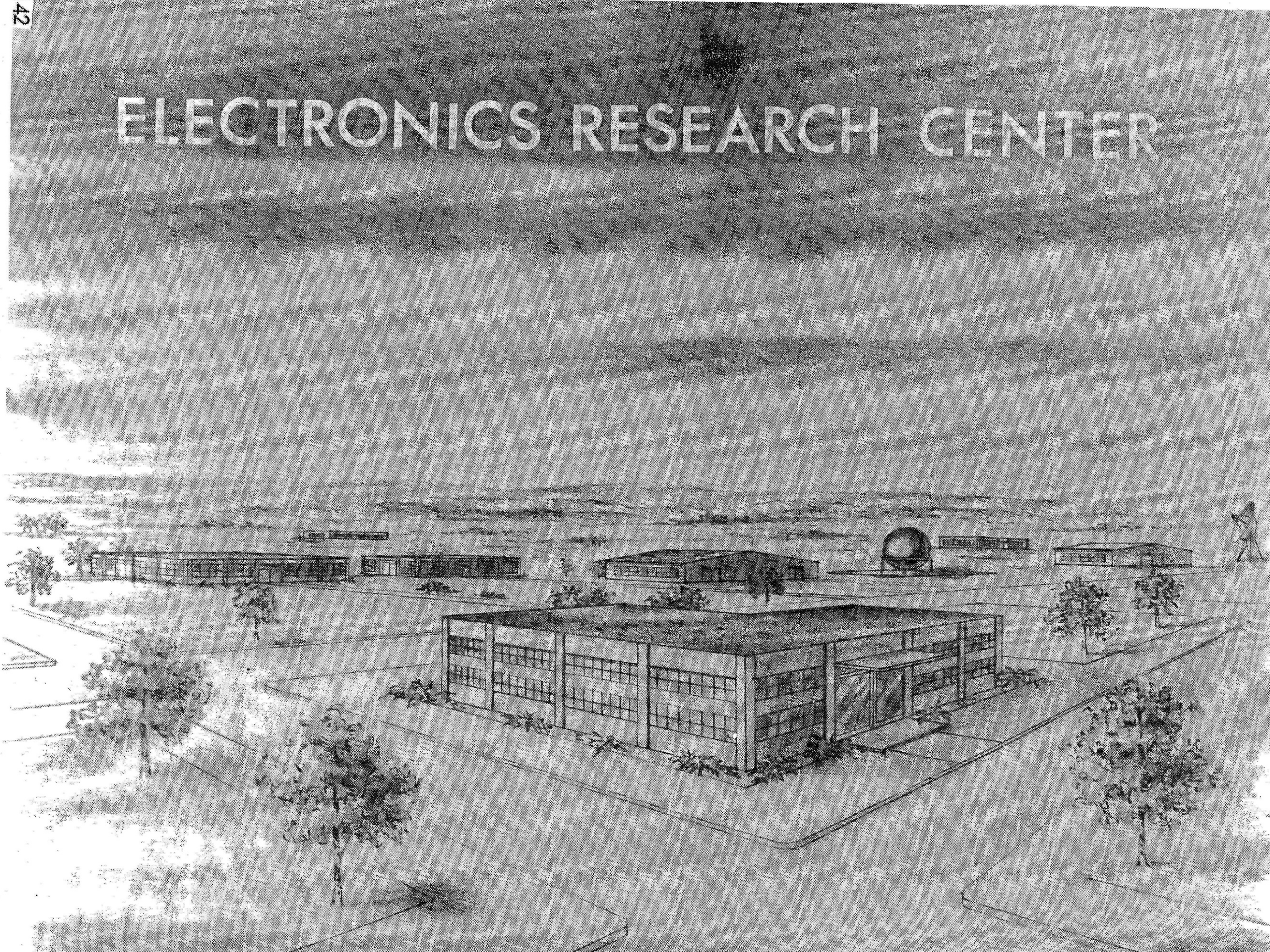
NASA’s Electronics Research Center

We Hardly Knew Ye

Andrew J. Butrica, Ph.D.

Historical Consultant


ELECTRONICS RESEARCH CENTER

- **Why and How the ERC was created**
- **The Kelley Study**
- **Gunn Effect**
- **Air Traffic Control Satellites**
- **Integrated Circuits**
- **The End**

Primacy of Electronics

- Lucrative electronics industry
- Rapid pace of technological change
- Rockets and electronics were central to NASA's successes in space
- Webb: "Our accomplishments in space have stemmed from two principal sources: the . . . modern rocket. . .; the second—whose importance must not be forgotten—is modern electronics."

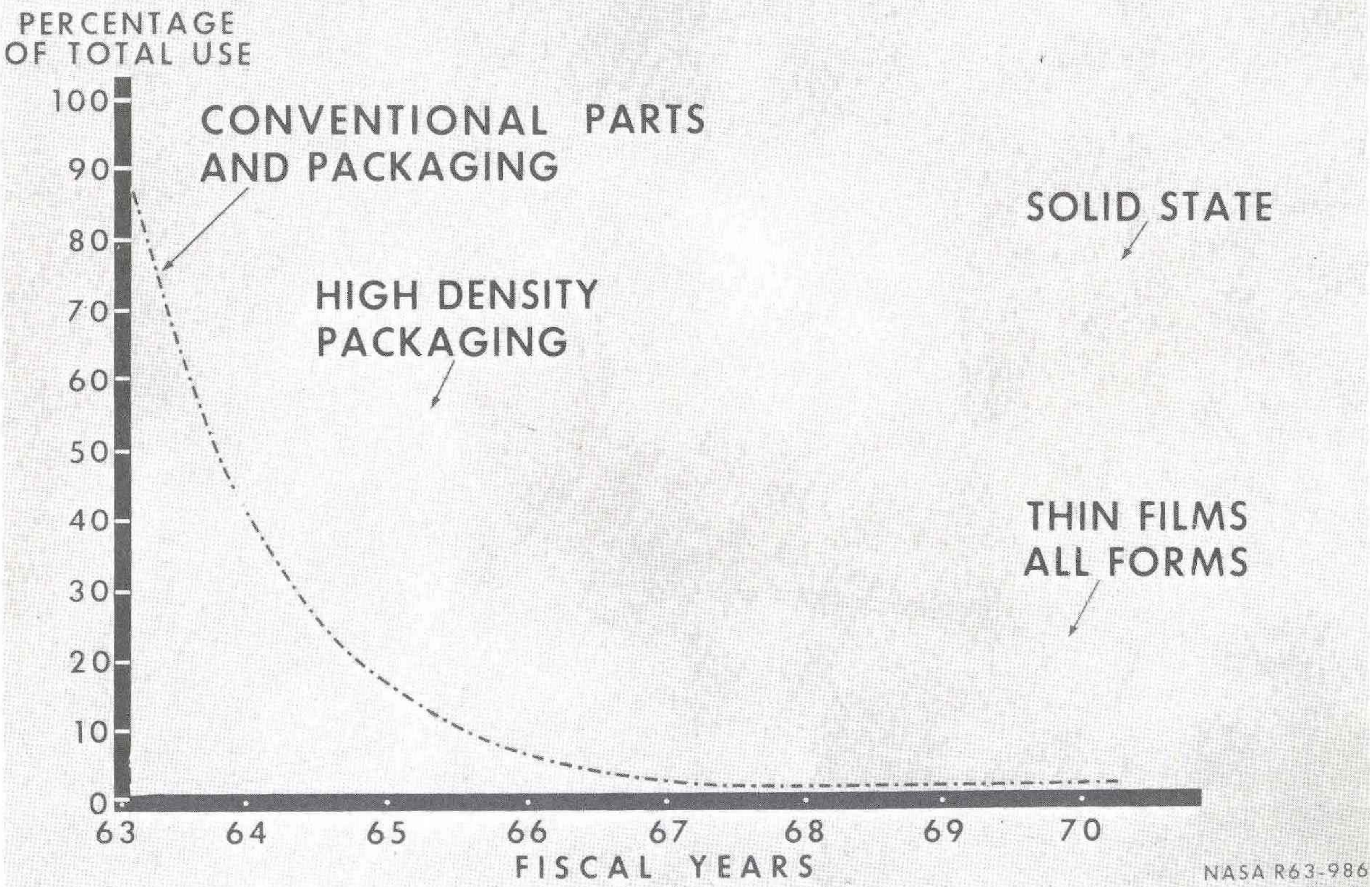
Primacy of Electronics

- Electronics costs represented a substantial portion of NASA's purchases
- Webb: "Electronics components account for over 40 per cent of the cost of our boosters, over 70 per cent of the cost of our spacecraft, and over 90 per cent of the cost of the resources going to tracking and data acquisition."
- Dependence on electronics meant that NASA needed its own electronics expertise, if for no other reason than to be able to do business effectively with electronics contractors

NASA Electronics Strategy

- Eventually NASA's "more complex spacecraft will use microcircuits by the hundreds of thousands."
- NASA estimated that by 1970, 70% of its spacecraft electronics would consist of integrated electronics
- This strategy, like the Apollo guidance computer decision, drove NASA toward finding highly reliable integrated circuits and microelectronic components for its many planned space missions

PREDICTION OF USAGE OF MICROELECTRONICS FOR AEROSPACE APPLICATIONS



NASA R63-986

OART Established

- November 1, 1961: NASA Headquarters reorganization
- Responded to President J. F. Kennedy’s mandate to put an astronaut on the Moon by the end of the decade
- Established Office of Advanced Research and Technology (OART)
- Organized along disciplinary lines

THIS IS THE NASA ORGANIZATION THAT WILL MANAGE THE ART

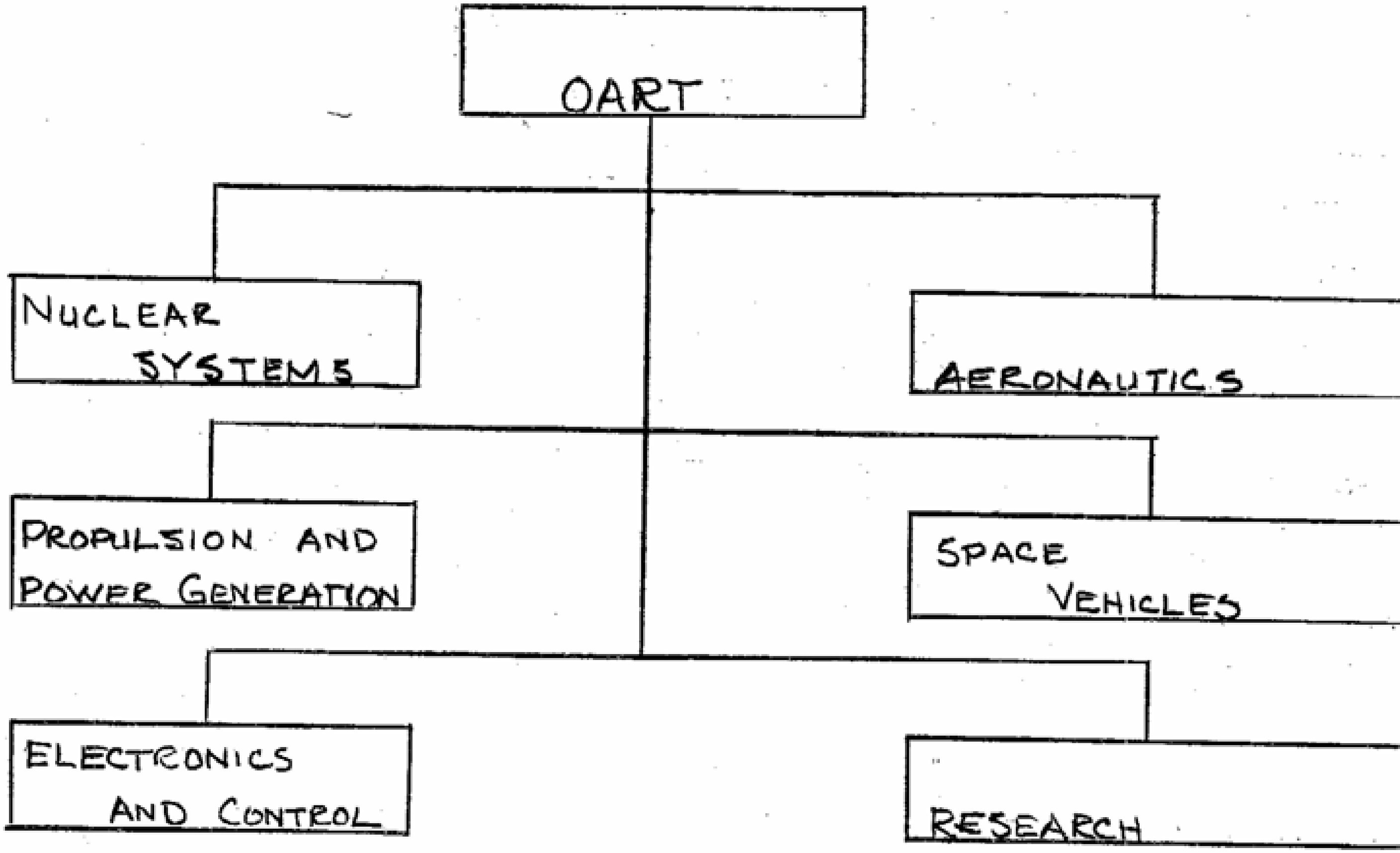


FIGURE 6

Electronics and Control Directorate

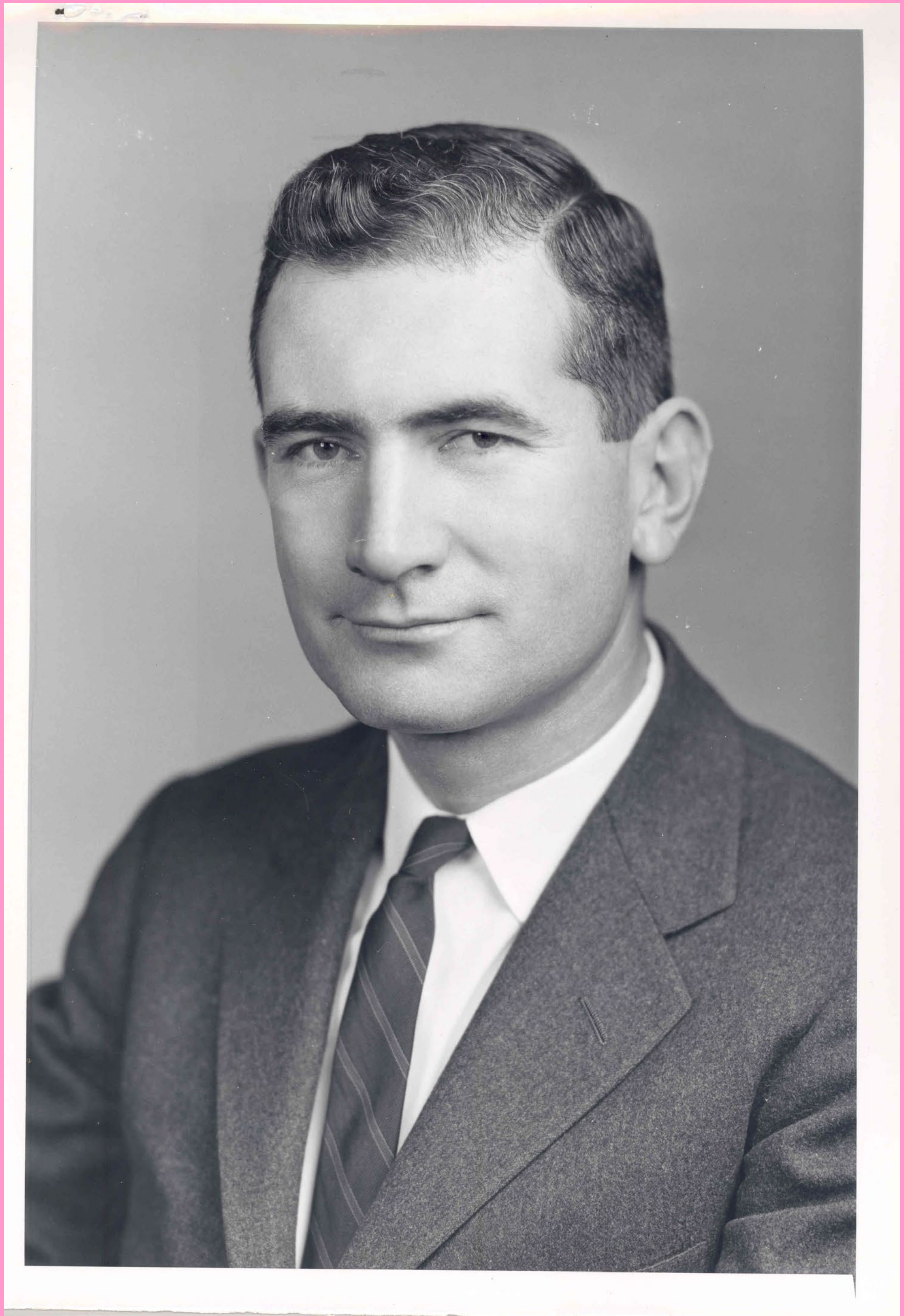
instrumentation & data processing
control & stabilization
techniques & components
communications & tracking
guidance & navigation

Kelley Study

Memorandum, March 2, 1962

Dr. Robert C. Seamans, Jr., NASA Associate Administrator

OART to present "a plan to strengthen NASA's capability in the electronics and guidance and control field"



Albert J. Kelley

Kelley Study

- June 1962
- Areas of NASA strength in electronics expertise:
  - guidance and navigation
  - control and stabilization
  - communications and tracking
  - instrumentation and data processing

Kelley Study

- **BUT:**
- Expertise "widely diffused throughout the Centers with spotty emphasis, in short a heterogeneous group of bits and pieces."
- Center-funded research projects tended to be "specific rather than basic, more technological than fundamental in nature, and of more immediate application than those that are supported by headquarters."

Kelley Study

- Orientation of research reflected the interests of the centers' researchers:

  "A substantial fraction of the capable electronics personnel at the centers are concerned primarily with project management or space flight project engineering," rather than with long-range research

Kelley Study

- **Conclusions:**
- NASA lacked adequate employees conducting research and development as well as applied research and technology
- NASA would have to rely extensively on research conducted by industry and academia
- Need to consider creating a new center

Kelley Study

- **Conclusions:**
- The new center:
- 2,000 to 3,000 new staff
- $50 million to $60 million in new facilities

Three Alternatives

First Alternative

- Establish Electronic Systems R&D Groups at a few centers
- Rejected:
- Denied electronics research “the primary attention that it warranted”
- Precluded “the creation of an essential ‘critical mass’ or concentration of electronics capability”

Second Alternative

- Create one major electronics group at an existing center
- Models:
- Life Sciences Group at Ames Research Center
- Space Task Group at Langley Research Center

Second Alternative

Disadvantages

- Would result in doubling the size of the center
- Unwieldy research management situation
- Adversely affect the center's "quality of performance" and the quality of the electronics research
- Advantage: the necessary "critical mass" of expertise

Langley Satellite Study

- July 1962: Langley study commissioned by OART
- Establish an electronics satellite facility at Langley?
- The satellite facility: staff = 3,275; buildings costing $50,800,000
- Why Langley?
- Had 43% of all NASA electronics research professionals

Langley Satellite Study

Disadvantages

- Too large to be managed efficiently
- Like trying to run two centers with one management structure
- Managing the research would be a nightmare
- Research would not be focused on a few large projects, but would be highly compartmentalized and diffused

Langley Satellite Study

Disadvantages

- Manage hundreds of relatively independent projects at any given time
- Managing them would require detailed and closely coordinated management
- NASA Deputy Assistant Administrator Boyd Meyers: "we felt that we would wind up with maybe a 6,000-man laboratory, which we felt is kind of large and difficult to manage, particularly when you have aeronautics and structures and propulsion and aerodynamics and so forth going on in one laboratory, and then to put electronics on top of that."

Third Alternative

- Create a new center just for electronics research
- Obviate the management disadvantages of expanding an existing center
- Provide the desired emphasis on electronics research
- Conduct both basic research and advanced technology programs
- Develop agency-wide performance parameters and standards for electronics components

Third Alternative

- Liaison between NASA and its researchers in academia and industry
- Award grants and contracts to industry and academia to undertake research and development
- Focus of NASA-wide initiatives to encourage industry to increase its research and development capacity
- Furnish technical advice on selecting contractor research designs to NASA

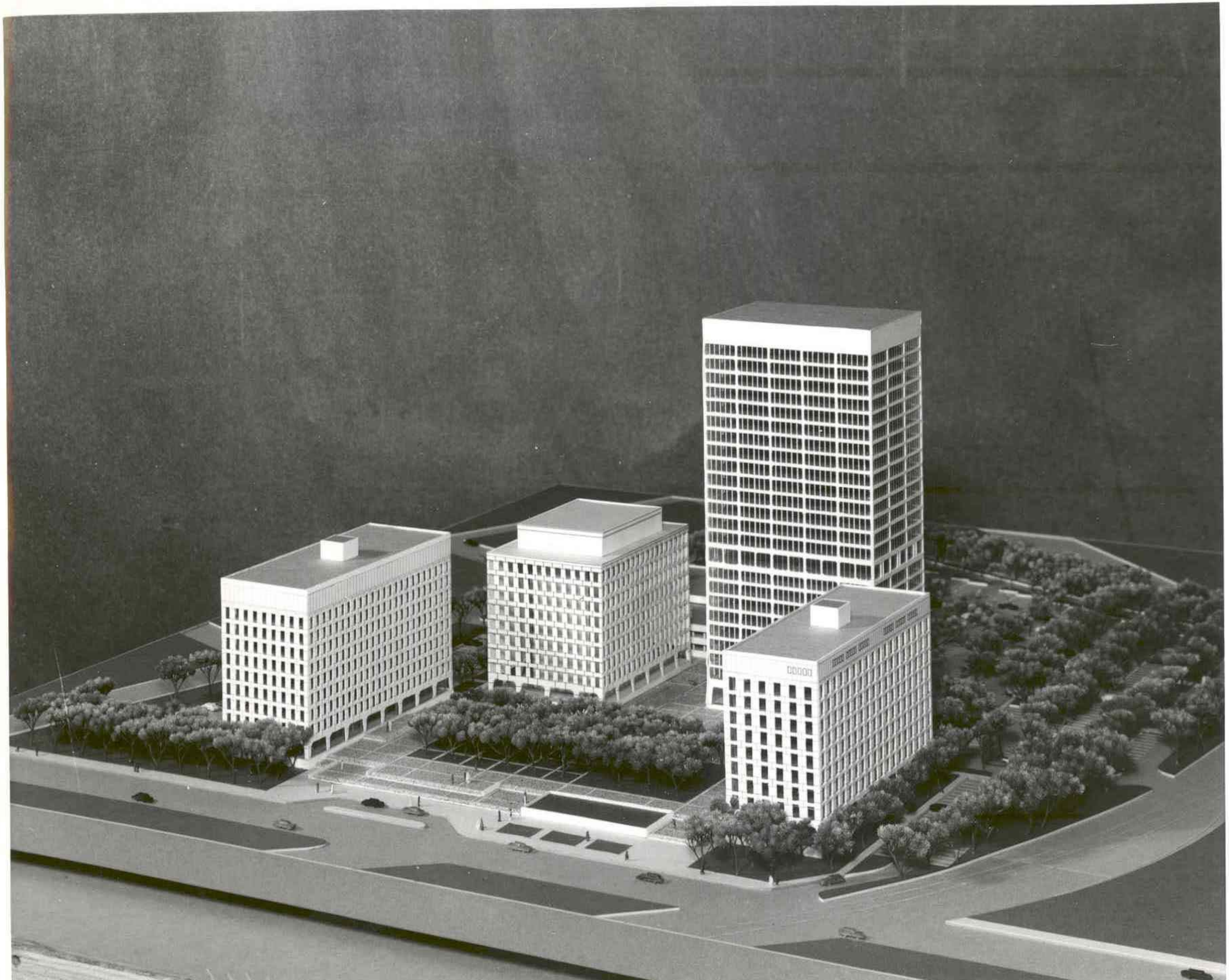
Third Alternative

- Rival in size (staff and facilities) to Langley or Marshall
- Staff of 2,100
- 900 engineers and scientists
- Facilities costing over $60 million

Third Alternative

Location: Cambridge

- MIT and Harvard
- Electronics industries along Route 128
- Air Force's Cambridge Research Laboratory
- Mitre Corporation
- MIT Lincoln Laboratory
- MIT Instrumentation (Draper) Laboratory

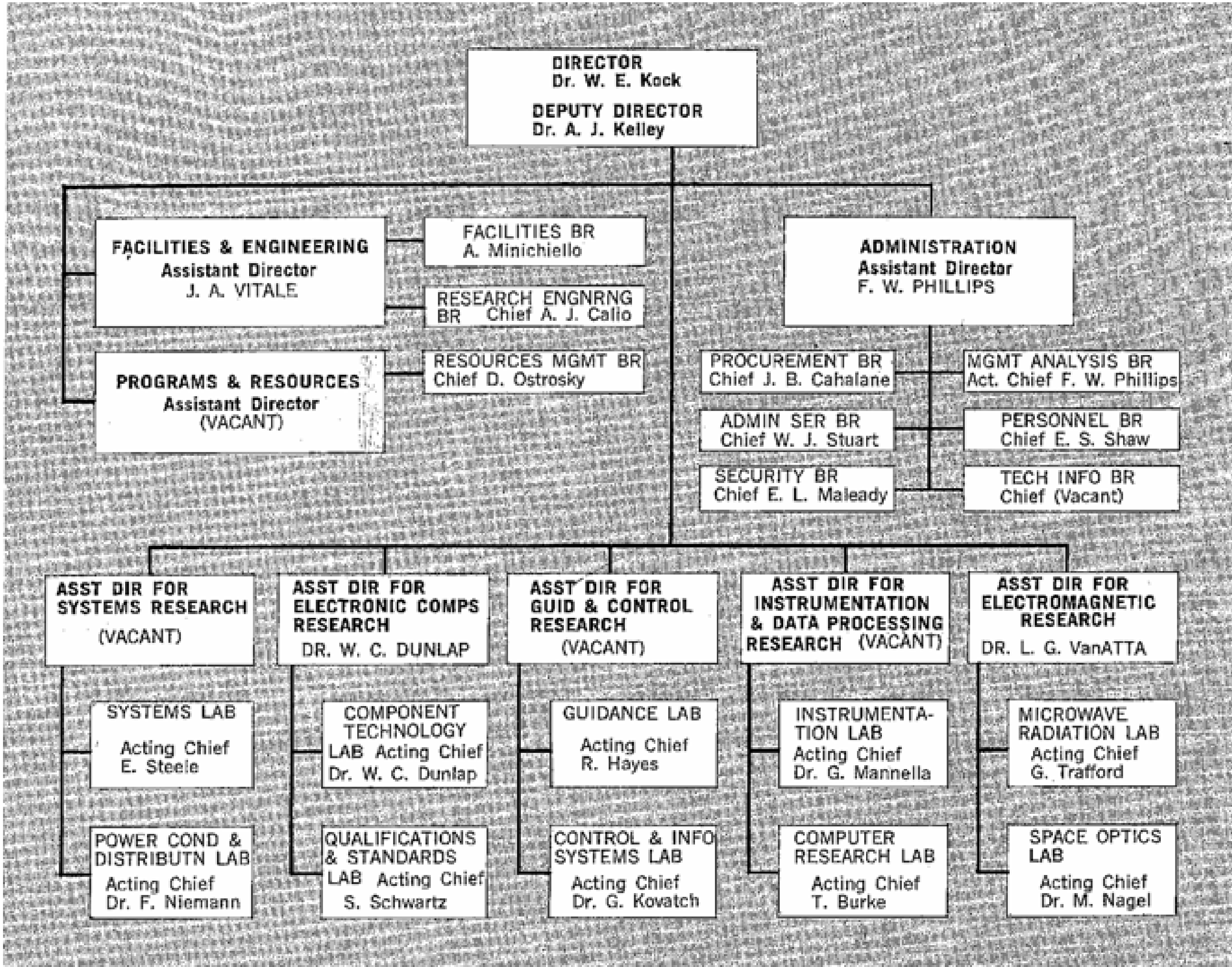


Electronics Research Center

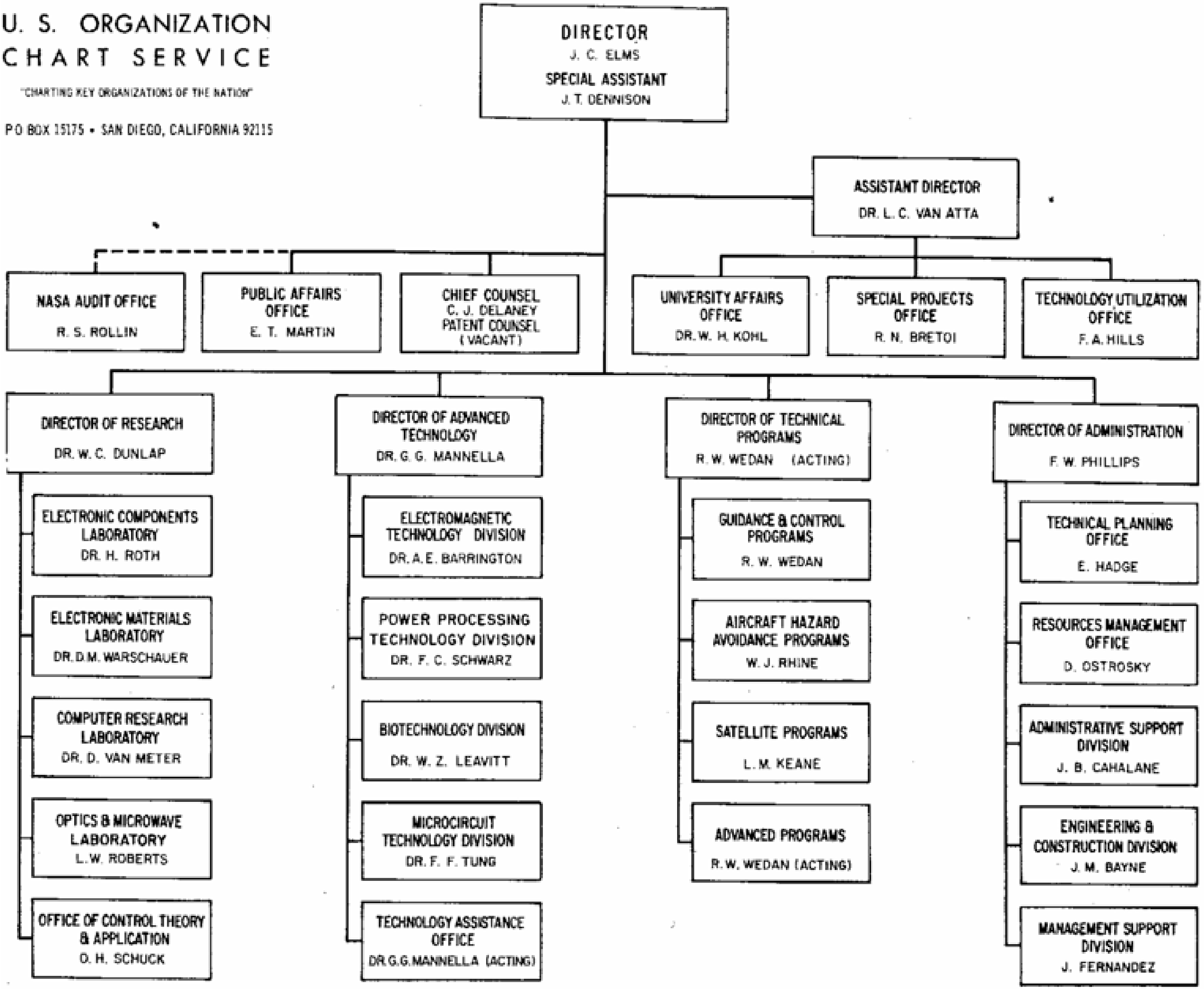
- September 1, 1964: officially opened
- Rented rooms and buildings
- Created by merger of NEO and ERTG
- July 1962: New England Operations Office
- February 1963: Electronics Research Task Group (Electronics and Control Directorate)

ERC Laboratories

- Space guidance
- Systems
- Computers
- Instrumentation
- Space optics
- Power conditioning and distribution
- Microwave radiation
- Electronics components
- Qualifications and standards
- Control and information systems



ELECTRONICS RESEARCH CENTER organization chart.



U. S. ORGANIZATION CHART SERVICE
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Gunn Effect

Gunn Effect

- Discovered by J. B. Gunn (IBM)
- Published discovery in 1963
- Ridley-Watkins-Hilsum-Gunn effect
- Brian K. Ridley; T. B. Watkins, Cyril Hilsum
- The production of microwave oscillations when a constant voltage in excess of a critical level is applied to opposite faces of a semiconductor (gallium arsenide, later indium phosphide)
- Gunn patents (assigned IBM)

Gunn Effect

ERC Research

- Variety of devices, variations
- Gallium arsenide studies
- 1967: Gunn diode rooftop test
- Handheld unit beamed music from the roof of ERC to roof of the Prudential Tower (Boston), completed in 1964 (229 m, 750 ft)
- Distance: one mile
- Researchers: Dr. Harold Roth, W. Deter Straub, and John A. Ayer

Gunn Effect

- 1968: Successful demonstration of Gunn microwave device between Boston and New Hampshire
- Distance: 81 miles
- Line-of-sight transmission between Mount Kearsarge, NH, and the Prudential Tower
- Gunn devices operated at X-band, peak power of 1-1/2 watts
- With 5 watts now available, estimated that communication link can be extended to more than 700 miles

Gunn Effect Patents

- Wilhelm Rindner, Harold Roth, "Voltage-tunable Gunn-type Microwave generator," U.S. 3,509,491, applied June 2, 1967; issued April 28, 1970
- Rindner, Roth "Gunn-type Solid-state Devices," U.S. 3,667,010; applied July 6, 1967; issued May 30, 1972
- Dr. Frank R. Holmstrom, "Shielded cathode mode bulk effects device," U.S. 3,614,557; applied May 16, 1969; issued October 19, 1971

Air Traffic Control Satellite

1963

- TRANSIT: military navigation satellite system (Navy)
- DoD-NASA agreement (January 1963) assigned to NASA responsibility for exploring nonmilitary uses of the system
- 7-month study to determine requirements of nonmilitary ships and aircraft
- FAA, Cost Guard, Coast and Geodetic Survey, Maritime Administration, Bureau of Commercial Fisheries

Requirements of a Nonmilitary Navigation System

- All weather availability
- Global coverage
- Moderate cost
- Simplicity of operation
- High reliability
- Ease of maintenance
- Versatility (different user types)
- Long life

1963 Study

Conclusions

- No great need for an additional long-distance system to provide position determination for merchant ships
- Urgent need for a positioning and traffic control system for aircraft, especially over the North Atlantic
- Situation will become more critical as SSTs become operational

1963 Study

- “*If*, however, such a system could, as part of its routine operation, provide means for air traffic control for all classes of aircraft now in operation or contemplated, it would solve one of the major problems confronting the world today, a problem expected to become increasingly urgent with the anticipated increase in number, variety, and performance of aircraft using the airspace.”

Nonmilitary Limitations of TRANSIT

- Cost of receiving equipment for some time to come is likely to be too high for general use
- TRANSIT equipment of necessity will be complex, and will require use of a computer
- Nonmilitary ships may find difficulty in meeting the requirements for accurate velocity vector input
- Need for adequate maintenance personnel aboard ship

Nonmilitary Limitations of TRANSIT

- TRANSIT equipment not likely to be suitable for aircraft use
- Complexity of satellites may impose severe useful life limitations or system reliability hazard
- Technique provides only positional information and time signals
- Military restrictions may limit use by civilians
- Exceptions: hydrographic and oceanographic survey ships; useful as a geodetic tool

Overcoming Limitations of TRANSIT

- Remove complexity of the system from ships and aircraft and satellites
- Shift complexity to ground stations

More Studies

System definition studies

- General Electric – UNIVAC
- Westinghouse

Design study (CY 1964)

Development and fabrication (CY 1965)

NASA/FAA Cooperation

- 1966: NASA & FAA considered developing a satellite system for worldwide navigation and communications
- Main concern: use in navigation, traffic control, and communications among ships and aircraft in ocean areas, initially the North Atlantic.

ERC

- October 1966: NASA HQ considered a request from ERC to undertake a study to define the required research areas and to establish the system concepts for the satellite configuration
- Created Study Project Group
- Dr. Stanley E. Ross, Systems Lab, Project Leader
- Gilmore H. Trafford, Microwave Lab
- Leo M. Keane, Guidance Lab

VHF Studies

- Application Technology Satellite 1
- Launched December 7, 1966
- VHF experiment for communications with aircraft, ships, meteorological remote terminals, and to evaluate VHF satellite navigation

VHF Studies

- Application Technology Satellite 3
- Launched November 5, 1967
- Initial tests of NASA's Omega Position Location Experiment (OPLE) for aircraft and ship navigation
- Showed that OPLE could provide a position location accuracy of about a mile
- Tests units for an FAA airplane and a Coast and Geodetic Survey ship to be used in future OPLE experiments were delivered to NASA.
- Five aerospace companies submitted proposals for a navigation experiment to use range signals between an aircraft and ATS 1 and 3

VHF Studies

- OPLE came within 1 to 2 miles of locating a station wagon
- April 1968 test: vehicle had VLF antenna to receive Omega signals, VHF antenna to communicate with ATS 3; vehicle moved at speeds up to 60 mph
- May 1968 test: NASA aircraft outfitted with VHF and VLF antennas
- OPLE operated satisfactorily at aircraft speeds as great as 185 mph
- OPLE located the aircraft within about 5 miles of its “true” position

VHF Studies

- Maritime Administration conducted communications and range-navigation tests between the *SS Santa Lucia*, a commercial vessel sailing from New Jersey to Chile, and the ATS 1 and 3 satellites
- Preliminary analysis:
- VHF signals can include voice transmissions, radio-teletype, data transmissions, time signals, and weather facsimile
- No interference to or from the radar, HF radio, or VHF ship-to-shore aboard the *Santa Lucia* reported

VHF Studies

- OPLE test: an aircraft was located within two to four miles, a ship and buoy within three miles, and a balloon within half a mile
- Aircraft supplied by FAA
- Buoy and ship by Environmental Sciences Services Administration
- Drifting balloon by National Center for Atmospheric Research

VHF Studies

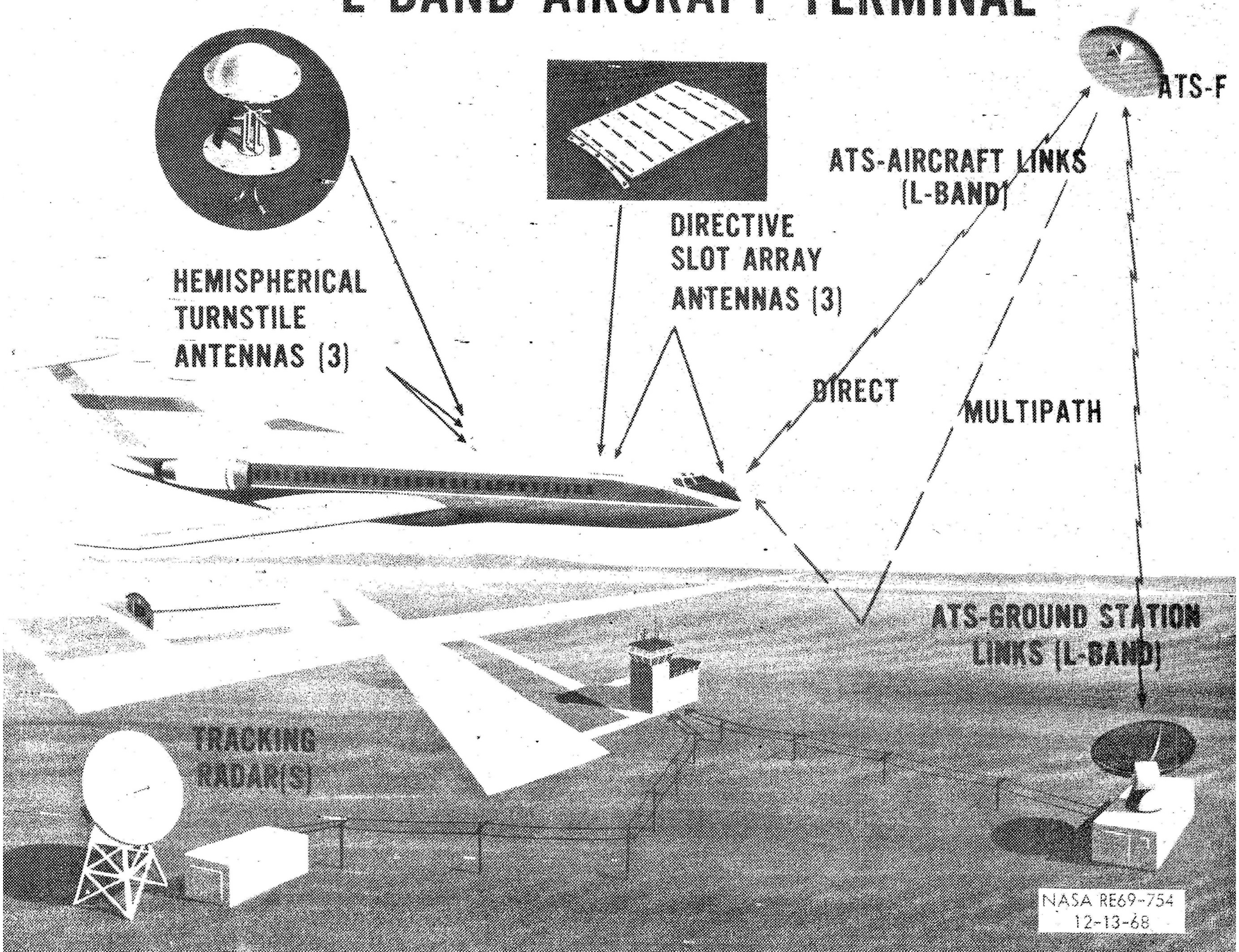
NASA-DoD Cooperation

- OPLE used ATS 3 and DoD's Omega navigation system to continue position location and data collection experiments
- February 1969 tests conducted in cooperation with the Office of Naval Research
- Located a large fixed buoy in Bermuda waters within 1-1/2 miles
- OPLE transmitted oceanographic data to Goddard Space Flight Center

UHF Study Proposed

- May 1969: FAA proposed that NASA-FAA investigate the possibility of a preoperational UHF aeronautical satellite system for one-ocean aircraft communications and surveillance
- Study satellite location and capability, ground stations, and satellite management needs
- NASA agreed to study; assembled a study team of scientists and engineers from ERC, Goddard, and Headquarters

L-BAND AIRCRAFT TERMINAL



L-Band

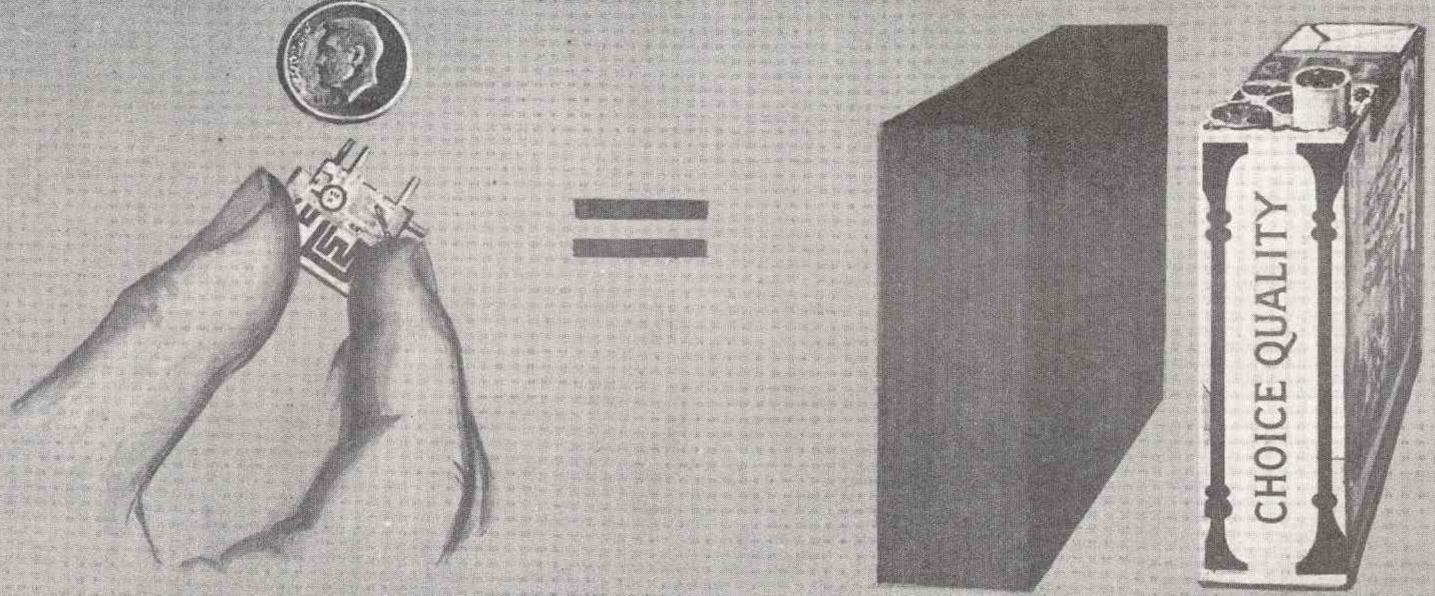
- April 1969: ERC's Communications and Navigation Satellite Programs Office completed and published the ATS 5 experiment plan
- Use jet aircraft and an L-band transponder on the satellite to gather flight test data necessary to evaluate the feasibility of using L-band frequencies for communications and position location functions in an air traffic control system

ATS 5 & 6

- ATS 5 launched August 12, 1969; malfunctioned
- ATS 6 launched May 30, 1974
- Studies carried out at L-band (1550-1650 MHz): relay links to aircraft were established and multiple aircraft tracking was demonstrated
- Position Location and Aircraft Communication Experiment (PLACE)

Integrated Circuits

ADVANCED MICROELECTRIC DEVICES



TYPICAL MICROELECTRONIC
THIN FILM DEVICE
- RELIABLE
- RADIATION RESISTANT
- SMALL
- LIGHT

CONVENTIONAL TRANSISTOR
ELECTRONICS

NASA R63-3

Integrated Circuits

- NASA spin-off (“technology utilization”) literature: economic impact of NASA on the development of integrated circuits
- Fails to distinguish the separate influences of NASA and Defense Department funding
- Apollo Guidance Computer
- Eldon Hall et al
- MIT Instrumentation Laboratory
- NASA supplied need and money

NASA and Electronics

- Electronic components not compatible with space conditions (radiation and temperature extremes, e.g.)
- Systems operate unattended for long times
- Webb: "Electronics components account for over 40 per cent of the cost of our boosters, over 70 per cent of the cost of our spacecraft, and over 90 per cent of the cost of the resources going to tracking and data acquisition."

Ranger 6 Diodes

- Electronic and electrical fabrication problems
- 1962 Ranger 5 failure => Ranger Board of Inquiry (Kelley Board)
- Ranger 6: Two serious test failures in the General Electric guidance components resulted from short circuits caused by loose gold flakes in certain diodes (Continental Devices)
- How could flight equipment containing many contaminated diodes have passed all JPL tests without failure?

Wafer Fabrication

- Low portion (10%) of integrated circuits produced on a given wafer that were suitable for aerospace uses
- Only 75% of the chips on a completed wafer were in working condition
- That portion fell to 50% following further handling
- Of the remaining 50%:
- About half were suitable for low-quality commercial applications
- 30% were suitable for high-quality industrial or governmental (military) uses
- Only 20% were suitable for aerospace applications

Microelectronics Subcommittee

- Parts Steering Committee
- Office of Reliability and Quality Assurance chaired the Parts Steering Committee, which included representatives from all NASA centers
- **Set up the Microelectronics Subcommittee**
- NASA Management Instruction (NMI) 5320, "NASA Microelectronics Reliability Program," established the agency's reliability program for microcircuits
- Provided a uniform approach for the specification, test, and procurement of microelectronics
- NASA merged its requirements with those of the Defense Department in order to establish a set of standard government requirements.

Microelectronics Subcommittee

- Agency-wide effort to improve the reliability of microelectronic devices, especially integrated circuits
- Symposia
- Technical handbooks on approved electronic components and other critical publications (two-volume handbook was a database of approved electronic parts)
- Research
- ERC PREDICT facility

ERC IC Improvements

- Design
- Fabrication
- Testing

Integrated Circuit Design

- Computer-aided circuit design
- Collaboration with industry, academia, and military

IC Fabrication Process

- Ion implantation of dopants
- Method for separating semiconductor wafers into chips
- Glass-passivated integrated circuits
- Selective gold diffusion of monolithic silicon devices and circuits
- Formation of P-N junctions in gallium antimonide
- Technique for depositing silicon dioxide on indium arsenide
- Scribing silicon wafers with a laser
- New method for stripping photoresist material
- New photoetching technique for metal-oxide layers

IC Testing

- Scanning electron microscopy of integrated circuits
- Automated testing and diagnostics of electronic components
- Use of x-ray spectrograph to measure the thickness of aluminum deposited on silicon
- Reliable method for testing gross leaks in semiconductor component packages
- Reliable non-destructive method for measuring the thickness of a selected area of a semiconductor device
- Development of new techniques in reflectometry as applied to testing and diagnostics of microcircuits

IC Research

- Thin films
- Superconducting electronics
- Microwave integrated circuits
- Research into metal-oxide semiconductors (MOS)
- Metal-oxide semiconductor field-effect transistors (MOSFETs)
- Metal nitride oxide semiconductors (MNOS)

MOSFET

- Goddard used ERC-developed MOSFETs on the Interplanetary Monitoring Platform (IMP) Explorers 33, 34, and 35
- IMP was a Goddard proposal to establish a network of satellites in order to obtain continuous monitoring of space radiation in support of the Apollo program
- The IMP spacecraft used 1,000 integrated circuits to replace 15,000 discrete parts
- The MOSFETs 1) on average had ten active devices in each integrated circuit, and 2) operated successfully for about 200,000 hours in space
- MOSFET ICs performed multiple functions versus usual integrated circuit

Cambridge NASA, 750 Jobs Saved; Transportation Dept. Takes Over

Boston Globe

March 25, 1970

GOOD NEWS ABOUT CAMBRIDGE NASA — Bay State delegation hears President Nixon announce Cambridge NASA building will become U.S. transportation center. From left, Sen. Edward Brooke, Gov. Francis Sargent, President Nixon, and John A. Volpe, U.S. Transportation Secretary. (AP)

By Matthew V. Storin, Globe Staff