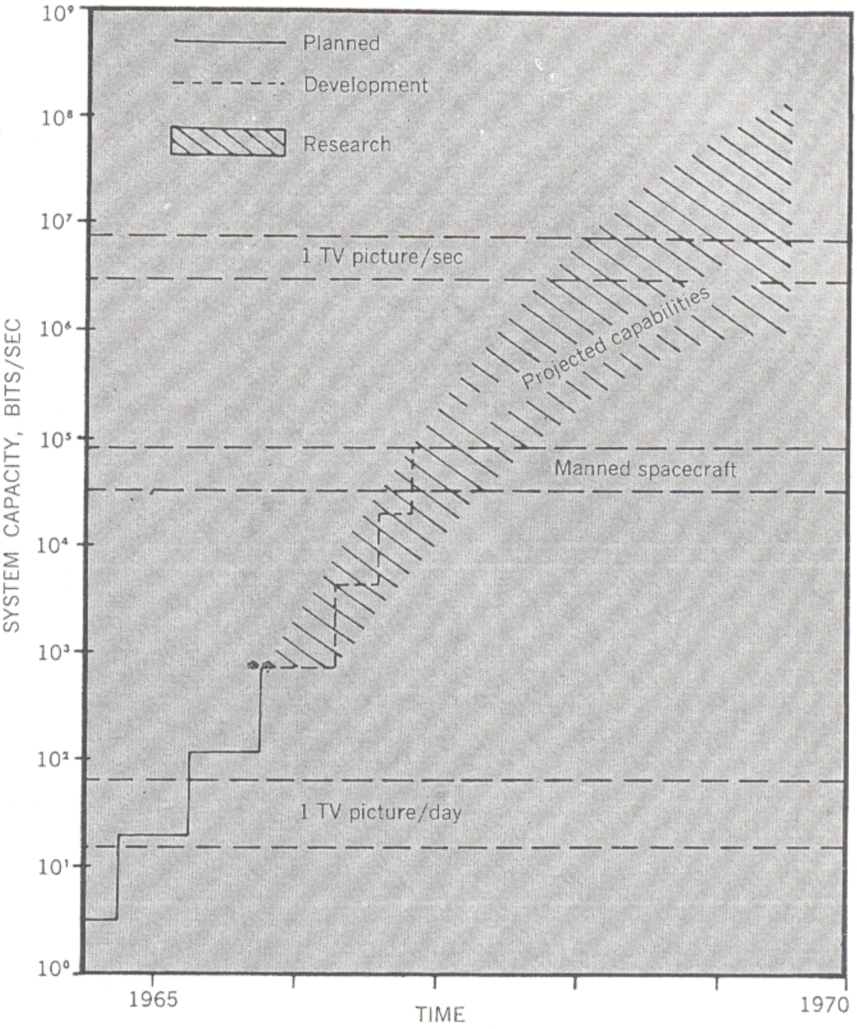
In terms of environmental and performance, *space electronics* is different. It represents a relatively new field. There is no pipeline filled with proven techniques, components, and practices that can be used to build envisioned operational systems, and there is little likelihood these will develop independently. Space-qualified electronic components and systems, once achieved, represents a limited market at present, and there is little incentive for industrial firms to invest heavily in research and development to provide them.

As a first step in seeking a solution to this problem NASA established an Electronics and Control Div. in its Headquarters Office of Advanced Research and Technology in November 1961. This Division was charged with formulating a research program in space and aeronautical electronics that would attract the best capabilities of universities, industry, and nonprofit organizations. It was directed, moreover, to investigate how in-house competence in electronics research could be built up in order that NASA might have the capability to serve as a catalyst, to communicate with the scientific and engineering community, to define requirements, and to guide and evaluate research effort by university and industrial laboratories.

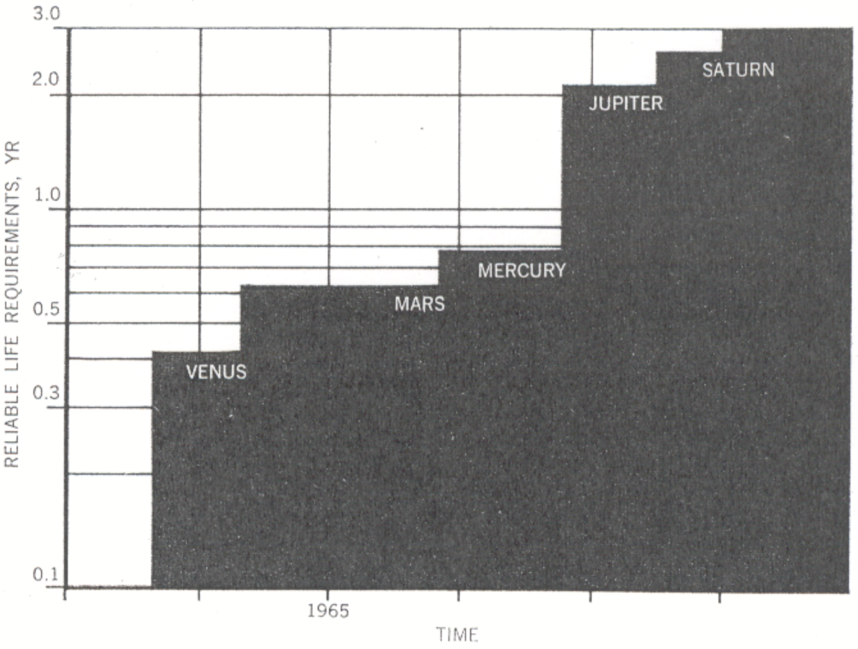
By building on pockets of capability already in its existing centers, electronics research effort by NASA since 1961 has increased markedly, actually by an annual budgetary factor of 14, comparing Fiscal Years 1962 and 1964. This increase, while overshadowed by public attention given the proposal for a new Electronics Research Center (ERC), shows priority

PROJECTED COMMUNICATION REQUIREMENTS FOR NEAR PLANETS

Unlike signal-propagation time, message time, or data rate, can be improved by technological advances. Data rate appears below as bits/sec for a typical planetary distance of 240-million mi., with mission capabilities represented by various bit rates.



RELIABILITY REQUIREMENTS FOR FUTURE PLANETARY MISSIONS



given by NASA to increased effort in space electronics research.

Even with ERC, a healthy capability in electronics research will be desirable at each of the NASA centers to enhance intra-NASA communications and to foster a balanced program of basic, applied, and experimental research. Before ERC was established, the electronics-research effort at the other NASA centers had largely been built up to the level desired. Future expansion will take place primarily at ERC, which, when fully developed, will be the major NASA center conducting electronics research.

The new Center will be a relatively small but highly qualified organization. It will aim primarily at acquiring knowledge and improving technology, rather than procurement and development of large flight systems. The exact function of the Center and its relation to the total NASA operations will be as follows.

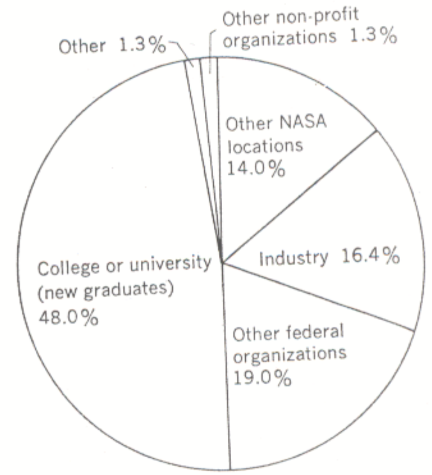
First, the ERC will manage grants and contracts on advanced research in electronics, with feedback of results through the Center to facilitate the rapid utilization of breakthroughs and for guidance in the entire space effort.

Second, it will carry out a program of in-house research designed to attack important research areas and to provide the basis for assembly of a staff of highest technical competence.

To accomplish ERC planning, an Electronics Research Task Group (ERTG) was established in January 1963 at NASA Headquarters. When ERC was established on Sept. 1, 1964, ERTG transferred to Boston and joined forces with the regional NASA North Eastern Office to form an initial cadre of 70.

By 1969, ERC will have a staff of 2100, of whom approximately 900 will be scientific or engineering professionals. The graph at bottom shows the anticipated cumulative yearly personnel growth. The pie chart shown here gives a breakdown of expected sources from which professional personnel will be drawn. ERC intends initially to staff heavily from the top down, concentrating early recruitment efforts toward attracting top research personnel. This will be followed by concentrated recruiting at the fresh-out-of-college level. Half the total professional staff will come directly from colleges or universities.

EXPECTED SOURCES OF PROFESSIONAL PERSONNEL



This idea of attracting college graduates and upgrading their education while immersing them in a research environment weighed heavily in the initial NASA decision to locate ERC in Greater Boston.

After further review, an urban site was chosen, close to MIT and Harvard, near the center of gravity of the vast academic resources of that area. A suburban auxiliary site, to be selected at a later date, will be used for sensitive laboratory testing and high-powered transmitting ranges, such as will be required for radar and laser experimentation.

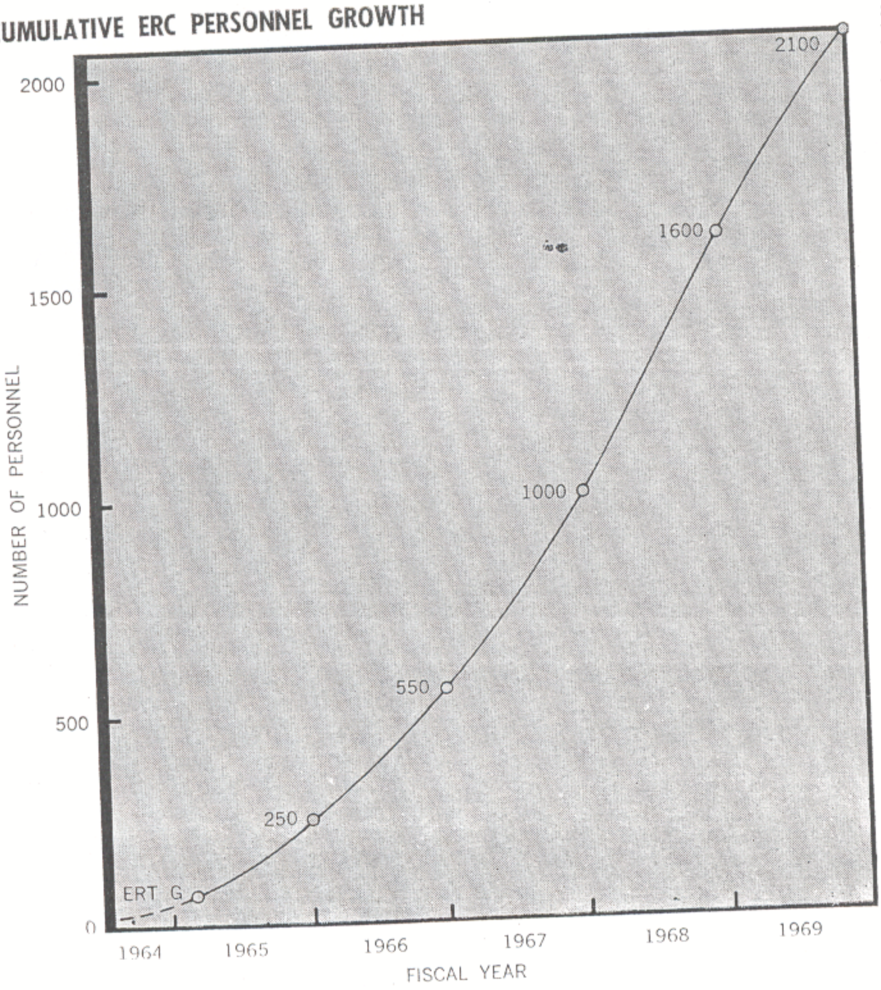
The facilities at the main urban site will consist of 10 laboratories, together with an Engineering and Administration building. The laboratories, listed below in order of construction, give an indication of the scope of ERC effort:

Qualifications and Standards Lab
Electronic Components Lab
Space Guidance Lab
Microwave Radiation Lab
Space Optics Lab
Computer Research Lab
Systems Lab
Instrument Research Lab
Control, Information Systems Lab
Power Conditioning and Distribution Lab

Research operations in each of these laboratories, which were planned by the Electronics Research Task Group, are already underway in temporary rental quarters near the permanent site. Both contracted research and in-house laboratory investigations will be expanded over the next few years in all laboratories to make an orderly transition from temporary to permanent facilities.

The research program, which amounts to approximately $2 million in Fiscal Year 1965, will expand until it reaches $50 million in Fiscal Year 1969. Of this, $42 million will be expended for contracted research tasks

CUMULATIVE ERC PERSONNEL GROWTH



and $8 million for procurements in support of in-house research.

The research program will encompass the following principal technical areas and consist of approximately 25% basic research, 50% applied research, and 25% advanced technological development:

Component Technology
Solid State
Materials
High Vacuum
Electromechanical
Environmental Testing
Standards Theory
Design Criteria

Instrumentation, Data Processing
Astrophysical Measurement Techniques
Biomedical Instrumentation
Engineering Instrumentation
Computation Research
Flight Readiness

Systems
Systems Analysis
Engineering Psychology
Machine Simulation
Research Flight Experiments
Electrical Power Conditioning
Power Distribution and Regulation

Guidance and Control
Inertial Reference
Electromagnetic Sensors
Guidance Trajectories
Navigation Techniques
Control Systems
Control Theory
Control Devices

Electromagnetics
Circuits
Antennas
Propagation
Information Links
Stimulated Emission
Passive Devices
Information Theory

As it develops, ERC will provide a means nationally for analyzing electronic needs to meet future space goals, translating these into technical requirements, and communicating these requirements to those capable of providing solutions. In this way, the ERC will stimulate and guide a nationwide effort, in its field many times larger than the research program carried out by the Center itself.

ERC will be largely an outward instead of an inward-facing organization. This, in essence, is why we now have an ERC in operation—to be able to communicate with the electronics community nationwide, to get the electronic products we need, when we need them—in advance of our future spaceflight missions. ••

TACTICAL MISSILES

WALLEYE AND REDHEAD ROADRUNNER

Extensive activity in the development of these and other tactical missiles offers a variety of opportunities in the following:

ADVANCED GUIDANCE TECHNIQUES

Initiate studies, analyze, develop and evaluate sensor systems for incorporation in tactical missile guidance systems.

CONTROL AND STABILIZATION

Analyze and design autopilot and actuation systems using analog and digital methods.

ELECTRONIC TECHNIQUES

Conduct study and laboratory evaluation methods of processing target and background signals to derive steering signals for tactical missiles.

OPTICAL SYSTEM DESIGN

Determine requirements for optical elements to couple target energy to a sensor. Verify design by laboratory and field test.

PROPULSION

Originate and conduct analyses of advanced tactical missile propulsion systems including solid, liquid and hybrid rocket engines and air breathing systems for application to advanced tactical missiles.

GROUND SYSTEMS

Determine requirements for automatic and semi-automatic electronic checkout equipment for missile and ground systems.

ORDNANCE

Perform analysis, preliminary design and integration of warheads and conceptual mechanizations for fusing systems for non-nuclear and nuclear warhead systems.

FLIGHT MECHANICS

Initiate and conduct studies to develop methods for determining the desired trajectory characteristics for a given set of constraints.

Send resume to: Mr. J. H. Papin, North American Aviation, Inc., Professional Employment, Box AA-717, 4300 East Fifth Avenue, Columbus, Ohio 43216.

All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.

North American Aviation Columbus Division