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Lyndon B. Johnson
Space Center
Houston, Texas

Research and Technology Annual Report

FY-1980

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National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas
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NASA

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Reply to Attn of: AT2

Dr. A. M. Lovelace
Deputy Administrator
National Aeronautics
and Space Administration
Washington, DC 20546

Dear Al:

Enclosed are two copies of the annual Johnson Space Center R&T Report prepared in accordance with your request. For additional information or copies, contact M. E. Goodhart, Code AT2.

Sincerely,

Christopher C. Kraft, Jr.

Christopher C. Kraft, Jr.
Director

Enclosures

cc:
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JSC-16993

Research and Technology Annual Report FY-1980

Space Transportation Systems

Aeronautics and Space Technology

Space and Terrestrial Applications

Space Sciences

Prepared by
Program Planning Office
Technical Planning Office
Code: AT

November 1980

Preface

This report is prepared on an annual basis for the purposes of highlighting the fiscal year research and technology (R&T) activities. Its intent is to better inform the R&T Program Managers of significant accomplishments that promise practical and beneficial program application. The report is not inclusive of all R&T activities.

The document is organized into two distinct sections: (1) a general summary of the major R&T activities in each program area, and (2) a description of significant individual completed activities and their results.

This document will be updated November 1 of each year.

The JSC Annual R&T Report is compiled by the Technical Planning Office, Office of the Center Director. The personnel listed below have coordinated the technical inputs for their respective sections of the report. Detailed questions may be directed to them or to the technical monitors listed in the Significant Task indices.

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Summaries

Office of Space Transportation Systems

Summary

The Space Transportation System (STS) fiscal year 1981 activities plan highlights the establishment of permanent manned occupancy in low Earth orbit as the overriding goal for the 1980's with this capability to be expanded by a manned geosynchronous-Earth-orbit facility in the 1990's. Inherent in these goals are several time-phased STS augmentations as shown in the evolution table (table I). The Johnson Space Center (JSC) plays a major role in the definition and development of these capabilities. The research and technology activities sponsored by the Advanced Programs Office are divided into two major categories. The first category is that of major systems studies, which pursues the definition of augmentations to the Space Transportation Systems that are required to support new initiatives identified in the activity plan. These studies are carried from preliminary phase A analyses through phase B project definition. The second major

TABLE I.—EVOLUTION OF SPACE TRANSPORTATION SYSTEMS NEEDS

	Goal: Permanent/manned occupancy of low Earth orbit		Goal: Operation of manned geosynchronous facility
	1980 to 1985 Objective: routine operation of Shuttle/Spacelab Inertial Upper Stage, Spinning Solid Upper Stage, and Manned Maneuvering Unit	1985 to 1990 Objective: permanent facility in low Earth orbit	1990 to 2000 Objective: geosynchronous facility
Transportation	• Augment STS operational capability - Power Extension Package (PEP) - Shuttle thrust augmentation • High-energy Solar Electric Propulsion System (SEPS)	• High-performance upper stage such as advanced Centaur	• Orbital transfer vehicle (OTV) • Crew capsule (MOTV) • Shuttle-derived heavy-lift launch vehicle (HLLV)
Services	• Orbiter health determination • Satellite services near Orbiter (placement, retrieval, module replacement)	• Adapters, tools, and devices for operations using Orbiter Remote Manipulator System • Maintenance and repair of satellites in sight of Orbiter • Satellite services remote from Orbiter (placement, retrieval, module replacement)	• Service systems for routine operations remote from Orbiter in geosynchronous orbit
Platforms	• Large structures experiments definition • Free-flying power modules, experiment platforms, and materials processing modules (unmanned/STS-tended)	• Large structures experiments and demonstrations	• Large power module
Facilities		• Low-Earth-orbit facility with service, habitation, flight support, and construction capability	• Permanent mannable facility in geosynchronous orbit

category of activity encompasses supporting studies to identify subsystem hardware and software requirements and to carry those subsystem developments through breadboard and prototype demonstrations.

The bulk of the current JSC research and technology activity is centered on those objectives for the 1980 to 1985 time frame. Specific areas of near-term high priority include those of satellite services near the Orbiter and Shuttle augmentation. For the 1985 to 1990 time frame, the Space Operations Center (SOC) low-Earth-orbit manned facility is the highest priority new initiative. The following paragraphs highlight the current in-house and funded activities in support of these goals.

Satellite Services Near Orbiter

Satellite services is a high-priority evolutionary program at JSC. The baseline STS, through the use of the Remote Manipulator System (RMS), the Extravehicular Mobility Unit (EMU), and the Manned Maneuvering Unit (MMU), will offer users the capability to deploy and retrieve satellites and to provide limited payload services. Future near-term payloads are expected to require much more extensive supporting services that will necessitate longer extravehicular activity (EVA) periods and more extensive astronaut support equipment and service tools. The spectrum of activities that is expected to be required in the mid- to late-1980's is shown in figure 1.

The specific activities underway at JSC fall into both the major system studies and the supporting studies and advanced development categories. Two parallel studies are the augmenting of in-house activities aimed at identifying satellite services requirements and the specific hardware necessary to satisfy these requirements. Additional activities are underway to design, develop, and test prototype hardware that has already been determined to be a vital part of the satellite services program.

Two key hardware elements, reported in more detail in the text of this report, are the open cherrypicker (OCP) (fig. 2) and the Maneuverable Television (MTV) (fig. 3). The OCP will

Figure 1.—Near Orbiter satellite services elements.

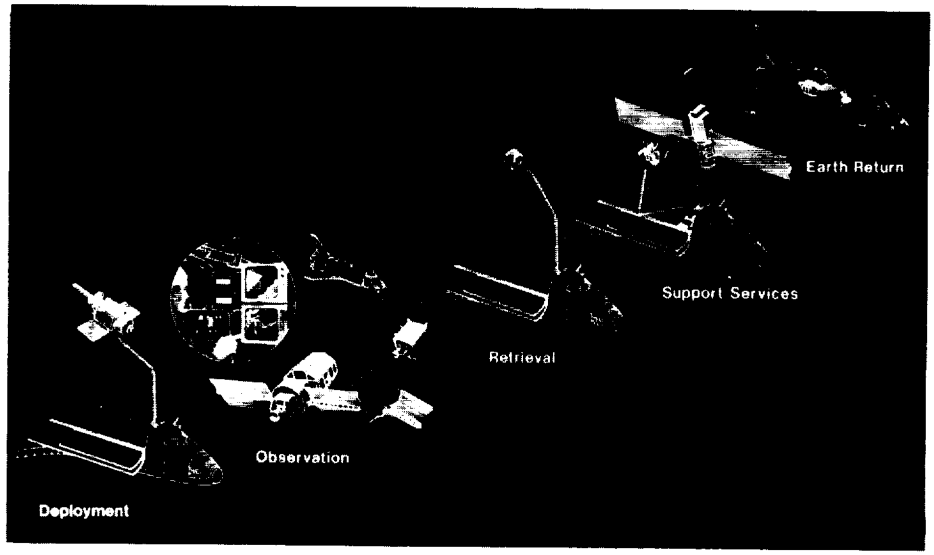
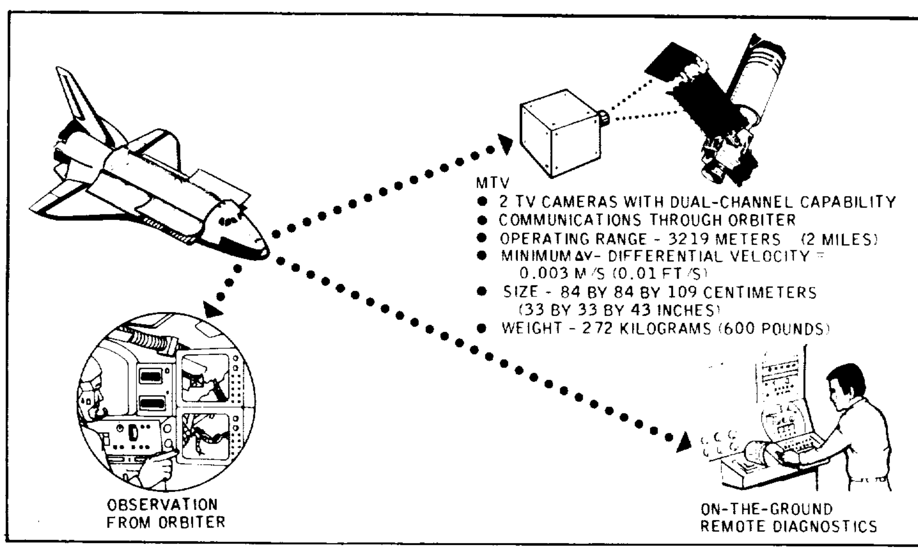


Figure 2.—The open cherrypicker.

Figure 3.—The Maneuverable Television.



provide the astronaut with a stable work station from which to access and service payloads that are attached in or near the payload bay. The OCP is attached to the end of the Remote Manipulator System and thus augments both the utility of the RMS and the capability of the astronaut to perform useful work. The MTV is a small free-flying television that will provide a vital inspection function in the near-Orbiter vicinity to determine the status of payloads before berthing with the Orbiter and to provide monitoring capability during satellite servicing. Additional capabilities and equipment that are being considered include zero prebreath suits to reduce EVA overhead, handling and positioning aids to provide access to payloads, and special tools to accomplish detailed service tasks.

Shuttle Augmentation

Shuttle augmentation activities for the next several years will concentrate on increasing the Space Shuttle capabilities, decreasing the weight and cost, enhancing reliability and safety, and reducing ground turnaround time. JSC continues an active research and technology program aimed at these areas to bring the STS to a routine operational status.

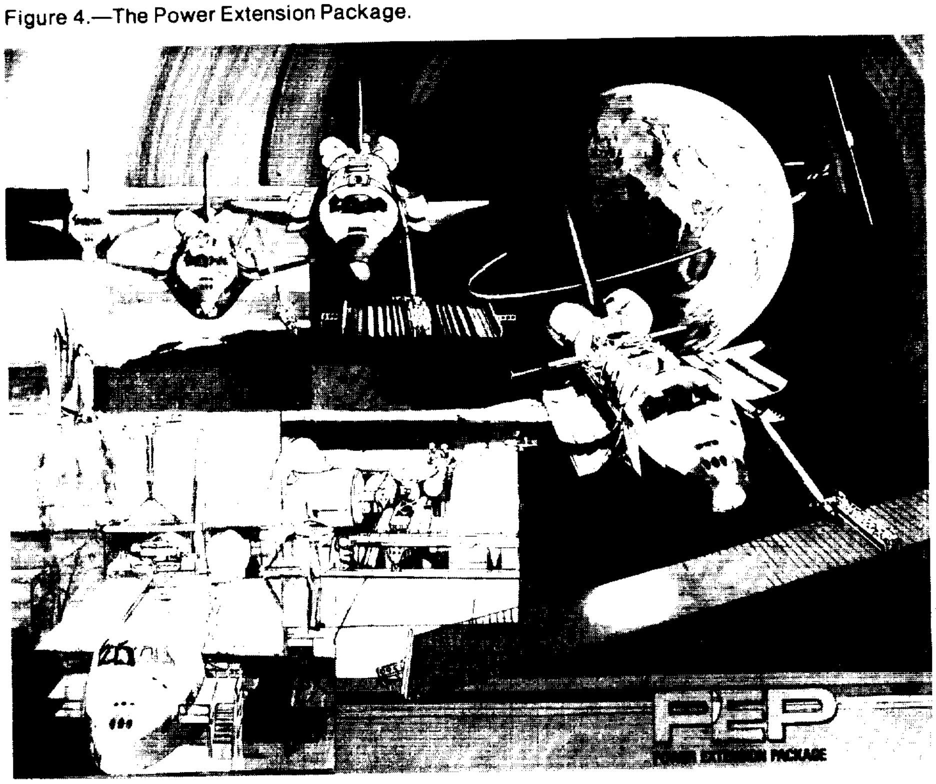
One major concern of the Space Shuttle payload community is the limited capability of the Orbiter for user onorbit energy requirements. For the last several years, a major portion of the JSC advanced programs activities has been the pursuit of augmenting this power capability. The Power Extension Package (PEP) (fig. 4) is a fiscal year 1982 new initiative that promises both increased user power and extended mission duration. It is an easily installed lightweight mission kit consisting of two deployable solar arrays that augment the cryogenic fuel cell power system. A typical PEP mission at 55° orbital inclination would provide an increase in user power to 15 kilowatts from the nominal 7 kilowatts while increasing potential mission duration to 20 days.

PEP performance is influenced by several mission-planning variables including altitude, inclination, launch date, launch time, orientation, and required power level. Significant progress was achieved in expanding the PEP performance data base addressing these variables. Results have been published with a complete description of the PEP design and operational characteristics in a convenient "PEP User's Handbook." This handbook highlights the major benefits of PEP starting with the increased power it offers payloads, the associated increase in electrical energy that allows mission extensions of two to three times the Orbiter baseline of 7 days, and its enhancement of Orbiter heat-rejection capacity resulting from reduction in fuel cell waste heat generation. Other major benefits are described including co-manifesting opportunities, all-altitude and all-inclination flight regimes, quick installation and removal of payloads for fast mission turnaround, light weight, and compact packaging.

Through an intercenter agreement, JSC and Lewis Research Center have initiated the development of large-area low-cost solar cells for application in the PEP program. The goal of this development is to achieve a reduction in solar cell procurement costs from current levels of approximately $100/watt to $30/watt. In this development, two solar cell vendors will develop wraparound contact cells as well as conventional top/bottom contact cells. Phase 1 of this activity (cell development and production readiness) will be completed by June 1981, at which time phase 2 (production verification) will begin. Both phases of the activity are scheduled to be completed before the initiation of PEP hardware development.

Another area of operational concern as mission durations increase is that of atmospheric revitalization. The Space Shuttle uses expendable lithium-hydroxide canisters for carbon dioxide removal. Mission durations in excess of 7 days with this system would impose severe stowage problems as well as increase weight penalties. A prime candidate for early incorporation is the regenerable solid amine carbon dioxide removal system that has been developed under the advanced development funding. Also high on the priority list for Shuttle enhancement is the Solid Polymer Electrolyte (SPE) fuel cell. The solid polymer fuel cell will provide an order of magnitude increase over the current fuel cell system. This system augmentation promises both cost and weight savings and considerably reduces ground turnaround requirements.

Figure 4.—The Power Extension Package.

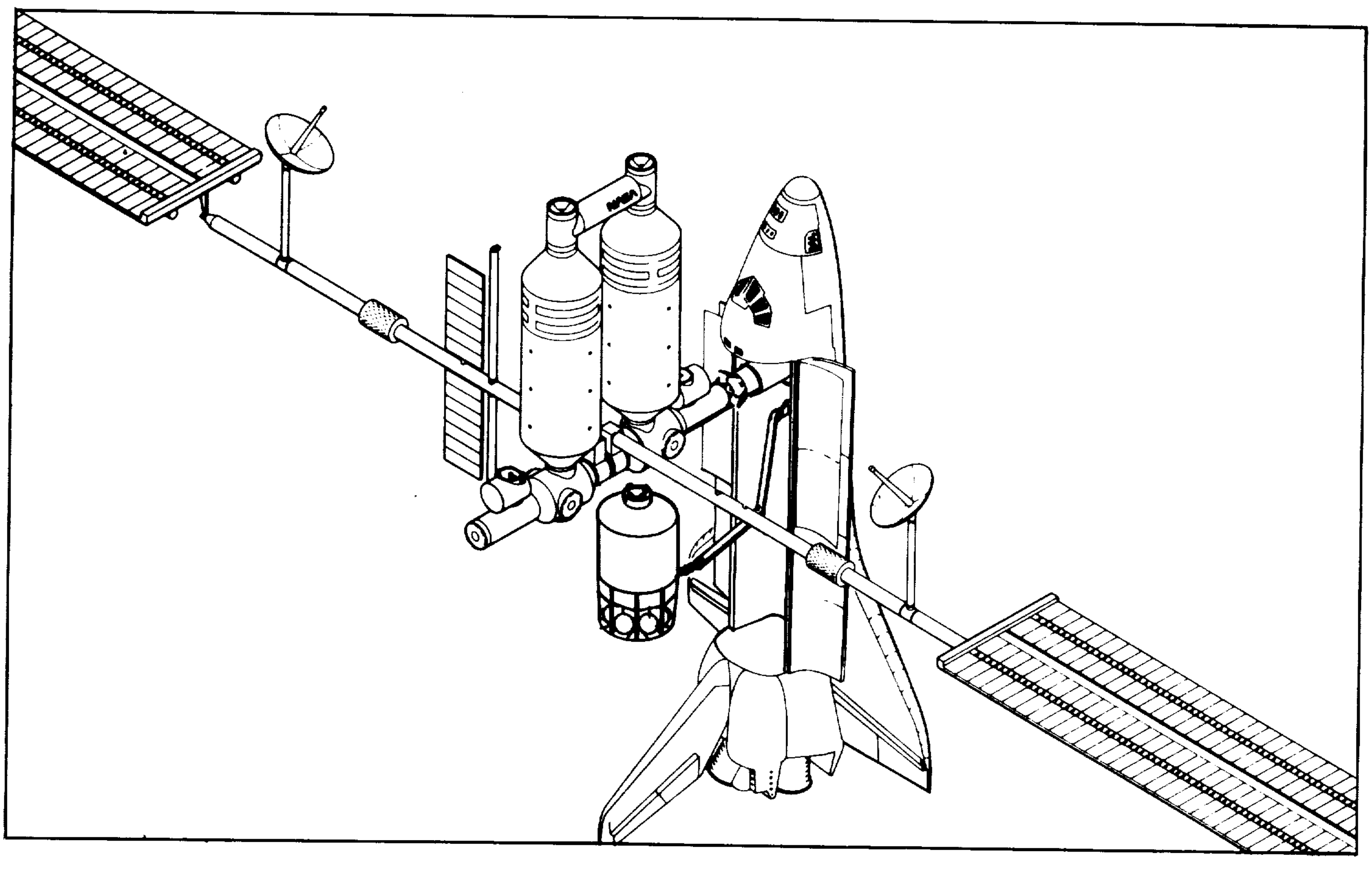


Space Operations Center

The Johnson Space Center continues in its role of principal proponent of a permanently manned low-Earth-orbit facility. A prime candidate for such a facility is the Space Operations Center (fig. 5). The SOC is intended to provide a permanent base for the construction of large structures, the servicing of orbital transfer vehicles and satellites, and the provisioning of scientific and medical endeavors. The concept was developed and analyzed by a JSC in-house study team in fiscal year 1979. In fiscal year 1980, studies were awarded to industry to provide further configuration definition and systems analysis and to define and analyze the interaction of the SOC with the Space Transportation System.

The JSC team that participated in the concept definition has been expanded and is now comprised of some 20 specialists covering all areas of system and subsystem design and analysis, operations, and programmatics and costs. In addition to supporting the technical management of the contracted studies, this group is continuing in-house tasks that reinforce the industry study efforts. It is also a key participant in the program planning activities that are developing the various options available to establish a manned operational facility by the end of the decade. The SOC is currently proposed as a new initiative for fiscal year 1985 with initial operational capability in 1988.

Figure 5.—Space Operations Center.



Office of Aeronautics and Space Technology

Summary

The activities at Johnson Space Center (JSC) funded by the Office of Aeronautics and Space Technology (OAST) involve aeronautical, space, and energy research and technology (R&T) development. These research and technology areas encompass future developments of all NASA program offices as well as other Government agencies. The use of the Space Shuttle Orbiter as an experimental vehicle, the development of space-based power satellites to beam energy to Earth, the electrolysis cell/fuel cell orbital energy storage systems, the advanced onboard propulsion technology and the large space systems technology are areas of continuing JSC interest and activity.

The major activities in space research and technology at JSC during fiscal year 1980 were (1) support to the Orbiter Experiments Program for which JSC continues to provide overall integration management and program planning, technical development for specific experiments (including development of supporting equipment), and integration of experiments into the Orbiter; (2) in-house and funded system definition studies of the solar power satellite (SPS) system that would generate terrestrial electric power from orbiting SPS systems; (3) large-capacity orbital energy storage systems research and technology, which include electrolysis cell/fuel cell development, laboratory modeling of space plasma environmental interactions of large high-voltage solar arrays in the large vacuum chamber, and development of advanced thermal management systems for space use; (4) advanced onboard propulsion technology; (5) advanced synthetic aperture radar; and (6) large space systems technology to lower cost of space assembly, fabrication, or deployment of large space systems. Another major area of continuing JSC activity is the transfer of Shuttle-related technology developments to an all new technology airplane with lower weight and reduced operational cost.

Experimental Programs

The Orbiter Experiments Program will use the Space Shuttle Orbiter as a flight research vehicle to obtain in-flight data over a broad flight spectrum for a variety of technology disciplines (fig. 1). As the lead center for the overall project, JSC is responsible for project management and integration of various Orbiter experiments. These experiments are designed to augment the research and technology data base for design verification of current and future vehicles by collecting Shuttle flight data in related technology disciplines and to verify, correlate, and extrapolate data derived from ground-based facilities with the flight data.

Solar Power Satellite

JSC in-house and contractor studies have shown that space generation and transmission of solar power is an attractive candidate for augmenting terrestrial fossil-fueled electric power generation plants in the future. As a result of these studies, NASA and the Department of Energy (DOE) initiated the Solar Power Satellite Concept Development and Evaluation Program. This evaluation program is guided by a joint DOE-NASA plan that covers the period from mid-1977 to mid-1980.

Figure 1.—Shuttle mission experiment opportunities.

The overall objective of this program is to conceptually define a reference system (fig. 2) and to understand the economic practicality and the social and environmental acceptability of the SPS system. The program is divided into four major components: system definition; environment, health, and safety; socioeconomic issues; and comparative assessment. NASA is responsible for conducting the system definition activity and the DOE is responsible for the other three. The objective of the activity at JSC is to conceptually define a reference SPS system and to identify alternative technologies within the reference concept. The four major elements of the JSC activity are as follows:

1. Energy conversion in space
2. Power transmission to Earth
3. Space transportation
4. Space construction

The first milestone of the joint DOE-NASA plan was completed with the delivery of the Reference System Document in October 1978. The DOE has made extensive use of these data to perform environmental, comparative, and socioeconomic assessments. In 1979, JSC continued system definition studies to iterate design of the reference concept with major emphasis on updating the system concept, optimizing the construction and maintenance approach, defining the industrial and Earth transportation complex, defining the total SPS operations, defining the SPS integration with the grid network, preparing technology advancement plans, and performing cost and schedule analyses. The major study areas for fiscal year 1980 include the following.

1. Summary reports were submitted to DOE in support of the SPS Program Assessment Report that is being prepared by DOE.
2. Workshops were conducted in the technical areas of microwave power transmission, space structures and construction, energy conversion and power management, and space transportation.
3. System definition studies were conducted with emphasis on costing the reference system and on defining alternative concepts that included laser-power transmission, reduced-size cargo launch vehicles, and solid-state microwave systems.
4. Critical supporting investigations were completed in the areas of (a) solid-state combining device assessment (which allows the combination of several low-power solid-state devices into an efficient high-density microwave generator), (b) fiber optics investigations (for phase-control system circuits), (c) evaluation of a retrodirective phase-control breadboard system, and (d) the SPS microwave/ionosphere interaction experiment.

The results of the ionosphere heating experiment indicate that the 23-mW/cm^2 power density limit for the microwave beam is too conservative and could be raised. Effects produced by simulated SPS ionosphere heating are many times less than natural ionospheric disturbances as introduced by solar flares. The ionospheric power density limit is a critical SPS system sizing parameter and has a significant impact on the cost. A higher limit allows more power to be delivered to a smaller rectenna.

Three additional efforts that also support the SPS study are (1) large space systems technology, (2) space plasma interaction experiments for large power systems, and (3) a continuing study of techniques to use lunar materials for space construction.

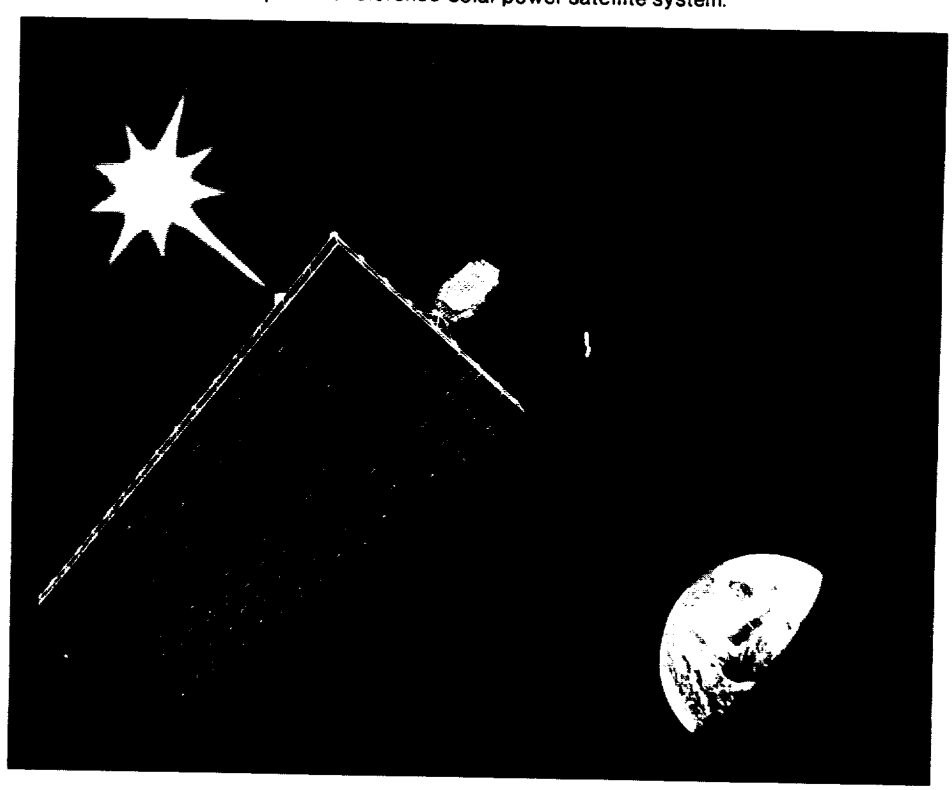
Integrated Orbital Energy System

Advances in critical space power research and technology at JSC in fiscal year 1980 include (1) low-cost solar arrays in support of the Orbiter Power Extension Package, (2) high-capacity energy storage based on the Solid Polymer Electrolyte membrane fuel cell, (3) thermal management of onorbit energy systems, and (4) modeling of space plasma environmental interaction of large high-voltage solar arrays.

A subauthorization from Lewis Research Center aided in developing low-cost solar cells for the Power Extension Package Solar Array being developed by JSC with sponsorship by the Office of Space Transportation Systems.

The regenerative fuel cell/electrolysis cell integrated energy system involves development of technology with many applications. With readily available water as the resupply commodity, it is a prime candidate as the preferred energy system for any extended duration manned or unmanned orbiting spacecraft. From Shuttle-supplied water, this system

Figure 2.—Artist's concept of the reference solar power satellite system.



can also be used for orbital manufacture of propellants for orbital transfer vehicles. It is ideally suited for space platforms in which experiments could draw power and/or hydrogen or oxygen for propellants, for feedstock for space manufacturing processes, or for life support use as required. Thus, the system serves as an orbiting utility substation.

Research and technology in integrating thermal management concepts for onorbit power systems was originally initiated by the Office of Space Transportation Systems. Joint funding was provided by the Office of Space Transportation Systems and the Office of Aeronautics and Space Technology in fiscal year 1980. The Office of Aeronautics and Space Technology will continue to sponsor the effort in fiscal year 1981 and beyond. The work in fiscal year 1980 provided a feasibility demonstration of the dual-passage high-performance heat pipe design that forms the basic component of a large-scale long-life space-constructable heat pipe radiator.

The large vacuum chamber at JSC was used to perform several experiments in a simulated low-Earth-orbit/ionospheric space plasma environment. Initial engineering verification tests were performed using a prototype Power Extension Package solar array module in flight configuration. The prototype PEP array was performance tested under conditions of solar thermal vacuum and low-Earth-orbit plasma, both separately and in combination, to fully explore and verify its response under actual space operational conditions. The results verify satisfactory performance under combined solar and plasma conditions with plasma leakage current losses less than 2 percent. Arcing to the plasma was observed at voltages over 500 but was shown to cause no damage to the array.

Advanced Onboard Propulsion Technology

The advanced onboard propulsion technology project will develop a candidate reusable onboard propulsion system using nontoxic propellants for future spacecraft. The fiscal year 1980 effort at JSC involved the characterization of nontoxic propellants and corresponding properties of ignition and burn systems (thrust chambers, nozzles, etc.).

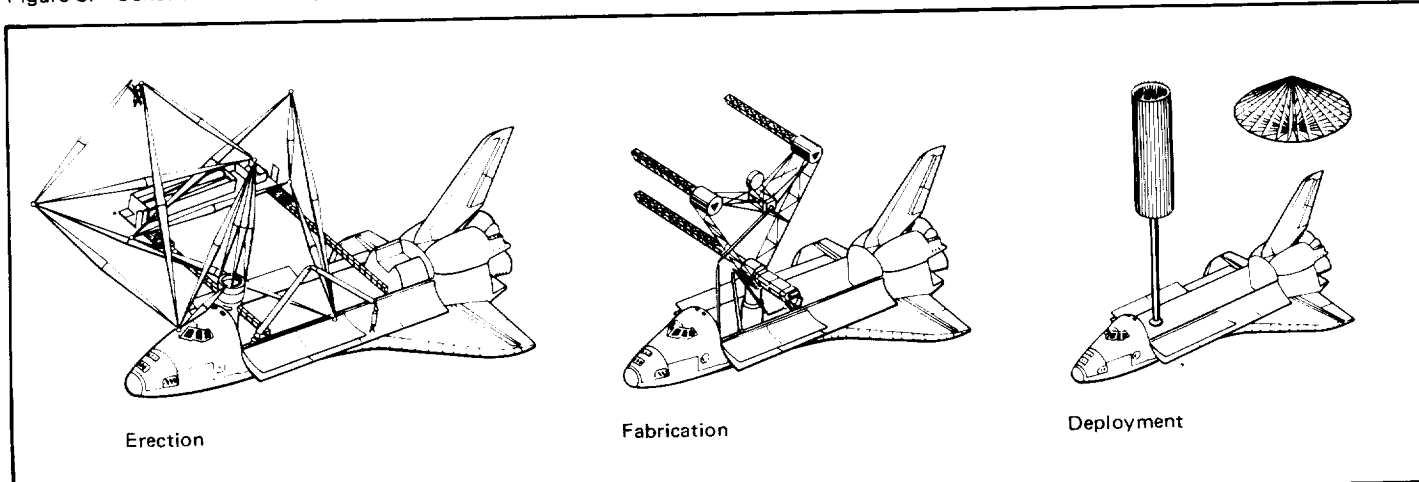
Advanced Synthetic Aperture Radar

The Advanced Synthetic Aperture Radar project is designed to develop a low-cost automated capability to perform active (radar) sensing in multifrequencies and multipolarizations for multi-incidence angles. Such a system would enable multimission execution at a substantial cost savings. An antenna, a calibration technique, and control logic for easy use by principal investigators to enable multimode operations are the critical technologies to be developed. The goal is to develop an aircraft system before developing a space capability.

Large Space Systems Technology

A large space system technology program has been initiated to develop techniques for space construction (fig. 3). These techniques include erection, deployment, and automated fabrication methods.

Figure 3.—Construction techniques.



Automated fabrication is believed to be a key requirement for a viable program to construct large-scale space systems. Some laboratory work is underway to study such machines. In addition to the fundamental construction techniques, numerous other elements of construction systems are being identified (fig. 4).

Large space systems technology advances for fiscal year 1980 include (1) designing and fabricating a full-scale functional model of a hexagonal-frame/berthing-latch interface mechanism, and (2) forming and welding a composite material (graphite-fiber-reinforced thermoplastic) for space structures.

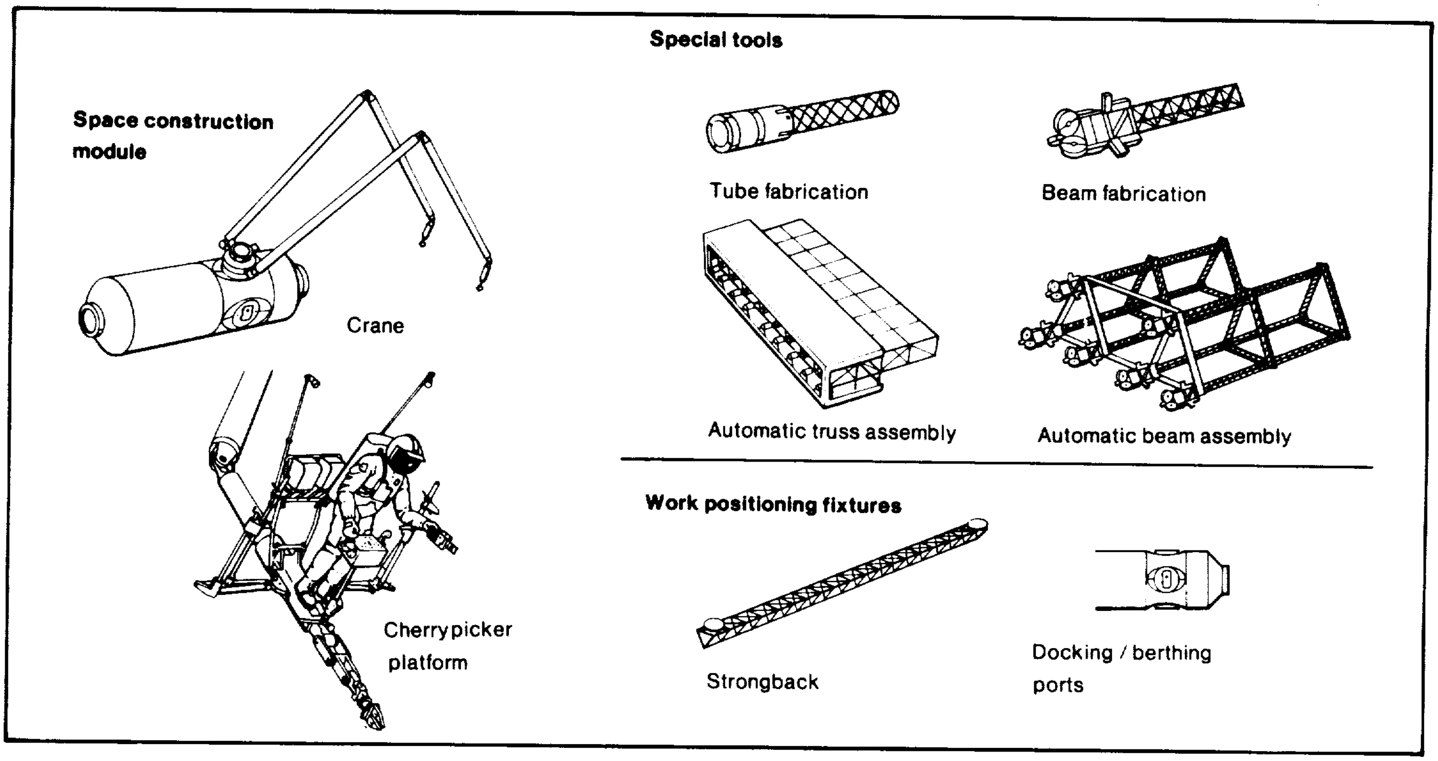
The design requirements for the interface mechanism were derived from an analysis of Orbiter constraints, platform interface requirements, and Orbiter Remote Manipulator System performance.

The graphite-fiber-reinforced thermoplastic has many desirable material properties for application to space structures. It has a high strength-to-weight ratio and modulus of elasticity and exhibits very little thermal distortion. Extensive modifications to an existing bench test machine, which includes use of heaters and coolers, provided forming capability and commercial ultrasonic welding machines joined the material.

Application of Advanced Electric/Electronic Technology to Commercial Aircraft

In fiscal year 1980, JSC conducted a study to evaluate the potential of designing an aircraft that would integrate the many subsystem technology advances during the past decade, including those demonstrated in the Orbiter avionics system. These technologies include (1) redundant digital fly-by-wire flight control and stability augmentation, (2) computer management of vehicle systems, (3) electric actuation for aircraft control surfaces, (4) fiber optics communication and data transmission, (5) laser gyros, and (6) high-voltage electrical power systems. The study concluded that an all-electric secondary power system on a wide-body advanced transport aircraft fleet of 300 aircraft would save $9 billion in direct operating costs over a 16-year period. This conclusion supports further work by NASA in the development of these technologies for aircraft applications.

Figure 4.—Construction system elements.



Office of Space and Terrestrial Applications

Summary

AgRISTARS Program

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) is a 6-year program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources beginning in fiscal year 1980. The program is a cooperative effort of the U.S. Department of Agriculture (USDA), NASA, the U.S. Department of Commerce, the U.S. Department of Interior, and the Agency for International Development.

The goal of the AgRISTARS Program is to determine the usefulness, cost, and extent to which aerospace remote-sensing data can be integrated into existing or future USDA systems to improve the objectivity, reliability, timeliness, and adequacy of information required to carry out USDA missions. The overall approach is comprised of a balanced program of remote-sensing research, development, and testing that addresses domestic resource management as well as commodity production information needs.

The program specifically addresses the seven information requirements identified in the USDA Secretary's Initiative.[1]

1. Early warning of change affecting production and quality of commodities and renewable resources
2. Commodity production forecasts
3. Land use classification and measurement
4. Renewable resources inventory and assessment
5. Land productivity estimates
6. Conservation practices assessment
7. Pollution detection and impact evaluation

While all seven are important to the USDA, the first two—early warning and commodity production forecasting—have been given emphasis because of the immediate need for better and more timely information on crop conditions and expected production.

The technical program is structured into eight major projects, as follows.

1. Early Warning/Crop Condition Assessment
2. Foreign Commodity Production Forecasting
3. Yield Model Development
4. Supporting Research
5. Soil Moisture
6. Domestic Crops and Land Cover
7. Renewable Resources Inventory
8. Conservation and Pollution

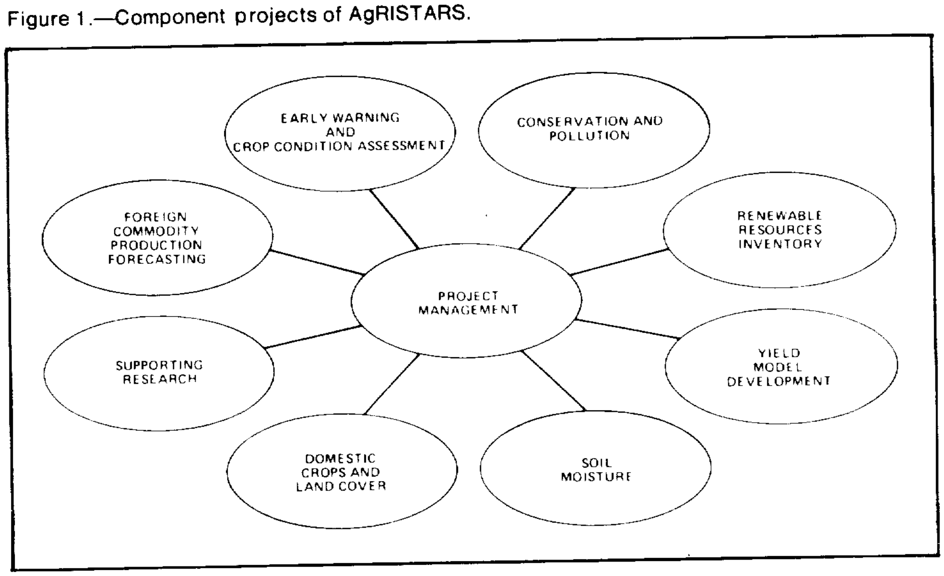
These elements (fig. 1) are interrelated through research, exploratory experiments, pilot experiments, USDA user evaluations, and large-scale application tests.

The Early Warning/Crop Condition Assessment research effort is designed to develop and test the basic techniques required to support the operational crop condition assessment division of the USDA's Foreign Agricultural Service. This effort addresses 20 crop and region combinations in the United States and seven foreign countries (U.S.S.R., Argentina, Brazil, Canada, People's Republic of China, Mexico, and Australia) for six major commodities (wheat, barley, corn, soybeans, rice, and cotton).[2] The techniques used for early warning are assumed to be largely crop dependent and country independent.

[1] Joint Program of Research and Development of Uses of Aerospace Technology for Agricultural Programs, dated February 1978.

[2] These crops and regions may change in response to USDA information needs.

Figure 1.—Component projects of AgRISTARS.



The Foreign Commodity Production Forecasting activity addresses 12 crop and region combinations in the United States and six foreign countries (U.S.S.R., India, Argentina, Brazil, Canada, and Australia) for five major commodities (wheat, barley, corn, soybeans, and rice). This project will develop and test procedures for using aerospace remote-sensing technology to provide more objective, timely, and reliable crop production forecasts several times during the growing season and improved preharvest estimates for the crops and regions of interest. The Foreign Commodity Production Forecasting activity builds upon the existing remote-sensing technology base and extends this technology to additional crops and regions. Large-scale applications testing of candidate technology for making estimates of production in foreign countries will be conducted by the USDA.

The Yield Model Development will support USDA crop production forecasting and estimation by (1) testing, evaluating, and selecting crop yield models for application testing; (2) identifying areas of feasible research for improvement of model usefulness; and (3) conducting research to modify existing models and to develop new crop yield assessment methods.

The Supporting Research project covers research, development, and testing of new and improved remote-sensing technology. Research will be conducted in the following areas as related to applications of remote-sensing technology: area estimation, crop development stage estimation, spectral crop appearance in yield estimation, crop stress, and soils.

The Soil Moisture research is directed toward development of the measurement of soil moisture (in situ and remotely) for potential use in other applications, such as early warning, crop yield estimation, watershed runoff, and vegetative stress assessments.

The Domestic Crops and Land Cover objectives are directed at automatic classification and estimation of land cover with emphasis on major crops. Landsat and advanced sensor data will be used in conjunction with ground data to improve the precision of estimation and classification procedures at the substate level and to investigate change-monitoring techniques.

The Renewable Resources Inventory project involves requirements in seven major problem areas: regional and large-area inventories; current technology assessment; new technology development; detection, classification, and measurement of disturbances; classification, modeling, and measurement of renewable resources; determination of site suitability and land management planning; and analytical and cartographic support to the resource information display system.

The conservation assessment portion of the Conservation and Pollution project addresses applications in three areas: inventory of conservation practices; estimation of water runoff using hydrologic models; and determination of physical characteristics of snowpacks. The pollution portion of the project will provide an assessment of conservation practices through use of remote-sensing techniques to quantitatively assess sediment runoff, to detect gaseous and particulate air pollutants, and to assess their impact on agricultural and forestry resources.

Forest Resource Information System

The prime goal of this project is to determine the viability of using satellite remote-sensing technology for industrial forest management applications in the Southeastern United States. It is a 3-year cooperative project between the Southern Timberlands Division of the St. Regis Paper Company, the Laboratory for Applications of Remote Sensing of Purdue University and the Johnson Space Center (JSC). The project represents the first private sector (wood products industry) user in NASA's Earth resources programs and is significant since the user also shares in the management and cost responsibilities for the implementation of the Forest Resource Information System. JSC is primarily responsible for the contractual support with the Laboratory for Applications of Remote Sensing in developing specified quantifiable forest resource information from Landsat multispectral-scanner data and correlating this information with St. Regis-furnished inventory data on specific test sites. The contractor will develop the software and classification analysis procedures and provide for the technical training of St. Regis personnel. This project also calls for the establishment of a Forest Resource Information System design and implementation based on the project results and, finally, documentation of these results for release to the public domain.

Wildland Vegetation Resource Inventory

A Wildland Vegetation Resource Inventory Application Pilot Test is being jointly undertaken by the Bureau of Land Management of the Department of the Interior and JSC to test and implement an interactive system to assist in the inventory of public lands. This test is presently in the third and final phase. Each phase—Alaska, Arizona, and Idaho—was related to a different ecological zone; the sites were carefully selected to represent the varied lands under the management of the Bureau of Land Management. The Alaska phase, which began in May 1977 and was successfully completed in July 1978, was primarily a land-cover inventory of approximately 2.5 million acres in South Central Alaska. The Arizona phase, October 1978 through June 1980, not only used the experience and knowledge gained in the Alaska project but went one step further by developing productivity estimates for range forage (pounds per acre) and forest and woodland volume (cubic feet per acre) by type. The Bureau of Land Management tested the knowledge gained during the project by doing an independent land-cover classification of the Arizona Test Site. The Bureau of Land Management is presently conducting a project over the Idaho Test Site using all the capabilities learned during the other two phases of the Application Pilot Test. The NASA contractor is completing project documentation and transfer of the technology to the Bureau of Land Management with the Application Pilot Test scheduled for completion in March 1981.

Texas Application System Verification and Transfer

The JSC is participating with the State of Texas in a joint Application System Verification and Transfer Project to develop, evaluate, and transfer techniques for applying Landsat and other data to the needs of Texas natural resources management agencies. The major objectives of the project are (1) to update and integrate state-of-the-art remote-sensing technology with other information sources available to the State to form a functional Texas Natural Resources Inventory and Monitoring System, and (2) to test and evaluate the utility and cost-effectiveness of natural resource information derived from Landsat data and other sources when applied in a total system context to selected State agency management activities. The Texas Applications Project began in June 1978 and spans 3 years.

The remote-sensing component of the system is NASA's major responsibility. A prototype of the system will be operational on Texas facilities in late 1980. The system is being tested and evaluated in support of application categories in the areas of coastal zone management, forestry, water resources, mineral resources, and wildlife management.

Office of Space Sciences

Summary

Lunar and Planetary Sciences

During fiscal year 1980, planetary sciences came of age at the Johnson Space Center (JSC) as evidenced by the broad range of experimental and theoretical investigations currently being pursued. Sample-oriented research on lunar and meteorite materials continues to be the major activity of JSC scientists. New and continued studies of Mars, Venus, and the Galilean satellites of Jupiter demonstrate involvement in up-to-date planetary research. The consolidation of research on the ancient crust of the Earth has been gratifying as such research will form a solid base for planetary research during the decade of the 1980's.

The activities of JSC in lunar and planetary sciences that are summarized in the following paragraphs include lunar studies, meteorite studies, Earth's ancient crust, Mars, Venus, cosmic dust, comets, Galilean satellites, cratering, and technology.

Lunar Studies

As research in Lunar and Planetary Sciences diversifies, the fraction of total effort devoted to lunar studies continues to decrease and now accounts for about one-third of the total; but there are three investigations that demand special mention.

A study of the relative composition of the elements samarium, titanium, and scandium in lunar plutonic rocks found that the processes that are responsible for the formation of the lunar crust were strongly constrained. This work demonstrated that anorthosites did not experience a previous ilmenite fractionation whereas norites and troctolites did. Conversely, all plutonic rocks experienced some previous pyroxene fractionation, although this effect is more important for the norites and troctolites than it is for the anorthosites.

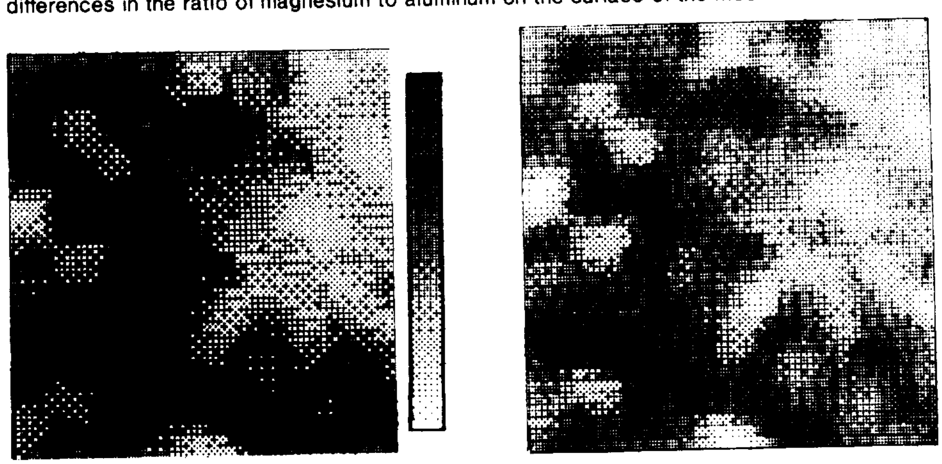
The rocks that form the lunar crust are widely believed to have formed from an outer shell of liquid rock several hundred kilometers thick early in lunar history. A problem is how to account for the compositions of the observed rocks if the liquid shell, called a magma ocean, has a composition like the bulk Moon. A study of the effects of impact showed that the impacts that account for the accretion of the Moon were of relatively low velocity and as such could not produce impact melts. However, impact melts are melts with compositions of the bulk Moon. What low velocity impacts can produce is general heating which, in excess, will produce partial melting. A magma ocean formed by partial melting will be basaltic, and not of bulk Moon composition. This idea simplifies the problem of accounting for the compositions of the observed rocks.

One of the most important Apollo experiments was the X-ray map of a portion of the Moon obtained during Apollo 15 and 16. However, the usefulness of that data has been very limited because of the low spatial resolution. One scientist, in a new effort using image-enhancement techniques, has improved the spatial resolution of the X-ray data by a factor of two (fig. 1). This advance should provide the grist for many interpretative investigations.

Meteorite Studies

The JSC continues to be involved in the collection and curation of Antarctic meteorites in association with the National Science Foundation and the Smithsonian Institute. The meteorites are proving to be a vast storehouse of secrets concerning the solar system. The early examination of the meteorites in the meteorite laboratory is yielding important new data concerning meteorite populations.

Figure 1.—An example of a portion of the X-ray map for the Moon revealing the improved resolution and contrast of geochemical "pictures." The two views illustrate the power of the new JSC image enhancement technique. The improvement in spatial resolution is obvious by inspection of the two images generated by a computer printer. The density of the regions represent differences in the ratio of magnesium to aluminum on the surface of the Moon.



Original
Southeast Mare Serenitatis

Enhanced
By Laplacian Subtraction

Research on Antarctic and other meteorites covers a range of descriptive topics. A particularly important result involves the discovery of a young age for several achondritic meteorites.

Earth's Ancient Crust

Recognition that the Earth is a planet that is accessible to detailed study has directed significant effort to use the Earth as a model for the general planetary process of crustal formation. JSC efforts have been directed toward the origin and development of the Earth's continental crust. Several parallel studies are being followed in the disciplines of geochemistry, petrology, geochronology, and field geology. One project consists of systematically locating and documenting the oldest rocks in North America. Rocks as old as 3700 million years have been found in Minnesota and rocks as old as 3200 million years have been discovered in Ontario, Wyoming, and Montana, although much of this ancient terrain is only 2800 million years old (fig. 2). Both petrography and geochemistry are being performed on these ancient rocks.

Ancient anorthosites from Minnesota and Ontario are being investigated as a model for the basaltic growth of continents. Recent work has demonstrated that ancient anorthosite complexes are chemically richer in aluminum than younger anorthositic complexes.

Theoretical studies are attempting to integrate the knowledge gained directly from the Moon and apply it to the study of the Earth. Models have been generated that demonstrate how an Earth magma ocean would work and what type of crust it would produce. The possible existence of an Earth magma ocean is being investigated by a worldwide study of the oldest rocks on Earth.

Mars

There are several studies underway to learn about weathering on Mars. One study uses soil core tubes collected from the dry valleys in the Antarctic because those valleys are candidate analog environments to the cold dry conditions on Mars. A second experimental study uses a Mars weathering simulation chamber. The chamber experiments demonstrate that Mars is heated by sunlight and that the heating causes Mars to be red.

Venus

Venus is Earth's twin in size and density, but its surface is very different. The Venusian atmosphere is very hot (500° C) and consists of carbon dioxide with small amounts of sulfuric acid. A study to understand the surface environment has been performed and a model has been produced that suggests that the bottom of the Earth's oceans is a good analog to the surface of Venus. The model suggests that the very level surface of Venus (fig. 3) is due to windblown sediments and that the material in the level part of Venus is transported from the few plateau regions.

Cosmic Dust

JSC is pursuing a twofold thrust involving the collection and population analysis of cosmic dust. Population analysis flows from data collected on the Pioneer 10 and 11 spacecraft; new data will be obtained from the Galileo spacecraft. Collection studies are

Figure 2.—Isochron diagram for some ancient crustal rocks discovered in the Beartooth Mountains of Montana and Wyoming. This diagram shows that approximately 50 analyzed rocks fall on a line that yields an age of 2780 million years. The plot is based on the Rb-Sr radioactive decay system. ^{87}Rb decays to ^{87}Sr and ^{86}Sr is used as a normalization parameter. As a system ages, the line defined by the analyzed points rotates counterclockwise. The steeper the line, the older the rock system.

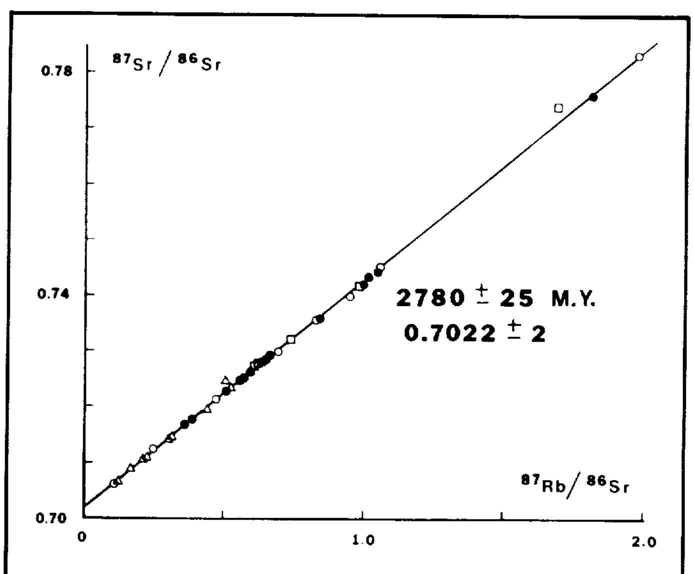
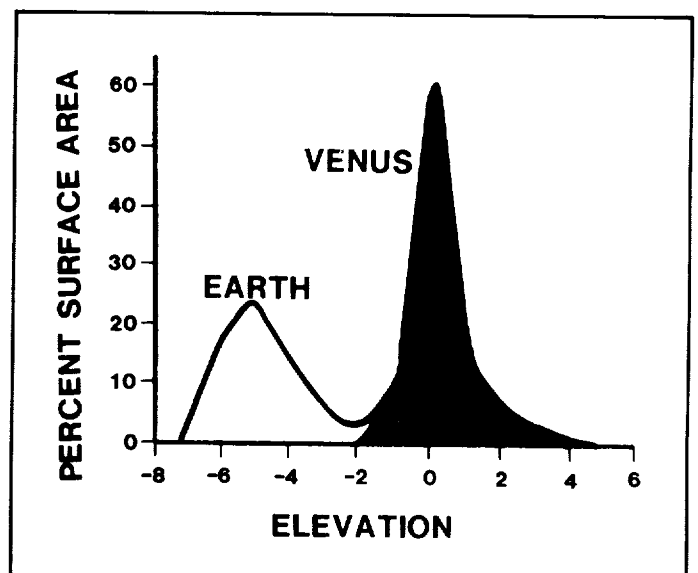


Figure 3.—Plot demonstrating the differences in the surface topography of Earth and Venus. This diagram shows that 60 percent of the Venusian surface has an elevation within 0.5 kilometer of the mean elevation. By contrast, Earth displays a much wider range of surface elevations. The two peaks on the Earth curve represent typical continental elevation and typical ocean bottom elevation.



based on spacecraft and airplane flights. The spacecraft experiment will consist of a cosmic dust collector on the Long Duration Exposure Facility that will remain in Earth orbit for over 1 year. The aircraft program consists of collecting cosmic dust on high-flying JSC aircraft. The collectors for the aircraft program are being fabricated and the first collection will be made in fiscal year 1981. Expectations are that much new and important data will be obtained from these collected materials.

Comets

One of the most exciting activities during 1980 was formally proposing two flight instruments for NASA's proposed mission to Comet Halley and Tempel-2. Both instruments were designed to collect comet dust and perform geochemical analysis on that dust. One instrument, the scanning electron microscope, analyzes individual dust particles for particle morphology and size and analyzes major elements and organic molecule content. The other instrument analyzes a bulk sample of comet dust for trace elements and isotopic composition and obtains an age for the comet (fig. 4).

Galilean Satellites

A new project was initiated in 1980 to study the global tectonics of Ganymede, the largest satellite of Jupiter. The contrasting dark and light cratered grooved portions of Ganymede are being interpreted as being in plate-tectonic relation to each other. The dark portions of Ganymede drift relative to each other and the light portion is a filler between the dark plates. A theoretical study was also performed to investigate the internal mineralogy of Io, the volcanic satellite of Jupiter. This study is based on a calculated phase diagram for the system iron-sulfur-oxygen. Voyager results prompted both of these studies.

Cratering

Cratering studies, which receive a continuing strong emphasis, have resulted in the publication of a major new model for the mechanics of crater formation as a function of the impacting projectile's composition and velocity and target composition and volatile content. This model was used to predict the effects of cratering on icy planets.

Technology

A major technology effort to improve the curation of Moon rocks and meteorites was completed with the opening and operation of the Lunar Curatorial Facility. Technology efforts also continue in a range of analytical endeavors. Fiscal year 1980 marked the first direct dating of an anorthosite. (The Adirondack Anorthosite is 1200 million years old.) Image enhancement of lunar X-ray data and new instrumentation for flight experiments have been mentioned previously.

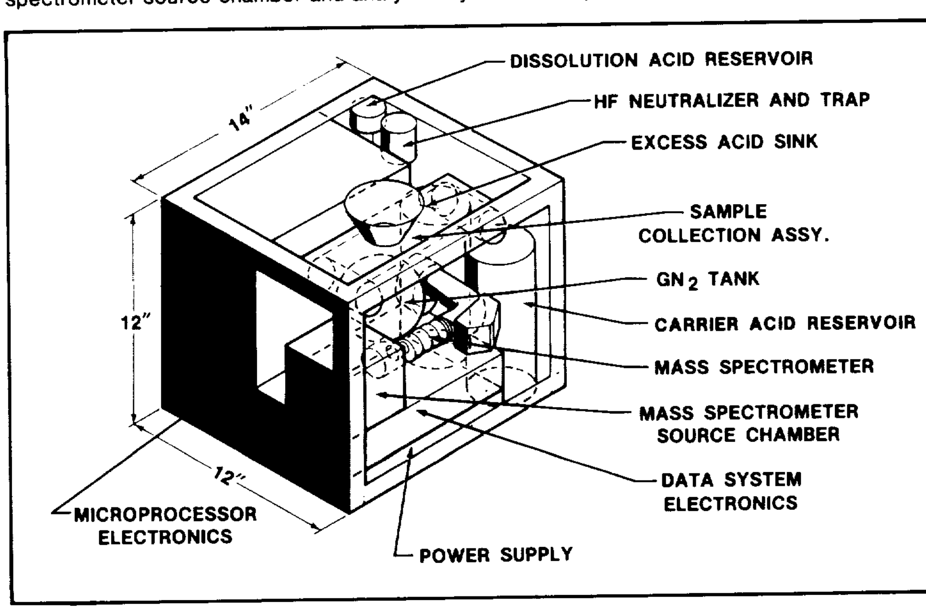
Life Sciences

The Medical Sciences Division of the Space and Life Sciences Directorate at JSC conducts a broad range of medical research and operations activities in support of the goals of the Office of Space Science. The basic objective of these activities is to assure the health and safety of all those who fly in space. In pursuing this objective, every effort is made to increase man's knowledge of the medical sciences and to apply this knowledge to the solution of man's problems on Earth as well as in space.

Research areas of significance to manned space flight include neurophysiology (space motion sickness), cardiovascular physiology, bone and muscle metabolism, endocrinology, and microbiology. The technology developed in carrying out investigations in these areas has resulted in several significant advancements in medical research during the past year.

An area of research of considerable importance to the Space Shuttle Program is that of space motion sickness. Although less than half of all those who have flown in space have shown any symptom of space motion sickness, this illness can incapacitate an affected crewman for several days. Thus, it is important that all avenues of research be explored thoroughly to assure that every step is taken to understand the cause, the effect, and the treatment of this space-associated

Figure 4.—Assembly diagram for the mass spectrometry isotope dilution experiment that JSC proposed for the Comet Halley/Tempel 2 mission. The sample collection assembly has a funnel to aid in collection of comet dust by concentration. The collected dust would be chemically processed using the dissolution and carrier acids with the excess acid being deposited in the excess-acid sink. The processed sample would be deposited on a filament in the mass spectrometer source chamber and analyzed by the mass spectrometer.



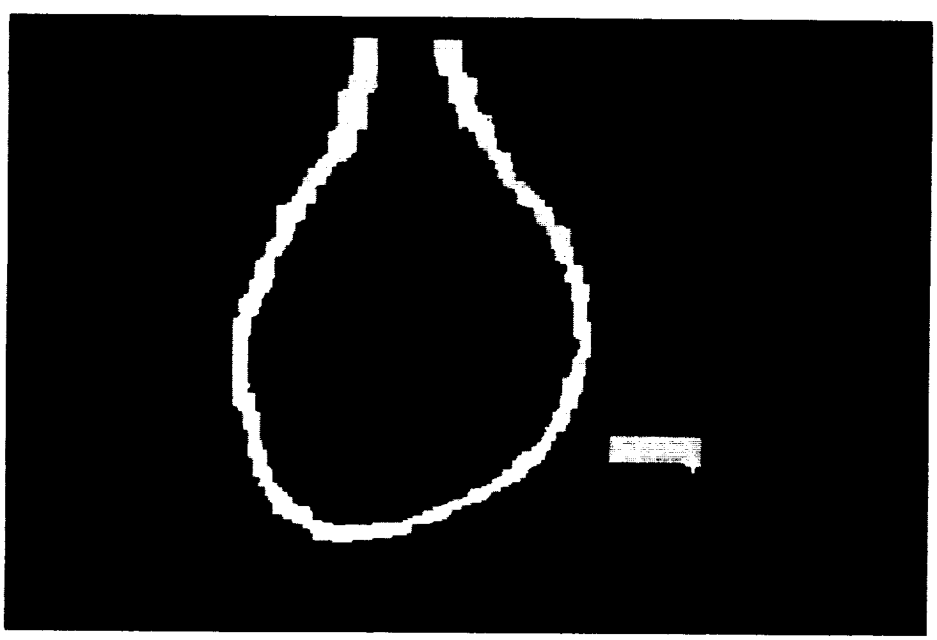
syndrome. It is widely accepted that alterations of the otolith receptors of the inner ear are primarily responsible for the vestibular disturbance that is characterized by the symptoms of motion sickness in space. Linear acceleration is one of the very effective stimuli used to induce a response in the otolith receptors. To study the otolith receptor and its response to controlled changes, a linear accelerator designed to carry one man was developed by NASA in conjunction with the University of Michigan.

A particularly promising application of NASA technology is the utilization of the multiwire proportional counting technique in medical imaging of cardiovascular performance. This device provides a series of pictures produced by injecting a short-lived radioisotope into the bloodstream and counting the radioactive particles given off as the isotope moves through the heart. Figure 5 shows a cardiac phantom with the image processed to display edge contour. The image was obtained with the phantom at diastole (140 milliliter volume) using a tantalum-178 tracer. This system can obtain measurements for determination of stroke volume, ventricular ejection fraction, and heart chamber wall movements that have significant diagnostic value in cardiology.

Over the past several years, NASA and the Baylor College of Medicine have cooperated in the development, testing, and use of a mobile biological isolation system. This system was developed for use by a young child afflicted with a severe immunization deficiency. During the past year, additional efforts have been made to improve this system.

The JSC Engineering and Development Directorate and the Space and Life Sciences Directorate cooperated with the Stehlin Foundation for Cancer Research in the development of improved radiofrequency heating techniques for the treatment of certain types of cancer. This project utilized NASA technology and expertise to develop a system for experimental treatment of small animals. This system was the prototype for a second system that was developed and used in the treatment of certain tumors in human patients.

Figure 5.—Cardiac phantom with image processed to display edge contour.



Significant Tasks

Office of Space Transportation Systems

Significant Tasks

23 Space Operations Center System Analysis

Funded by: Major Systems Studies (UPN-906)
Technical Monitor: S. H. Nassiff/EB
Task Performed by: Boeing Aerospace Company
Contract NAS 9-16151
Rockwell International
Contract NAS 9-16153

24 Power Extension Package Power Conditioning Evaluation

Funded by: Advanced Development (UPN-906)
Technical Monitor: W. C. Stagg/EH5
Task Performed by: Lockheed Engineering and Management Services Company, Inc.
Contract NAS 9-15800

25 Manned Remote Work Station Development

Funded by: Advanced Development (UPN-906)
Technical Monitor: S. H. Nassiff/EB
Task Performed by: Grumman Aerospace Corporation
Contract NAS 9-15881

26 Maneuverable Television

Funded by: Advanced Development (UPN-906)
Technical Monitor: R. H. Gerlach/ED4
Task Performed by: Lockheed Engineering and Management Services Company, Inc.
Contract NAS 9-15800

27 Advanced Extravehicular Crewman Work System

Funded by: Advanced Development (UPN-906)
Technical Monitor: M. Rodriquez/EC2
Task Performed by: Hamilton Standard Division
Contract NAS 9-15290

28 Satellite Population Assessment

Funded by: Advanced Development (UPN-906)
Technical Monitor: D. J. Kessler/SN3
Task Performed by: Lockheed Engineering and Management Services Company, Inc.
Contract NAS 9-15800
Analytical Computational Mathematics Inc.
Contract NAS 9-15883
Western Electric Co., Inc.
Contract NAS 9-16127

30 Solid Polymer Electrolyte Fuel Cell

Funded by: Advanced Development (UPN-906)
Technical Monitor: D. Bell III/EP5
Task Performed by: General Electric Company, DECP
Contract NAS 9-15286

31 Space Construction Experiments Concepts

Funded by: Major Systems Studies (UPN-906)
Technical Monitor: L. M. Jenkins/EB
Task Performed by: Rockwell International
Contract NAS 9-15718

32 Space Construction System Analysis

Funded by: Major Systems Studies (UPN-906)
Technical Monitor: S. H. Nassiff/EB
Task Performed by: Rockwell International
Contract NAS 9-15881

33 Loads and Dynamics of Variable-Geometry Structures

Funded by: Advanced Development (UPN-906)
Technical Monitor: John Schliesing/ES2
Task Performed by: Grumman Aerospace Corporation
Contract NAS 9-15895

34 Manned Geosynchronous Mission Requirements and Systems Analysis

Funded by: Major Systems Studies (UPN-906)
Technical Monitor: H. G. Patterson/EB
Task Performed by: Grumman Aerospace Corporation
Contract NAS 9-15779

35 Fiber Optics Multiplexing

Funded by: Advanced Development (UPN-906)
Technical Monitor: E. A. Dalke/EH42
Task Performed by: McDonnell Douglas Astronautics Company
Contract NAS 9-15585

36 High-Power Traveling-Wave-Tube Amplifier

Funded by: Advanced Development (UPN-906)
Technical Monitor: B. Kilker/EE3
Task Performed by: Hughes Aircraft Company
Contract NAS 9-15235

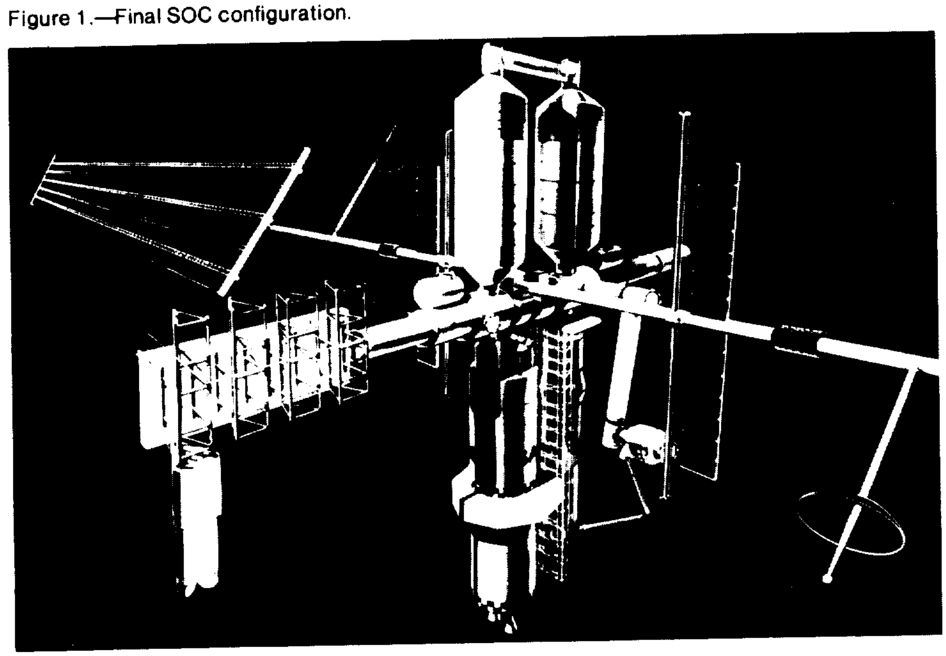
Space Operations Center System Analysis Study

The Space Shuttle will be the primary mode of space transportation for the next decade and will serve as the initial space base or platform for a number of planned missions of relatively short duration. However, many mission payload concepts now being proposed and under study will require operational support capabilities beyond those of the Space Shuttle. Future planned programs and projects indicate a need to deploy, assemble, and construct large systems in space and to support long-duration missions for science and applications, satellite servicing, technology development, and flight support for orbit transfer spacecraft. Additionally, a larger multiskilled crew will be required with the necessary habitability provisions and with provisions for increases in electrical power, communications, multidocking or berthing, propellant storage and transfer, and construction and manipulator equipment. A facility such as the Space Operations Center (SOC) is needed to provide these operational capabilities to accomplish current and future planned programs and projects.

The Space Operations Center system analysis performed by Boeing Aerospace Company will include identification of a mission model and requirements for facilities for construction, flight support, and satellite servicing. An overall system analysis will be performed that will include technology assessment for the SOC program. Rockwell International will analyze SOC/Shuttle interaction and will address the issues of Orbiter docking or berthing with SOC, SOC assembly and buildup, resupply and propellant transfer, and more specifically, SOC flight support facility requirements. A SOC assembly and buildup is shown in figure 1.

The output of the SOC/Shuttle interaction effort will be an input to the overall study of the SOC concept which has been underway in-house at Johnson Space Center for the past several years. Emphasis will be placed on the identification of constraints imposed by the Space Shuttle in its interaction with the SOC and on design or technical solutions that will allow satisfactory accomplishment of the interactions. The overall system analysis study will then provide SOC system requirements, system description, system analysis results, and a technology assessment and advancement plan that will be used in future development activities.

Figure 1.—Final SOC configuration.



Power Extension Package Power Conditioning Evaluation

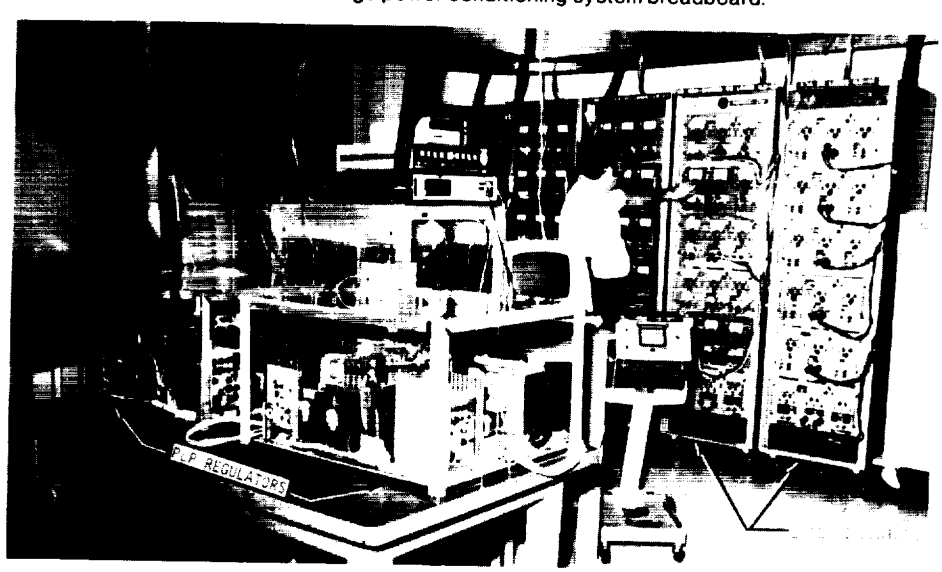
A highly critical element in the Power Extension Package (PEP) (fig. 1) system design is the choice of the power conditioner or voltage regulator used to convert the unregulated high voltage (130 to 170 V dc) at the output of the PEP solar array to regulated low voltage (30 V dc) for the Orbiter electrical power system. The conversion efficiency and peak-power-tracking efficiency of the regulator design are important because both affect the size, and consequently the cost, of the PEP solar array required to deliver 26 kilowatts electrical power to the Orbiter at the array end-of-life. Conversion efficiency is also important because it determines the heat load imposed on the Orbiter thermal control system by the regulators. Other factors that are critical are the overall system operating stability, the ripple produced, and the transient response when the regulators are supplying the Orbiter electrical buses in parallel with the Orbiter fuel cells. Early attempts to gather regulator performance data on which to base PEP regulator selection proved futile because of the immature development status of suitable regulators and the unique nature of the PEP application.

A study was initiated at JSC in April 1978 that had multifold purposes: (1) to conduct an industry-wide survey to determine predicted performance parameters for a number of regulators in various stages of development, (2) to select three or four of the most promising design approaches and obtain breadboard models for detailed evaluation testing in the Shuttle/Orbiter Electrical Power Distribution and Control (EPDC) breadboard (fig. 2) at JSC (the only high-fidelity simulation of the entire Shuttle/Orbiter electrical power system in existence), and (3) to select one or more successful models for further testing with an actual Orbiter fuel cell to validate the breadboard test results and to investigate fuel cell performance in the PEP operating mode. Following completion of the industry survey, four candidate regulator designs were chosen for testing in the EPDC breadboard: (1) a McDonnell-Douglas buck regulator, (2) a NASA Marshall Space Flight Center programmable power processor (P^3) (buck regulator), (3) a Lockheed Missiles and Space Company transformer-coupled converter, and (4) a series resonant converter from Wright-Patterson Air Force Base modified for the PEP application. A simulated single-string PEP was added to the Orbiter EPDC breadboard, including a high-fidelity solar array simulator, high- and low-voltage distribution wiring, and high-power switching contactors and fusing. Test plans and procedures were developed and testing began in August 1979. The parameters evaluated included conversion and peak-power-tracking efficiencies; input and output ripple; response to a variety of load transients; regulator and fuel cell load sharing at various regulator output voltage set points; and overvoltage, overload, and short circuit fault protection techniques.

To date, three of the four regulators have been tested in the EPDC breadboard with results that tend to verify earlier predictions of PEP performance. Buck-type as well as transformer-coupled converters/regulators have been demonstrated to operate with conversion efficiencies as high as 92 percent and peak-power-tracking efficiencies as high as 99 to 99.5 percent. Load sharing between the regulators and the fuel cell simulator has been as expected and varies with regulator voltage as predicted. Final verification of these results is expected to be achieved through actual fuel cell tests during early 1981.

Figure 1.—Orbiter Power Extension Package.

Figure 2.—Power Extension Package power conditioning system breadboard.



Manned Remote Work Station Development

A prime Space Shuttle requirement is that the Shuttle will have the capability to service the satellites that are attached in the payload bay and detached in a free-flying mode. Studies have identified the specific hardware development necessary for the extravehicular activity (EVA) astronaut to increase orbital productivity for satellite servicing and maintenance, inspection, and repair of the Orbiter. One identified need is to provide the astronaut with a stable platform from which he can perform a variety of work functions coupled with the capability to transport replacement modules to and from the Orbiter. The manned remote work station "open cherrypicker" (OCP) is a versatile system that can provide these capabilities. The cherrypicker is attached to the end of the Orbiter Remote Manipulator System (RMS) and the RMS and OCP are controlled and operated by an EVA astronaut located on the OCP work platform. The cherrypicker will not only enhance Space Shuttle operations in the near term for satellite servicing, but it will also provide the capability to demonstrate early onorbit construction techniques and operations that can be used to optimize construction of future large-system projects.

A program that includes flight-qualified basic OCP structure and development test article components and mechanisms has been formulated for early OCP flight demonstration. This approach includes engineering simulations, environmental testing, water immersion facility (WIF) tests, ground and flight tests, and hardware development and cost for a flight article available by 1985. A simulation program has been developed and is currently underway to perform OCP systems evaluation and to demonstrate satellite servicing using a six-degree-of-freedom simulator. The open cherrypicker is shown servicing a satellite attached to the Orbiter payload bay in figure 1.

Two full-scale OCP development test articles (DTA's) have been built. One has been used in recent water immersion facility testing at JSC to evaluate system components and operation. The other OCP is located at Grumman Aerospace Corporation on the six-degree-of-freedom simulator. Additional WIF tests are planned to evaluate the cherrypicker subsystems and to demonstrate satellite servicing. The OCP DTA will be integrated with the JSC Manipulator Development Facility in mid-1981 and used in simulations on the end of the RMS arm while both are supported on an air-bearing floor (fig. 2). Future applications of the manned remote work station include closed pressurized cabin versions, railed work stations, and free-flying work stations.

Figure 1.—Open cherrypicker simulation.

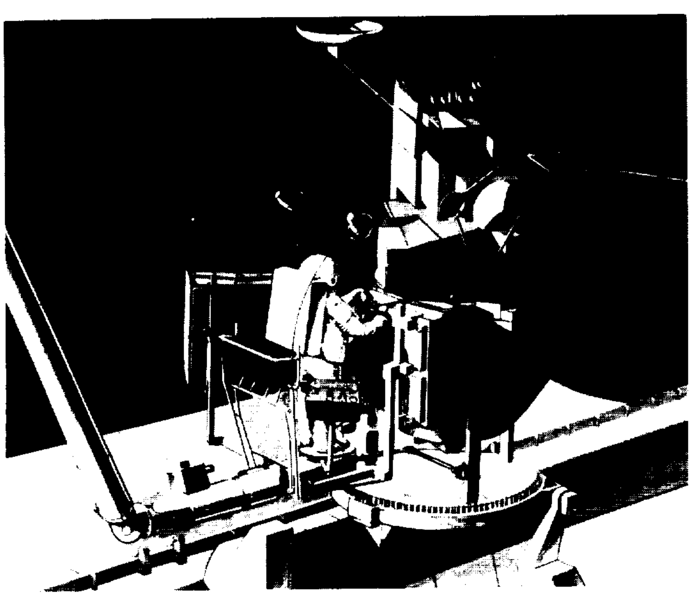
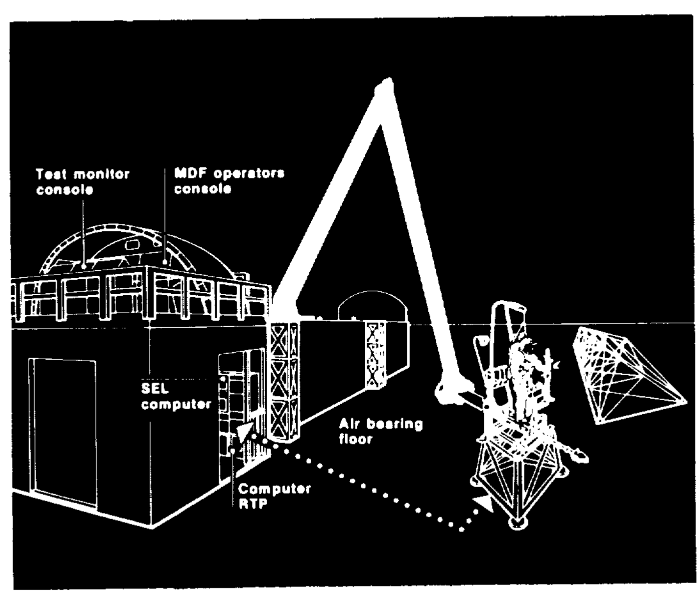


Figure 2.—The manipulator development facility and the open cherrypicker on the air-bearing floor.



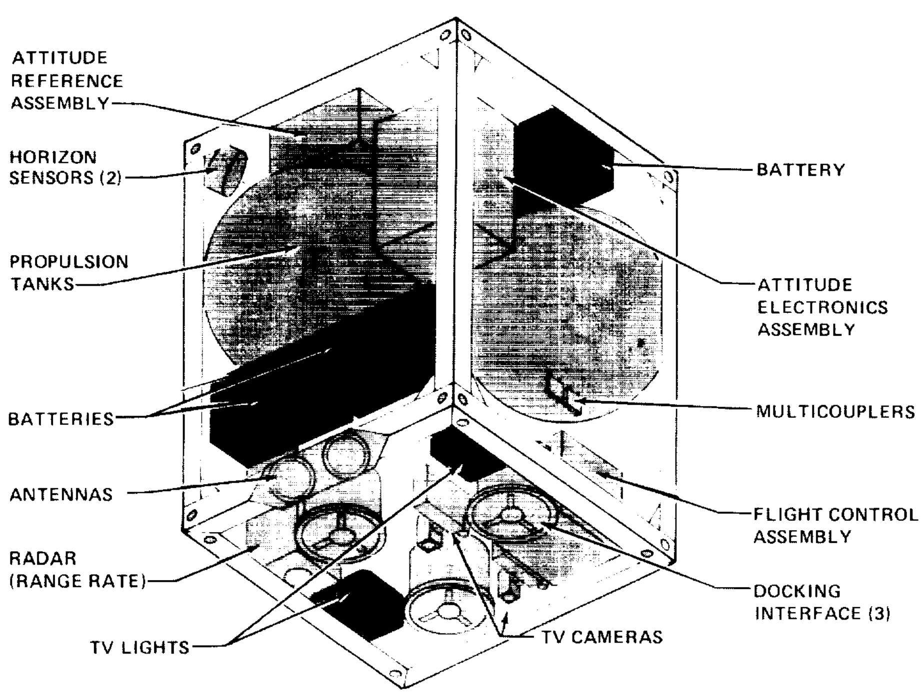
Maneuverable Television

The Space Shuttle mission model includes many payload deployment and retrieval operations to support satellite servicing. Many payloads will require inspection and may require maneuvering assistance during deployment and retrieval. The Maneuverable Television (MTV) (fig. 1) is a versatile subsatellite to support the satellite services requirements for the Orbiter by providing this remote capability.

A study was initiated in fiscal year 1978 to define an inspection and documentation device that could extend the remote television viewing capability of onorbit cameras attached to the Orbiter vehicle and to the remote manipulator. The effort identified a maneuverable television concept for a subsatellite that will free-fly in the vicinity of the Orbiter. This television is remotely controlled by the crew of the Orbiter and is directed by a crewman to fly to the desired inspection point. The maneuverable television is approximately 1 meter on each side and is berthed in the payload bay of the Orbiter. Docking and undocking is remotely controlled and real-time transmission is provided to the crew during flight. An in-house JSC program was initiated in fiscal year 1980 to define and develop an engineering model of the MTV to demonstrate feasibility.

The subsystems of the vehicle were identified and designed using primarily off-the-shelf equipment. The components and parts have been fabricated at JSC and the electronic boxes have been obtained. A flight control system computer model has been developed for analysis. The full-scale chassis has been assembled and the subsystem components are being installed. The full-scale engineering model will be completed in fiscal year 1981. The model will be operated on the air-bearing facility at JSC.

Figure 1.—The Maneuverable Television.

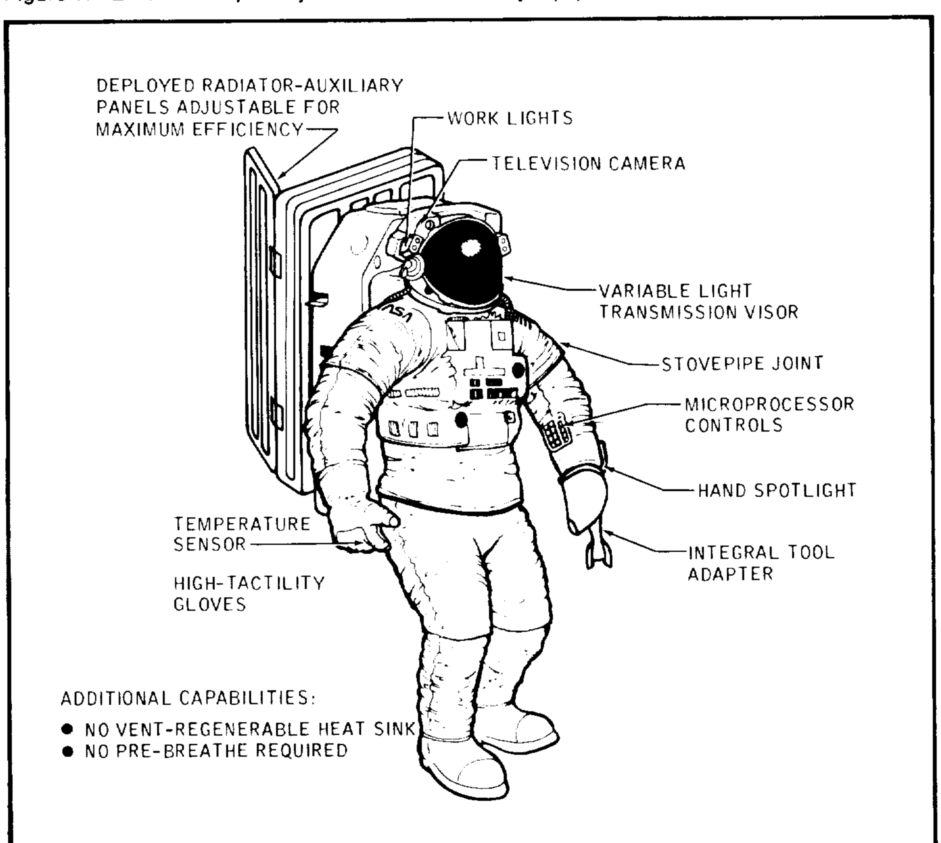


Advanced Extravehicular Crewman Work System

As the Space Shuttle Program matures, a "next generation" extravehicular activity (EVA) work system will be required to support advanced activities such as satellite servicing and long-range missions such as the Space Operations Center. Satellite servicing will necessitate a sophisticated EVA system that not only allows the crewman to perform the required activities but also incorporates high-technology diagnostic equipment for fault isolation. To properly support typical Space Operations Center activities, there is a need to improve the existing EVA technology base so that routine low-overhead long-duration noncontaminating EVA's can be conducted.

The advanced Extravehicular Crewman Work System study was initiated to explore the additional requirements imposed by the new Space Transportation System (STS) operations inherent in the NASA 5-year plan. The study, which was completed in July 1980, was to generate an Extravehicular Mobility Unit (EMU) development/growth plan to coincide with the projected development of the STS. The results indicate a need for a phased development initially aiming at satellite servicing and gradually evolving into the development of the subsystems required for EVA operations in high-energy orbits.

Figure 1.—Enhanced capability extravehicular activity equipment.



Promising EMU design improvements include (1) liquid absorbent for carbon dioxide that is regenerated electrochemically in the spacecraft, (2) a thermal control concept using a radiator on the rear surface of the portable life support system (fig. 1) as part of a simple vapor compression refrigeration cycle to reject heat, (3) lithium thionyl chloride or sulfuryl chloride batteries for increased energy density and recharge capability, and (4) advanced microprocessor techniques for controlling supply and demand by adjusting ventilation and water controls to the crewman and to the refrigeration compressor.

For the space suit assembly, candidate concepts include (1) an electronic transparency control for the visor areas to provide automatic peripheral sunshades and glare protection, (2) the application of magnetic-pulse-forming technology to improve the integrity of fabric-to-metal space suit attachments, (3) use of single-piece toroidal mobility joints based on heat-shrinking a combination bladder/restraint layup on a master mandrel to eliminate the reliance on costly sewn seam construction, (4) use of a triaxial fabric to provide better load distribution and avoid fabric distortion, (5) improved shoulder joint using truncated or "stovepipe" surfaces, and (6) an integrated glove/tool end adapter to provide a powered tool assembly universally adaptable to a variety of applications.

Satellite Population Assessment

As the number of artificial satellites orbiting the Earth continues to increase, the possibility that they may interfere with future operations in space also increases. Research is being conducted to identify potential hazards, evaluate alternatives, and recommend policy changes as necessary. The analysis to date has identified three areas of concern: the hazards from the tracked population, from the untracked population, and from the future population. These concerns are identified for both low Earth orbit (less than 2000 kilometers) and geosynchronous orbit.

Tracked Population

The NORAD is currently tracking approximately 4700 objects in space. Most of them appear to be larger than about 10 centimeters in diameter, in low Earth orbit, and to originate from explosions either from U.S. spent stages or from U.S.S.R. antisatellite tests (table I). The observed growth has been between 10 and 13 percent/yr with the greatest concentration between 500 and 1100 kilometers. The probability of collision for a 50-meter-radius spacecraft is calculated to be 0.005/yr at 500 kilometers and 0.01/yr at 1100 kilometers. For geosynchronous altitudes, the calculated probabilities are between 1×10^{-5} and 1×10^{-4}/yr. However, only objects larger than approximately 1 meter in diameter are detected at this altitude.

Untracked Population

Knowledge that an untracked population exists follows from two principal sources: (1) that the more than 50 explosions in space would have been expected to have produced many objects too small to be tracked and (2) that objects that appear to be as small as 4 centimeters in diameter are frequently detected by NORAD radar just prior to reentry. Objects of this size are sufficiently energetic in low Earth orbit that, at their average relative velocity of 10 km/s, they would penetrate approximately 20 centimeters of solid aluminum upon collision. Based on the observed number of these objects at 400 kilometers and on the size distributions that could be expected from low-intensity explosions, collision probabilities can be estimated. The probability of collision for a 50-meter radius spacecraft with the 4-centimeter and larger population is estimated to be 0.01/yr at 500 kilometers and 0.05/yr at 1100 kilometers. These probabilities are surely higher for smaller debris but insufficient data exist to make a reasonably accurate estimate. At geosynchronous altitude, the population to 4 centimeters may be approximately a factor of 10 larger than the observed population, leading to an estimated collision probability between 0.0001 and 0.001/yr.

TABLE I.— SOURCE OF IN-ORBIT POPULATION TRACKED BY NORAD

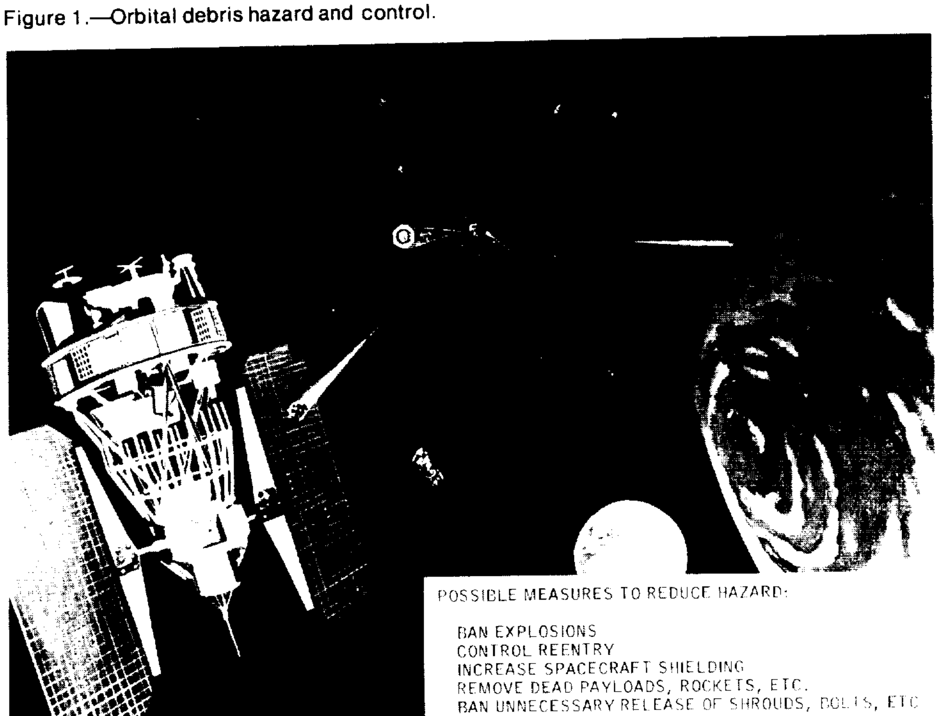
SPACE OBJECT	PERCENTAGE OF TRACKED POPULATION IN ORBIT	NOTES
Operational payloads	5	Distributions are roughly equally divided between the U.S.S.R. and the United States.
Nonoperational payloads	12	
Mission related (rocket bodies, shrouds, etc.)	18	
Explosion fragments	54	6 Delta stages 20 percent; 3 Agenas 12 percent; 2 other 10 percent (United States 42 percent); 8 U.S.S.R. satellite tests 12 percent
To-be-determined origin	11	Whereas a certain fraction of these objects may prove to be nonexistent, most are probably explosion fragments. Many will reenter before they become part of the official catalogue. Some are in geosynchronous orbit and are possibly refound objects with orbits that are no longer maintained.

Future Population

If past trends continue, the number of objects in space can be expected to double to quadruple within the next 20 years, thus increasing the previous probabilities by a corresponding amount. However, more importantly, there may be a sufficient number of objects in space that several collisions could be expected between non-operational objects in low Earth orbit (fig. 1). The consequences of only one of these collisions would be to produce a distribution of fragments that includes 1.4×10^4 particles larger than 1 centimeter and 3.5×10^6 particles larger than 1 millimeter. A 1-centimeter object in low Earth orbit would penetrate a 5-centimeter thickness of solid aluminum. The collision frequency on a 50-meter spacecraft with the 1-centimeter population in the year 2000 could be about 0.1/yr at 500 kilometers and 1/yr at 1100 kilometers. The larger number of smaller fragments could significantly affect the reliability of much smaller structures. In addition, this high-collision frequency could begin a cascading effect, further increasing the population growth of fragments and leading to a nonreversible fragmenting process.

A computer model to accurately define these issues is approximately 50 percent complete. The results to date tend to confirm previous preliminary analyses. This model, when completed, will predict spacecraft lifetimes from collisions and will evaluate the effectiveness of various control options. These options include the retrieval of large nonoperational objects, the planned early reentry of spent rocket stages, and the banning of future explosions in space. As a result of classifying each orbiting object for the computer model, it was determined that the current major source of objects is the accidental explosion of the second stage of the Delta rocket (table I). Consequently, new operational requirements have been implemented to prevent future explosions of this stage.

Figure 1.—Orbital debris hazard and control.



Solid Polymer Electrolyte Fuel Cell

The average electrical power requirements of the Space Shuttle have continued to increase as the system design matures. This growing need for power has put stress on the fuel cell life capabilities, greatly reducing the amount of useful life available for flight. This, together with increased hardware costs due to inflation, has caused serious concern regarding the continued use of alkaline fuel cells to support future spacecraft. In the past decade, the individual fuel cell power requirements have increased from a 3-kilowatt average onorbit and a 4.5-kilowatt peak during ascent to a 6.5-kilowatt average onorbit and a 10-kilowatt peak during ascent. This has resulted in a reduction of fuel cell life expectancy from 20 missions to as low as 4 missions depending on power levels and mission profile. Increased spacecraft turnaround time is also required for additional fuel cell changeouts, more frequent fuel cell refurbishments, and additional purchases of fuel cell components to support increased activity. As a result of the average mission energy growth, the Space Shuttle Program cost to support the power generation system is expected to increase dramatically.

Solid Polymer Electrolyte (SPE) acid fuel cell technology was studied to provide a fuel cell system that would improve cost, weight, performance, and efficiency while retaining the desirable characteristic of operating life. In addition, the SPE has the serendipitous characteristic of operating propellant grade reactants. These goals were met with a 1.1-square-foot cell that was representative of a Shuttle-designed component (fig. 1). The cell accumulated over 3200 hours of invariant performance at a current density range between 100 and 500 A/ft^2. A teardown analysis of this cell revealed no evidence of material degradation.

An 18-cell stack of 1.1-square-foot SPE cells (fig. 2) that represents one-half of a Shuttle-configured fuel cell has been assembled and a 2000-hour demonstration test has been initiated. After initial calibration, this hardware will be tested specifically to the Shuttle qualification load profile operating at Shuttle conditions of onboard gas-reactant pressures, temperatures, and heat-rejection capabilities.

The goal of the program is to develop a Space Shuttle fuel cell engineering model of the Solid Polymer Electrolyte type that is interchangeable with the Shuttle alkaline type now being used. This change would result in a weight savings to the Orbiter of approximately 171 pounds and also would reduce the average vehicle turnaround time significantly. Because the SPE fuel cell is compatible with propulsion grade reactants, a related weight reduction option is also available. Recovery of main propulsion system residual liquid oxygen for use with the Solid Polymer Electrolyte (only) fuel cells could provide an additional 1500-pound weight savings on missions of 4 days or longer. This option requires minor plumbing changes to the Shuttle vehicle; however, these are considered to be low-risk changes.

Figure 1.—Solid polymer electrolyte fuel cell components.

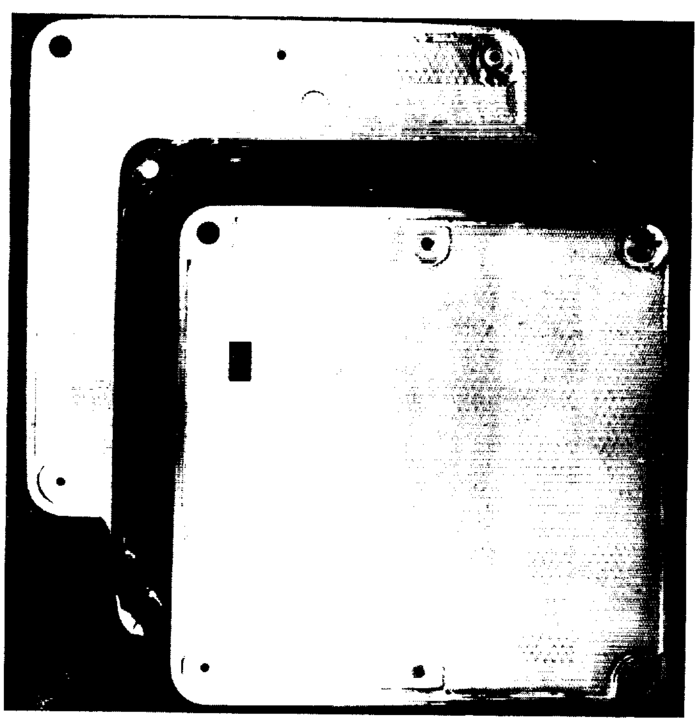
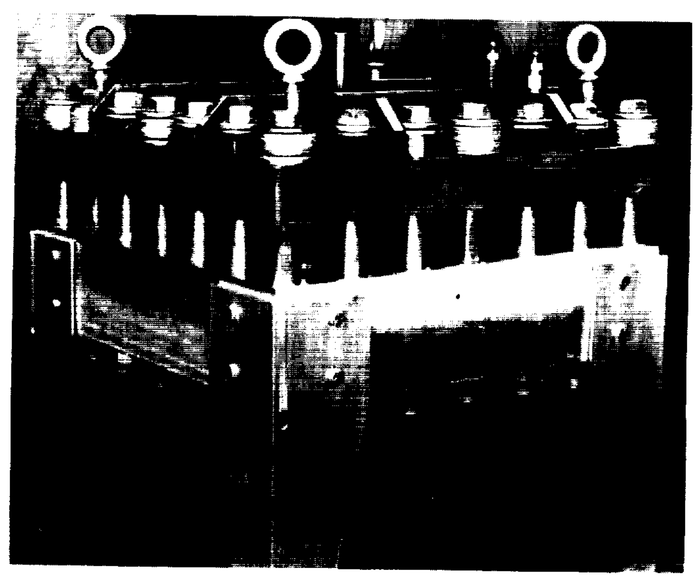


Figure 2.—A 7-kilowatt reactor stack with 18 cells.



Space Construction Experiment Concepts

Future space program plans include spacecraft with a size and/or weight that exceeds the volume limits or boosts the capabilities of the Space Transportation System (STS). Implementation of any of these programs will require the capability to construct large systems in space. These systems will initially be constructed from the Orbiter. Because the ability to construct and operate large space systems has not been demonstrated, users may be reluctant to employ large space structures concepts with the accompanying implications of high costs and high risks. Several complex ambitious demonstration projects have been studied; however, none has been of a practical size and cost that could be implemented in a simple Orbiter-based flight experiment.

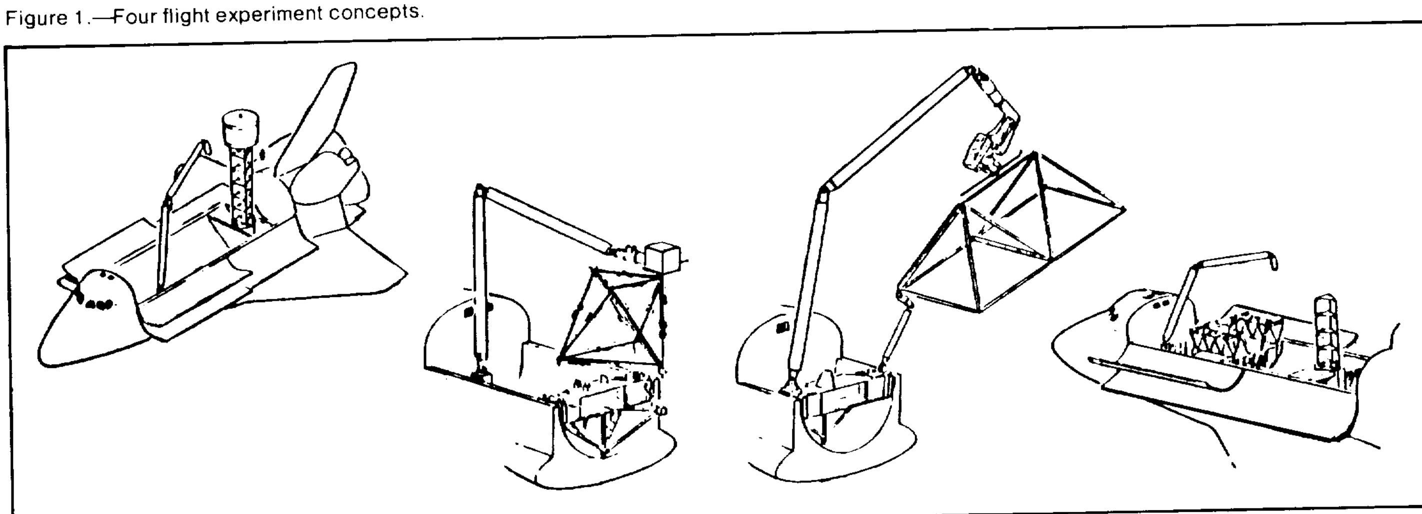
The approach used was to evaluate the construction requirements of the several large systems that were being examined in the Space Construction System Analysis study. From this list, concepts for flight experiments to evaluate specific issues were generated. Three principal areas of technical concern are the actual construction operations, the characteristics of the dynamics of low-frequency structure, and the ability to control the system during and after construction.

Four flight experiment concepts (fig. 1) were produced that, in conjunction with a ground test program, could generate the technology base needed to support construction of future large space systems. An early experiment concept was the use of the Remote Manipulator System (RMS) to deploy a structural subassembly, to effect multipoint attachment of the structure, and to install a simulated equipment module. A subsequent experiment would exercise extravehicular activity (EVA) and support equipment to access a structure for the installation of lines and systems. Another variation in the experiment concept would evaluate the joining of beam segments that might have been fabricated in space by a beam machine.

The interaction of a low-frequency structure with the Orbiter might be studied by the deployment of a long boom that could replicate the dynamic performance of a large structure element such as an antenna feed mast.

From the experiment concepts developed, a concept may be selected for a relatively simple early flight experiment that will be valuable in reducing the risk and uncertainty in planning large systems later.

Figure 1.—Four flight experiment concepts.



Space Construction System Analysis

Studies of large orbiting systems concepts have projected a need for assembly or construction in space to achieve operational configurations. Space construction methods and techniques need to be identified and evaluated for various sizes and shapes of structures. Although past studies have evaluated various construction methods, no detailed end-to-end analysis has been performed of a specific large space project system to understand and evaluate the construction techniques, the construction support equipment required, the time lines, the system installation/location, and the extravehicular activity (EVA) assisted subsystem installation and checkout.

Part 2 of the study was initiated in June 1979 to establish mission requirements and concepts for an Engineering and Technology Verification Platform (ETVP). This platform was selected to represent a future system that would eliminate most of the construction requirements envisioned through the decade of the 1990's. A detailed construction analysis was performed of time lines, Space Shuttle crew duty cycles, integrated lighting and power requirements, payload manifests, payload bay packaging, Shuttle launch requirements, and overall analysis of construction drivers. Determination of requirements for early Shuttle flight construction experiments was also identified and evaluated. The use of the ETVP as an advanced communications platform is shown in figure 1. A multiple fabrication and assembly concept used for construction of the platform is shown in figure 2.

The study was concluded in June 1980. Study conclusions indicate the following. Large space systems should be designed for space construction and constructed primarily by automated systems augmented by astronaut EVA. Uncertainties in space construction analysis must be resolved by early ground and flight tests. Linear structural configurations are preferred over the other configurations studied for Earth-oriented missions. Systems installation design is determined by construction and servicing requirements. Construction requirements should be incorporated into ongoing developments such as the open cherrypicker and the EVA mobility aids. The results indicate that the Orbiter can potentially be used as the construction facility; however, limitations on Orbiter power/energy may constrain this type of activity.

Figure 1.—The Engineering Technology Verification Platform in an advanced communications platform configuration.

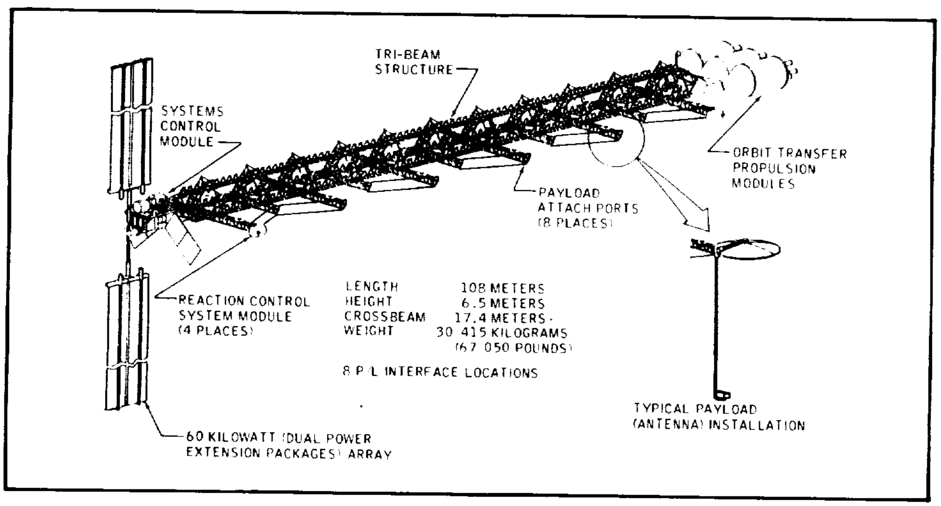
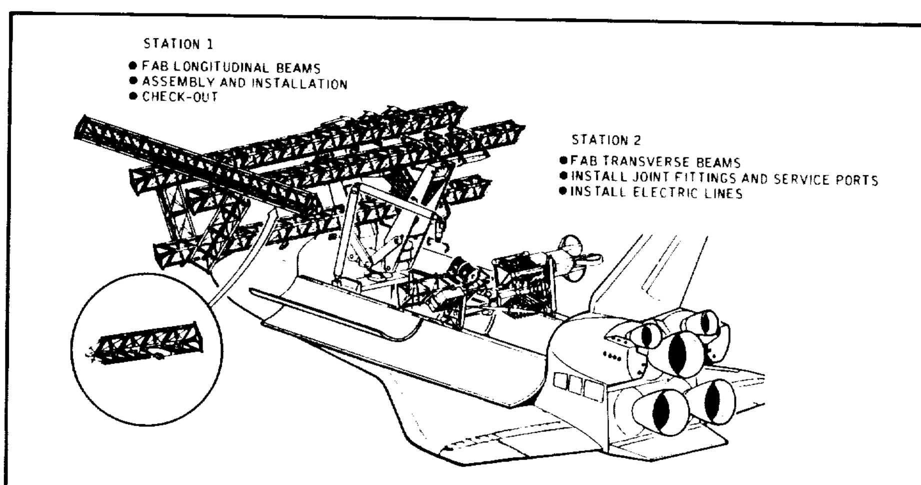


Figure 2.—The multiple fabrication and assembly station concept for use in platform construction.



Loads and Dynamics of Variable-Geometry Structures

Nearly all methods for dynamic structural analysis are applicable only to structures with fixed geometry. However, for new concepts in large space structures that require space construction or deployment, the capability is needed to predict dynamic responses and loads although the structural geometry is varying. The most direct approach to this problem — obtaining solutions using physical degrees of freedom — requires too much computing time for routine application on even moderate-size finite-element models. Therefore, a more economical dynamic-analysis method based on a reduced number of coordinates is needed. In addition, it would be desirable to develop innovative approaches by which the range of applicability of standard fixed-geometry structural-analysis programs such as NASTRAN could be extended to solve at least some of the variable-geometry problems.

Several variable-geometry space-structure concepts were reviewed in order to select a configuration for exploring new analytical techniques. The selected configuration is illustrated in figure 1. Two separate construction problems were studied. In the first task, beam fabrication, a beam is constructed by an Automated Beam Builder mounted in the Orbiter. Because of the inclusion of a power module with very flexible solar panels, problem 1 forms the basis for investigating beam fabrication from a flexible base. In the second task, beam relocation, the completed beam is grasped by the Remote Manipulator System (RMS) and moved through a large angle by rotating the manipulator about its shoulder joint.

Simple mathematical models of these structures were developed and computer programs were written to generate solutions by numerically integrating the equations of motion in physical coordinates. The models included a simplified closed-loop idealization of the Orbiter vernier attitude-control system. A new reduced-coordinate variable-geometry method and an approximate technique based on fixed-geometry methods were then developed. Finally, physical coordinate solutions were used as a standard of comparison to evaluate the accuracy of the approximate techniques.

The modal-analysis approach conventionally used for reducing the size of complex fixed-geometry problems was extended to variable-geometry problems. This new approach reduced the computer time by 85 percent with no appreciable loss in accuracy for the problems that were investigated. A sample time history generated with the new modal method is shown in figure 2. In this problem, a 100-meter beam is being fabricated from the Orbiter while the control system is correcting a 1° initial attitude error about each axis. The illustration shows the Orbiter pitch angle, the beam fabrication rate, and the elastic deformation of the beam relative to the Orbiter in the fore-and-aft direction.

It was also demonstrated that the dynamic response of the structure to excitation resulting from variable-geometry motion could be accurately determined by employing a standard fixed-geometry program, such as NASTRAN, in an innovative way. This technique is useful for studying responses during time intervals when problems are expected; e.g., when a sudden geometry change occurs, although it is limited to time spans for which the variation in geometry is small.

Figure 1.—Study configuration of construction problems.

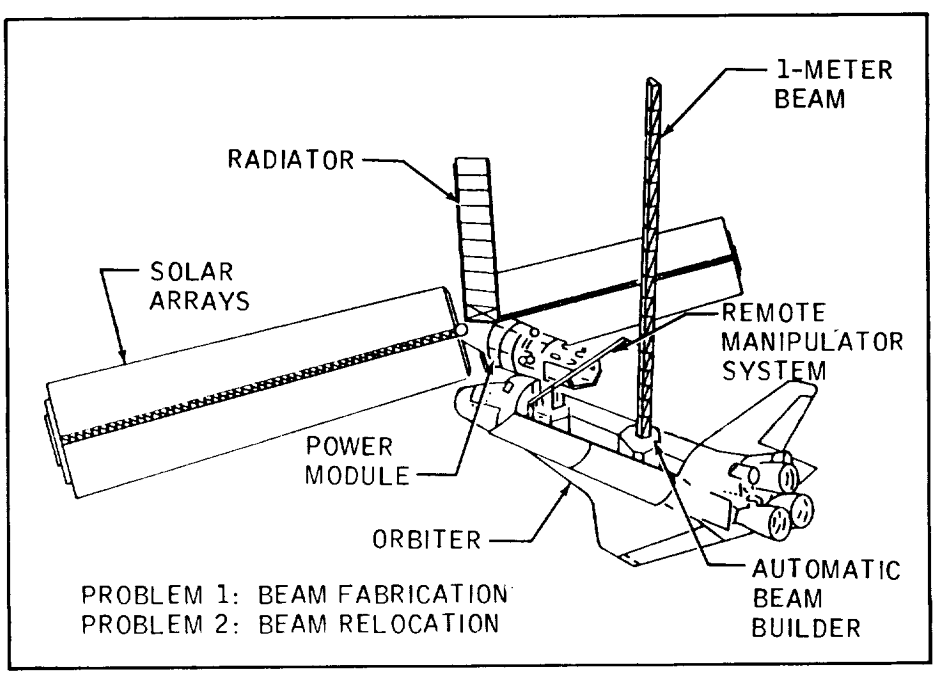
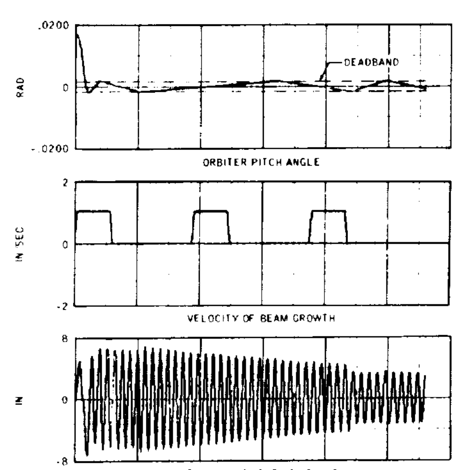


Figure 2.—Sample time histories for beam fabrication for the variable modal method.



Manned Geosynchronous Mission Requirements and System Analysis

The NASA is presently developing a manned Space Transportation System (STS) to low Earth orbit (LEO). However, advanced space mission planning includes both manned low-Earth-orbit and manned geosynchronous-Earth-orbit (GEO) missions. The activities potentially requiring manned participation in both LEO and GEO consist of construction, inspection, servicing, repairing, and operation of large space systems such as communications, solar power, and Earth observation satellites. To exploit the capabilities of the Space Transportation System and to develop the full potential of space operations, it is essential that developmental planning of Orbital Transfer Vehicles (OTV's) be expanded to include manned capability.

The main objective of this effort is to establish mission and systems opportunities and capability options for various levels of manned activity requirements, and to synthesize crew module and/or other manned system support necessary for extension of manned mission capability to geosynchronous orbit. This study emphasizes manned geosynchronous-orbit sortie missions and associated crew-system concepts.

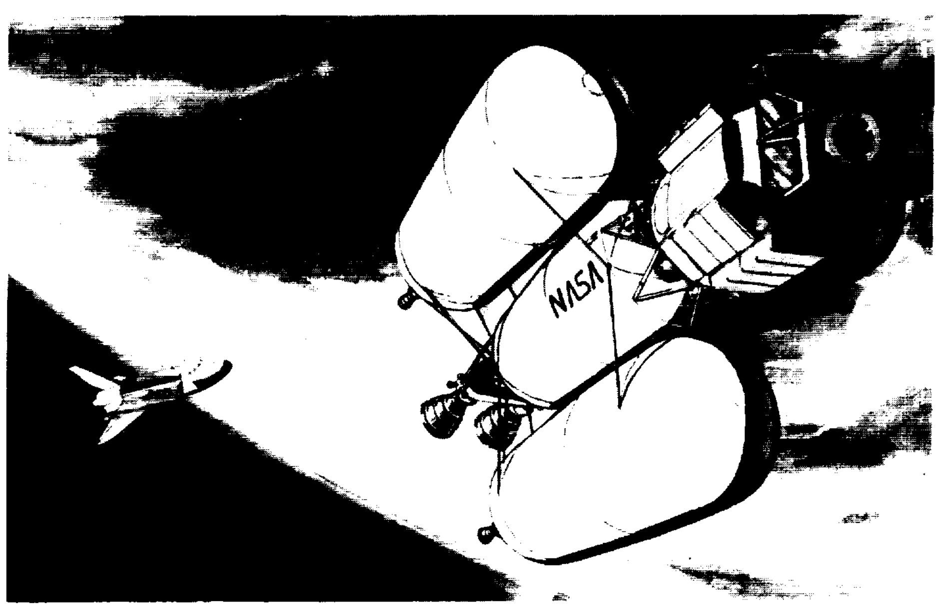
In phase 1 of the study, a broad range of generic missions was selected from which Manned Orbital Transfer Vehicle (MOTV) requirements were derived. These generic missions were divided into five categories as follows: inspection, service, and repair; operation of a large space system; debris removal; construction; and unmanned cargo transport. The missions range from short duration, two-man crews, and low mission-hardware weight to orbit to long duration, three-man crews, and heavy mission-hardware weight to orbit. The main objective was to develop a versatile MOTV concept that would encompass most of these generic missions with a minimum of modifications. The concept that was selected was an all-propulsive MOTV using a 1-1/2-stage propulsion system and a 25.0-cubic meter crew capsule. This concept can accomplish all missions except a 30-man crew rotation and supply mission. All remaining missions can be accomplished with one MOTV flight to orbit except the solar power satellite demonstration mission that requires four such flights because of the large amount of mission hardware needed to be transported to the construction site.

In phase 2 of the study, a communications satellite servicing mission was selected as the design reference mission. In this mission, four communications satellites, all using the standard Multimission Modular Spacecraft (MMS) for subsystem support functions and all identical to each other, are routinely serviced by the MOTV. The satellites are all located 90° apart in geosynchronous Earth orbit. Periodically, the MOTV visits each of these satellites and services the MMS subsystems.

Some of the significant results of the phase 1 and phase 2 portions of the study are as follows.

1. Two- or three-man crews and a mission of up to 30 days duration will accomplish 85 percent of the proposed Orbital Transfer Vehicle missions.
2. A 1-1/2-stage propulsion system concept (fig. 1) shows better performance and cost than a single- or two-stage vehicle.
3. Proposed MOTV missions can be accomplished with two to five STS launches.
4. One Space Shuttle performs all launches and loiter-mode recovery. A typical four-launch mission engages the Space Shuttle for 71 days.
5. The ground turnaround is baselined but low-Earth-orbit platform turnaround may be cost effective.
6. A capsule diameter of 3 meters allows mission equipment to be mounted externally.
7. Radiation protection requirements dictate that the capsule wall be of 1.1-centimeter aluminum equivalent thickness.
8. Protection against solar proton storms requires forecasting the size of solar events.
9. A single-deck crew module is preferred over a two-deck crew module.

Figure 1.—A Manned Orbital Transfer Vehicle accomplishing transfer to geosynchronous Earth orbit.



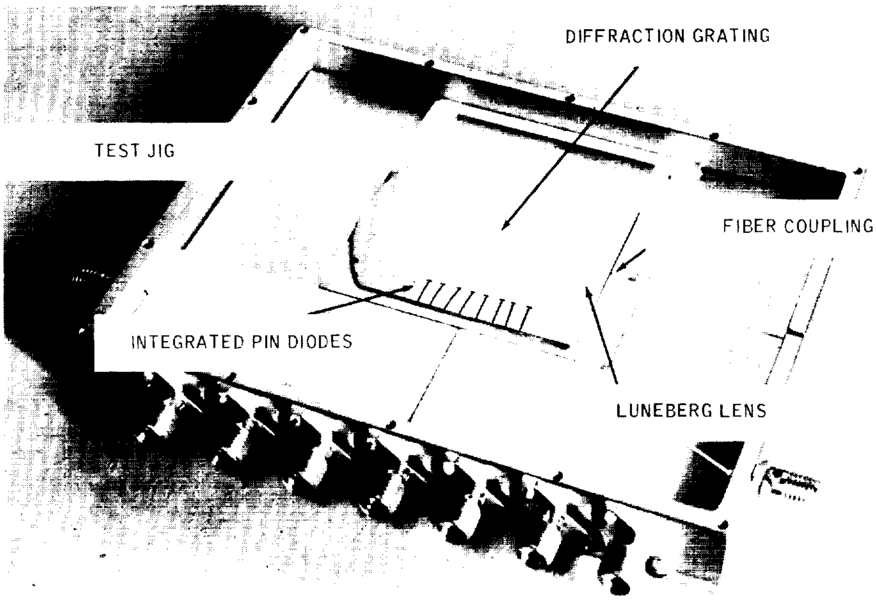
Fiber Optics Multiplexing

The monolithic integrated fiber optic terminal is being developed to use guided-wave optical technology to produce a passive optical wavelength multiplexing/demultiplexing system with a single-mode optical fiber serving as the transmission medium. The use of fiber optics for data handling and transmission is expanding rapidly in military and aerospace systems and in commercial applications. Significant advantages of using fiber optics for aerospace vehicle design are complete channel isolation, wide bandwidth, reduced electromagnetic interference susceptibility, small terminal size, low weight, reliability, and an ultimately lower cost.

The optical multiplexer/demultiplexer is an advanced technological instrument that provides for simultaneous transmission of multiple channels over a single fiber. The approach is wavelength multiplexing using "n" injection laser diodes biased to the lasing threshold and modulated by the input data. The lasers, each of which differ in output wavelength by an amount $\Delta\lambda$ = 17 nanometers, are coupled into the integrated optical transmitter/multiplexer chip that uses a chirped waveguide diffraction grating to combine the spatially separate laser beams to produce a single-wavelength multiplexed beam. The multiplexed beam is coupled to a single-mode fiber for transmission. The output of the fiber is coupled to the integrated optical demultiplexer that separates the input beam into "n" separate beams that are absorbed by "n" P-I-N detectors. The detector output is an electrical signal representing the original input signal to the transmitter.

The primary emphasis has been on the demultiplexer development and demonstration. Currently, the demultiplexer (fig. 1) has been developed and is undergoing refinement. Emphasis is also shifting to the optical multiplexer. This activity has required significant technology developments in manufacturing processes and techniques for integrated optics construction. This includes ion-beam milling of diffraction gratings, optical lenses, and fiber-to-waveguide coupling.

Figure 1.—Fiber optics multiwavelength demultiplexer.



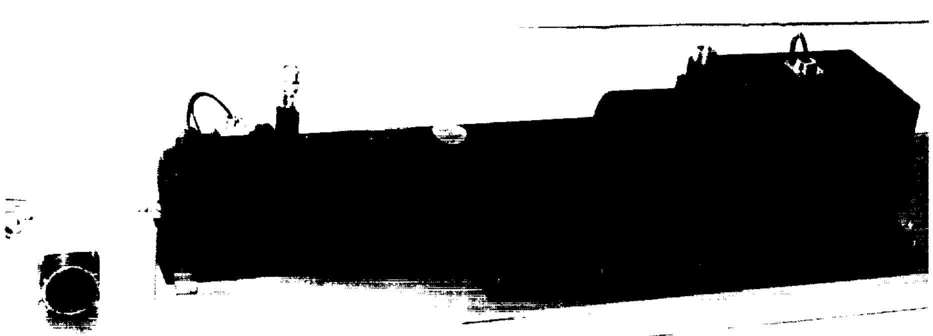
High-Power Traveling-Wave-Tube Amplifier

To increase the capability and range of spacecraft communications operation, higher power levels are needed. For manned spacecraft that require a cold plate interface with the environmental control system, the radiofrequency power output has been limited to approximately 120 watts. This limitation is due to inefficient methods of dissipating heat produced by the tube at higher power levels. Attempts to overcome this problem have generally led to decreased reliability and excessively heavy packages. The purpose of this project was to design a highly efficient high-power S-band traveling-wave tube that is both lightweight and highly reliable and that also demonstrates a "state-of-the-art" approach to cooling design.

A program was initiated to build a high-power high-efficiency traveling-wave tube using heat pipes in the base of the tube for cooling. Velocity-tapering and multistage collectors were used to provide a high overall efficiency. Integral heat pipes with stainless steel wicks were chosen using ammonia as the working fluid. Ten heat pipes were used in the baseplate, six transverse and four longitudinal. The majority of these heat pipes were placed near the hot spot of the tube, the collector, which is located at the output end of the tube.

The result of this project is a 300-watt traveling-wave tube (fig. 1) that is both electrically and thermally efficient. Testing at the Johnson Space Center indicates that this efficiency is accomplished without sacrificing other performance criteria such as low noise power density, low AM/PM conversion, low voltage standing-wave ratio, and a low level of harmonic and spurious signals. The traveling-wave tube is capable of producing more than 321 watts output at more than 54 percent efficiency. This efficiency is accomplished with a maximum baseplate temperature of 121° F by using a small blower on the cold plate. Heat pipes will be used extensively in tube design in the future not only for increased power capability but also for improved reliability.

Figure 1.—Traveling-wave tube.



Office of Aeronautics and Space Technology

Significant Tasks

41 Shuttle-Launched Research Vehicle

Funded by: Aeronautics Research and Technology Base (UPN-505)
(Subauthorization from Langley Research Center)
Aeronautics System Studies (UPN-791)
Technical Monitor: J. T. Visentine/ED4
Task Performed by: General Electric Company
Reentry Systems Division
Contract NAS 9-15977

42 Orbiter Experiments Project Support and Integration

Funded by: Space Technology Shuttle Payloads (UPN-543)
Technical Monitor: J. M. Sanders/ED4
Task Performed by: Rockwell International
Contract NAS 9-14000
Lockheed Engineering and Management Services Company, Inc.
Contract NAS 9-15800
Bendix Communications Division
(Aerodynamic Coefficient Identification Package)
Contract NAS 9-15588

44 Solar Power Satellite System Definition and Critical Supporting Investigations

Funded by: Energy Systems Development (UPN-775)
(Reimbursable funds provided by the Department of Energy)
Technical Monitor: T. E. Redding/EB
Task Performed by: Boeing Aerospace Company
Contract NAS 9-15636
University of Texas
(SPS Microwave/Ionosphere Interaction Experiment)
Contract NAS 9-16086

46 Electrochemical Orbital Energy Storage Program

Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: Hoyt McBryar/EP5
Task Performed by: General Electric Company
Contract NAS 9-15831

47 Space Constructable Heat Pipe Radiators

Funded by: Supporting Development (UPN-906)
Space Research and Technology Base (UPN-506)
Technical Monitor: W. E. Ellis/EC2
Task Performed by: Grumman Aerospace Corporation
Contract NAS 9-15965

48 Space Plasma Interaction Experiments for Large Power Systems

Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: J. E. McCoy/SN3
Task Performed by: Northrop Services, Inc.
Contract NAS 9-15425
Lockheed Engineering and
Management Services Company, Inc.
Contract NAS 9-15800
Houston Baptist University
Contract NSG-9076
Rice University
Contract NAS 9-15796
Contract NAS 9-16206
Lee Parker, Inc.
Contract NAS 9-15934

50 Advanced Manned Vehicle Onboard Propulsion Technology

Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: M. F. Lausten/EP2
Task Performed by: Aerojet Liquid Rocket Company
Contract NAS 9-15724
Contract NAS 9-15958

51 Advanced Synthetic Aperture Radar Technology

Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: K. Krishen/ED6
Task Performed by: Jet Propulsion Laboratory
Contract NAS 7-100
Texas A&M University
Contract NAS 9-16102
Environmental Research Institute
of Michigan
Contract NAS 9-16135
New Mexico State University
Contract NAS 9-16092
University of Texas
Contract NAS 9-16171
Lockheed Engineering and
Management Services Company, Inc.
Contract NAS 9-15800

52 **Large Space Systems Technology**

Funded by: Space Systems Technology Program (UPN-542)
(Subauthorization from Langley Research Center)
Technical Monitor: L. M. Jenkins/EB
Task Performed by: McDonnell Douglas Corporation
(Advanced Space Platform Technology Study)
Contract NAS 9-16001
General Dynamics, Convair Division
(Forming and Welding of Graphite
Composite Materials)
Contract NAS 9-15532
Northrop Services, Inc.
Contract NAS 9-15425

53 **Application of Advanced Electric/Electronic Technology to Commercial Aircraft**

Funded by: Aeronautics System Studies (UPN-791)
Technical Monitor: J. P. Bigham/EH
Task Performed by: Lockheed California Company
Contract NAS 9-15863

54 **Nonterrestrial Materials for Space Use**

Funded by: Space Research and Technology Base (UPN-506)
Space Systems Studies (UPN-790)
Technical Monitor: R. J. Williams/SN7
Task Performed by: Lockheed Electronics Company, Inc.
(Handbook of Lunar Materials)
Contract NAS 9-15800
Lunar and Planetary Institute
Contract NSR 09-051-001

55 **Fire-Resistant Low-Smoke-Generating Thermally Stable End Items for Aircraft and Spacecraft**

Funded by: Aeronautics Research and Technology Base (UPN-505)
Systems Technology Programs (UPN-534)
Technical Monitor: E. E. Supkis/ES5
Task Performed by: General Electric Company
Contract NAS 9-15763
Contract NAS 9-15533
McDonnell Douglas Corporation
Contract NAS 9-15591
Northrop Services, Inc.
Contract NAS 9-15425

56 **Toxicity Testing and Evaluation of Candidate Aircraft Materials**

Funded by: Materials and Structures Systems Technology (UPN-543)
Technical Monitor: Carolyn Leach Huntoon/SD4
Task Performed by: Northrop Services, Inc.
Contract NAS 9-15425
Southwest Foundation for Research and Education
Contract NAS 9-15690

57 **Adsorption Pumping Cryogenic Refrigeration**

Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: R. R. Richard/ED6
Task Performed by: University of Texas
Contract NAS 9-14491

Shuttle-Launched Research Vehicle

The initiation of operational Space Shuttle Orbiter flights in the 1980's will provide the aerospace community with many unique opportunities to demonstrate and evaluate advanced space vehicle design concepts. The narrow entry corridor of the Orbiter and the inherent limitations of ground-based laboratories to simulate entry and aerothermal flight environments dictate a need for a separate category of entry research vehicles. The frequency of flights into space by the Orbiter will provide a recurring capability to carry advanced unmanned aerospace vehicles into Earth orbit and perform research and technology demonstrations in many related disciplines while these vehicles maneuver, enter, and fly in the upper atmosphere before initiating a land-based recovery.

The Shuttle-Launched Research Vehicle (SLRV) program will enable the NASA flight research centers to expand their knowledge in entry and hypersonic technologies for future developments in the Earth and planetary space programs, and will provide principal investigators with a dynamic flight research facility that will lead to new generations of operational space flight vehicles.

The SLRV would be used to demonstrate new technology concepts in hypersonic flight environments that lie outside the operational envelope of the Shuttle Orbiter. These concepts include aeromaneuvering systems for reusable orbital transfer vehicles, advanced thermal protection system materials for planetary entry probes and Earth-to-orbit vehicles, and control-configured designs for heavy-lift launch vehicles.

The SLRV program uses the Orbiter's payload capability for advanced technology research and development and extends the aerodynamic and aerothermodynamic research that will be conducted from the Space Shuttle during the Orbiter Experiments Program.

The SLRV concept provides a common electronics "core" system to which various aeroshell or fuselage configurations can be attached. This "core" will provide all normal avionics, control, data, communications, power, and maneuvering capability for unmanned subscale reentry vehicles. Experiments selected for these vehicles would be designed to provide research data to support the Office of Aeronautics and Space Technology research programs in advanced space transportation systems and planetary entry technology. Aeroshell and fuselage configurations would satisfy specific experimental objectives and would fall into three categories: ballistic, medium lift-to-drag (L/D) ratio lifting bodies, and high L/D ratio lifting bodies.

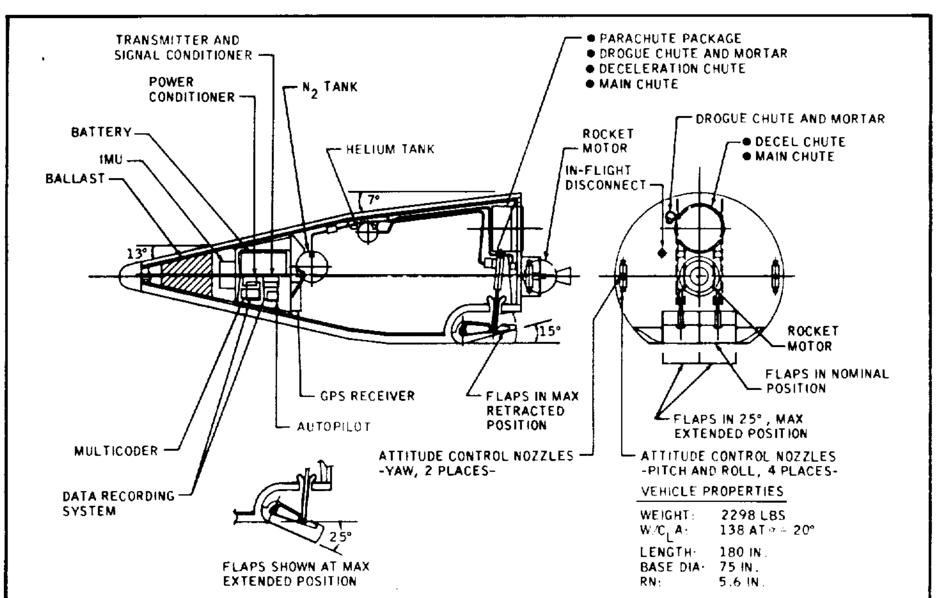
The SLRV development program is designed with primary emphasis directed toward cost-effectiveness. This program employs a phased programmatic approach whereby development of the flight vehicles will be initiated on a modest scale. Major decisions for subsequent growth will follow technical advancements made during earlier phases of the flight research program and will include the research data obtained from the Orbiter Experiments Program.

Significant program activities accomplished this year at JSC include initiation of an SLRV applications and cost-benefits study and completion of two interagency reviews of the preliminary study conclusions, candidate applications, and proposed vehicle configurations.

The purpose of the study is to conduct a cost-benefits analysis of various combinations of SLRV's and research and technology experiments. The results of the analysis will be used to define a flight test program to advance hypersonic reentry and cruise-flight technology required for the development of advanced space transportation systems.

This study has resulted in the identification of 28 research and technology experiments and 3 candidate vehicle configurations for the SLRV. These vehicle configurations include ballistic, fixed-trim, and variable-trim. The variable-trim vehicle (fig. 1) provides the greatest versatility. This vehicle will use split windward flaps to fly at various angles of attack during entry. It will flight test both windward and leeward advanced thermal protection system design concepts and advanced flight control systems in severe reentry environments within reentry corridors that are unattainable using the Shuttle Orbiter.

Figure 1.—Maneuverable Shuttle-launched research vehicle (split windward flap configuration).



Orbiter Experiments Project Support and Integration

As a pioneer (launch to landing) space vehicle, the Space Shuttle Orbiter has the potential of providing cost-effective research and technology data needed for the development of a broad spectrum of future aerospace vehicle designs or enhancements. Although the Orbiter includes instrumentation necessary to perform design verification and to monitor select operations functions, the baseline Orbiter flight test and operations program does not include plans to collect specific research and technology data relevant to the design of future vehicles.

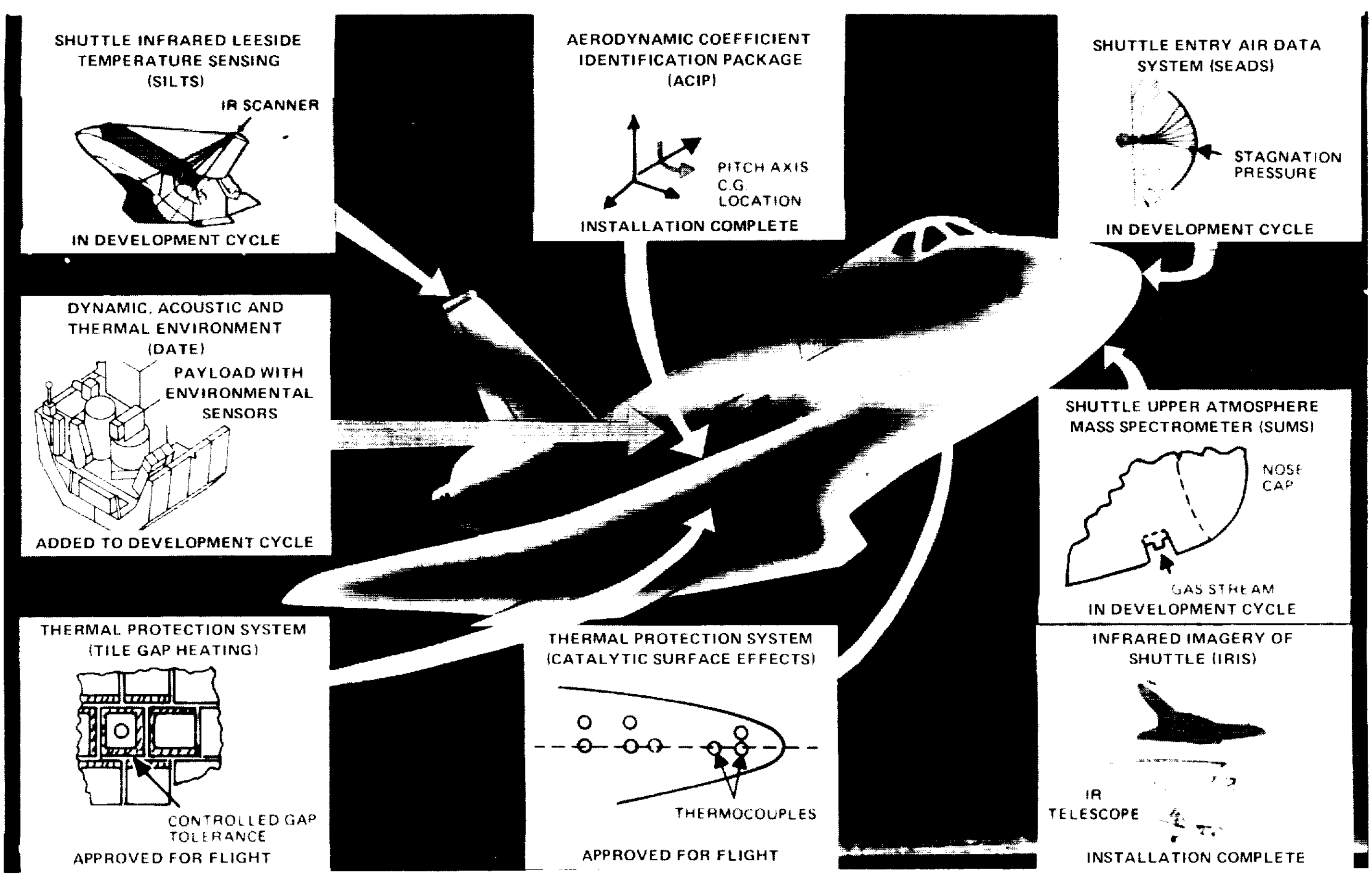
To capitalize on the opportunity to use the Space Shuttle as a means of acquiring flight data for a wide variety of technology disciplines related to vehicle design, the Office of Aeronautics and Space Technology has established the Orbiter Experiments Program, which uses the Orbiter as a flight research vehicle (fig. 1). JSC continues to support the Orbiter Experiments Program by providing (1) overall integration management and program planning, (2) technical development for specific experiments, and (3) integration of experiments into the Orbiter. The Orbiter experiments are designed (1) to augment the research and technology base for verification or enhancement of the operational efficiency of current and future aerospace vehicle design by collecting Orbiter flight data in all related technology disciplines, and (2) to correlate ground-based data with flight data by developing procedures to accurately extrapolate ground-based facility results to flight conditions.

All experiments in phase I have been "prioritized" from a flight spectrum that includes launch, orbit, and entry maneuvers. The experiments are selected by using the principles of development and succession. This unique approach has been cost-effective because of the maximum use of in-place hardware.

To obtain aerodynamic data during launch, orbit, and entry, the Aerodynamic Coefficient Identification Package (ACIP) has been installed on the Orbiter at Kennedy Space Center. It is expected to fly on all Orbiter flights through 1983. The ACIP hardware has undergone post-installation functional tests that included elevon calibration and dynamic stability tests.

An underflight of the Shuttle Orbiter is planned during entry of the first Orbiter flight to obtain an infrared image of the thermal protection system of the Orbiter. This project is known as the Infrared Imagery of Shuttle (IRIS) experiment. Flight experiment testing of the hardware mounted in an aircraft continues.

Figure 1.—Orbiter Experiments Program.



The thermal protection system experiments (Catalytic Surface Effects and Tile Gap Heating) have been assembled in kit form and are ready to ship to the Kennedy Space Center for installation. Hardware for both experiments is scheduled to be flown on six flights starting with the second Orbiter flight.

Three experiments in the development and checkout cycle include the Shuttle Infrared Leeside Temperature Sensing (SILTS), the Shuttle Upper Atmosphere Mass Spectrometer (SUMS), and the Shuttle Entry Air Data System (SEADS). A volume fit check of the SUMS hardware in the Orbiter vehicle and the SILTS hardware in the pod, which will be mounted on top of the Orbiter vertical stabilizer, has been accomplished. Electrical checkout of the SILTS hardware is continuing.

The Dynamic, Acoustic, and Thermal Environment (DATE) experiment has been added to the development cycle. The DATE experiment for STS-1 will use data from the existing Development Flight Instrumentation (DFI) system. Development of DATE hardware for Orbiter flights 2 through 4 includes a composite of Air Force and sponsoring NASA center requirements.

For the experiments in phase I, a transportable Orbiter experiments ground data processing station for use at the Kennedy Space Center is being validated (fig. 2). Data processing requirements for all hardware and analytical experiments for the first Orbiter flight have been published. In addition, 17 new phase II experiments in four technology disciplines have been approved for definition and are listed below.

Aerodynamics/aerothermodynamics

1. Shuttle Windward Entry Aerothermodynamic Experiment
2. Data Quality Enhancement for Stability and Control Technology Research
3. ACIP/Pulse Code Modulator II
4. Programed Test Input Software for Stability and Control Technology Research

Materials and structures

5. Structural Temperature Experiment
6. Photogrammetric Structural Monitoring Experiment
7. Advanced Nonmetallic Thermal Protection System Materials
8. Effect of Orbiter Flight Environment on Bearing/Lubricant System
9. Metallic Thermal Protection System Experiment
10. DATE II
11. Space Applied Thermal Protection System Materials Experiment
12. Catalytic Effects in Stagnation Regions

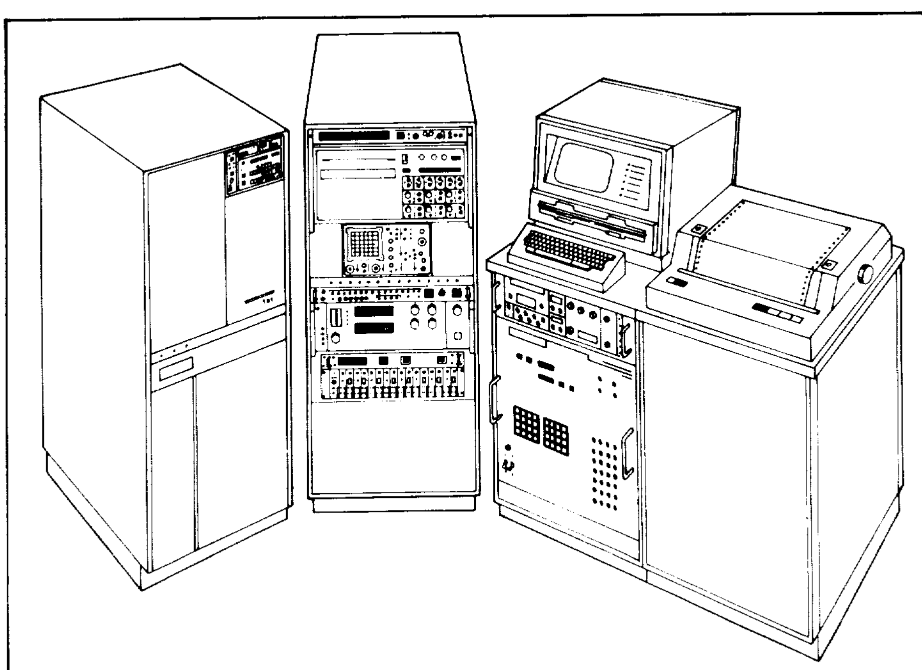
Electronics and human factors

13. Advanced Autopilot Experiment
14. Shuttle Altitude Measurement System
15. Free Drift Attitude Modes Experiment
16. Orbiter Flying Qualities

Propulsion and power

17. Particle Energy Detection Experiment

Figure 2.—Transportable Orbiter Experiments ground data processing station.



Solar Power Satellite System Definition and Critical Supporting Investigations

The possibility of generating large quantities of electrical power in space and transmitting it to Earth by satellites was first suggested in 1968. The solar power satellite (SPS) concept would provide an almost continuous supply of power to utility systems without consuming nonrenewable fuels. During the years following 1968, several studies of the SPS concept were conducted by NASA and industry. The energy shortage of 1973 spurred interest in the concept and in early 1976 the Department of Energy (DOE) (then the Energy Research and Development Administration) and NASA initiated the Solar Power Satellite Concept Development and Evaluation Program. This evaluation program is guided by a joint DOE/NASA plan that covers the period from mid-1977 to mid-1980. The basic objective of the SPS system definition studies is to define and characterize environmentally acceptable and economically competitive SPS systems.

The first milestone of the joint DOE/NASA SPS evaluation and development program was completed with the delivery of the Reference Concept Document in October 1978. Figure 1 shows the configuration of the SPS Reference System that used optional silicon or gallium-aluminum-arsenide solar cells for energy conversion. The reference system document was prepared by JSC and included data developed by both Marshall Space Flight Center and JSC. It has been used as a reference point for the DOE in conducting their studies within the joint program. The DOE has made extensive use of this document in performing environmental, comparative, and socioeconomic assessments. Beginning in fiscal year 1979, the funds for this program have been provided by the DOE. The funds at JSC were used for continued system definition studies and critical supporting investigations.

The DOE/NASA SPS Concept Development and Evaluation Program will be concluded in 1980 with the issuance by DOE of the Program Assessment Report. Continued efforts will depend on program recommendations following the completion of this report.

During fiscal year 1980, system definition studies were continued with emphasis on determining reference system costs; defining alternative concepts; and conducting workshops in the technical areas of microwave power transmission, space structures and construction, energy conversion and power management, and space transportation. Summary reports were also submitted in support of the Program Assessment Report prepared by the DOE.

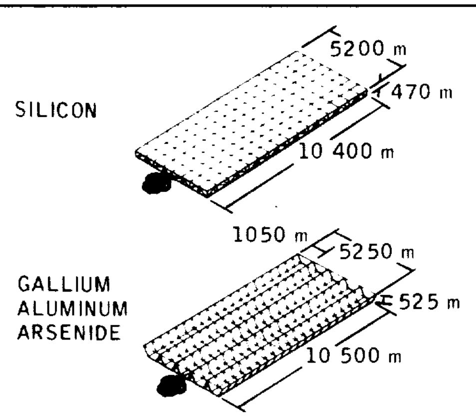
The alternative systems investigated included laser power transmission, reduced-size payload launch vehicles, and solid-state microwave systems. Studies of laser power transmission showed high satellite mass (more than twice that of the reference system) and atmospheric absorption of the laser energy as major concerns relative to microwave systems. A breakthrough in laser technology, however, could change this conclusion. The reduced-size payload launch vehicle study indicated that a 120-metric-ton payload vehicle would be more cost-effective and would have less environmental impact than the reference system 420-metric-ton vehicle.

The solid-state microwave system satellite concept using antenna-mounted converter devices optimizes at a lower power than the klystron tube systems and should have a higher reliability; however, the cost per kilowatt would be about 25 percent greater than for the reference system.

Critical supporting investigations were completed in the areas of solid-state combining device assessment, fiber optics investigations (for phase control system circuits), and retrodirective phase control breadboard system evaluations. A space structures control analysis effort conducted by the Jet Propulsion Laboratory for JSC was continued with completion scheduled for early 1981.

Investigations were also continued in the area of ionospheric testing. The microwave beam transmitting energy from a proposed solar power satellite in geosynchronous orbit to a ground receiving antenna (rectenna) will interact with the ionosphere by heating the free electrons in the ionosphere. A beam power density of 23 mW/cm^2 was originally proposed as a threshold for nonlinear interactions with the

Figure 1.—Solar Power Satellite Reference System.



	SILICON	GALLIUM ALUMINUM ARSENIDE
SOLAR BLANKET AREA	52 km^2	26 km^2
TOTAL AREA	54 km^2	55 km^2
SOLAR CONCENTRATION RATIO	1	2

ionosphere. A number of theoretical and experimental studies, sponsored by the Department of Energy, using the 1000-foot antenna (fig. 2) at Arecibo, Puerto Rico, and the ionospheric heating facility (fig. 3) at Plattville, Colorado, have been completed. The purpose of these studies was to ascertain ionospheric threshold levels and to determine the associated impacts on communication and navigation systems. The results indicate that the original 23-mW/cm^2 limit was conservative and can possibly be raised. Effects produced by simulated SPS heating are many times less than those from natural ionospheric disturbances as introduced by solar flares. The ionospheric power density limit is a critical SPS system sizing parameter and has a significant impact upon the cost of electricity. A higher limit allows more power to be delivered to a smaller rectenna.

In addition to the DOE studies on SPS impacts to communication and navigation systems, NASA conducted tests to determine the effects of errors introduced into the SPS phase control system by a heated ionosphere. The uplink phasing signal is transmitted directly through the center of the heated ionospheric region. The NASA tests used polar-orbiting NAVSAT satellites transmitting two coherent signals in the 150- to 450-megahertz frequency band through an ionosphere heated by the Plattville, Colorado, facility. Differential Doppler measurements were made to map electron density profiles. A phase perturbation model will use these profiles to predict phase perturbations on a 2.45-gigahertz uplink signal.

An analysis of phase fluctuations on a radio star signal through an unheated ionosphere has been made using data obtained from the National Radio Astronomy Observatory in Socorro, New Mexico. Thirteen sets of interferometers, each using two 25-meter antennas, yielded data indicating the phase fluctuations through an unheated ionosphere should be less than 1° during the 0.25-second period of the uplink/downlink signals. The final results of this analysis will serve as a comparison with phase fluctuations induced by a heated ionosphere, as measured in proposed 1981 tests using the Arecibo, Puerto Rico, heating facility.

Figure 2.—Arecibo, Puerto Rico, observatory ionospheric heating test.

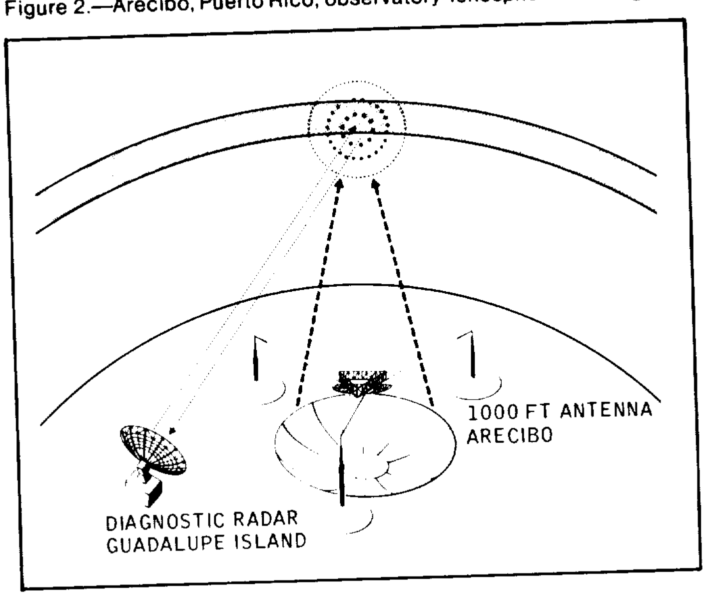
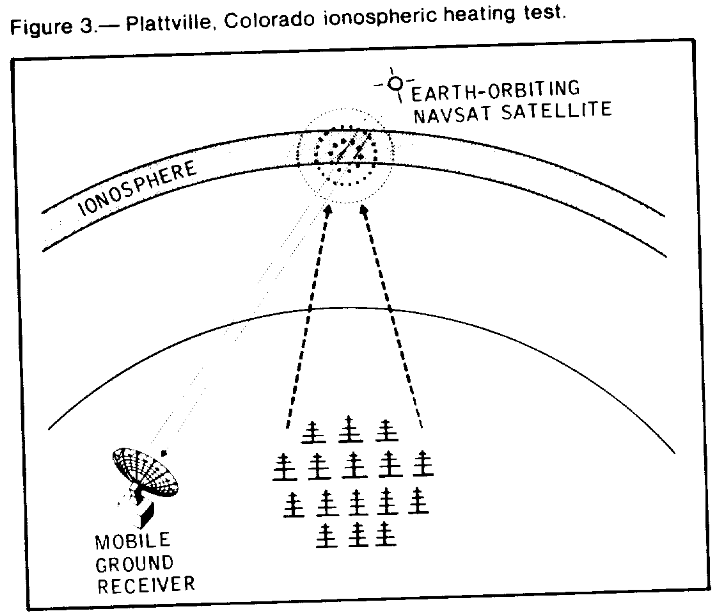


Figure 3.— Plattville, Colorado ionospheric heating test.



Electrochemical Orbital Energy Storage Program

The separation of water into hydrogen and oxygen by the passage of an electric current through an aqueous medium is essentially the reverse reaction of a fuel cell. The fuel cell has been the primary electrical power source for all U.S. manned space programs (except Mercury) because of superior flexibility, weight, and cost factors and continues to be the most viable candidate for 1 to 2 week missions to be conducted using the Shuttle. Since the Shuttle transportation system will probably be the space "workhorse" throughout the remainder of the 20th century (perhaps beyond), fuel cell electrochemical devices and derivatives (electrolysis cells) will have a major role in the conduct of the missions assigned to NASA.

In a regenerative fuel cell configuration, the role of fuel cells — in addition to providing electrical power to the vehicle and to the experiments on the dark side of the orbit — is to provide potable water for the crew and for certain thermal control requirements. The role of electrolysis cells is to recycle fuel-cell-produced water (and makeup water) using solar-array-produced power on the light side of the orbit and thus provide power for extending mission duration and/or enhancing mission flexibility.

Recycling of water in a regenerative system is an increasingly important consideration in space missions. In addition to regenerating the hydrogen and oxygen required for the fuel cell, anticipated propulsion system propellants are almost exclusively hydrogen and oxygen, and space manufacturing may use large quantities of hydrogen and oxygen for various processes. Thus, metabolic waste water that may be undesirable for recycling for metabolic use may be diverted to propulsion and/or to manufacturing requirements yielding multiple uses from a single commodity.

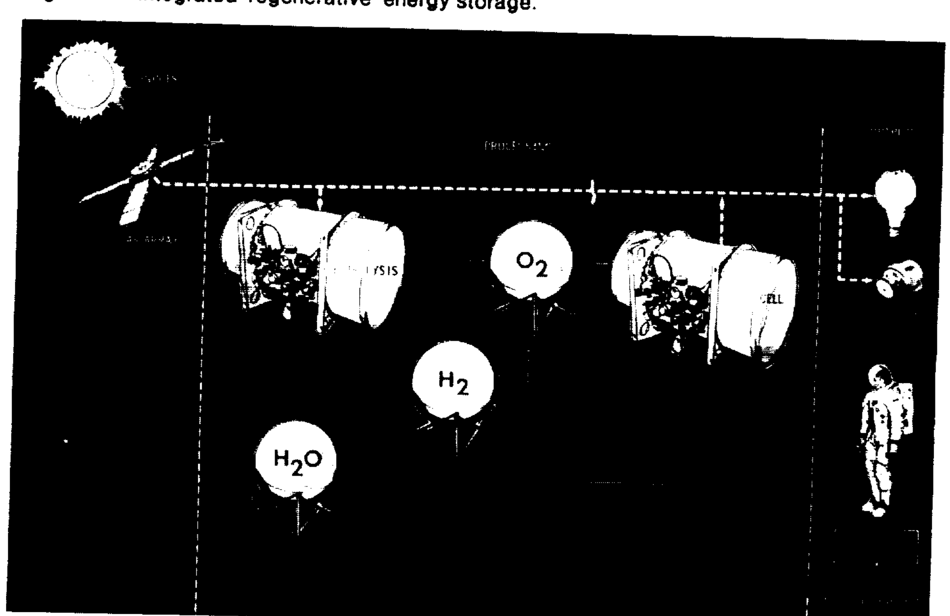
The expendables required for electrical power and propulsion and the life support systems required for long-duration manned space missions, such as work crews for space station or satellite construction, will become a substantial portion of the lift capability of launch vehicles. The solar-powered space station definition study of 1971 showed a weight and cost advantage using a solar-powered regenerative fuel cell system integrated with the life support system for a six-man, 25-kilowatt space station. Subsequent detailed design and analysis studies expanded the results and established definitive concepts. More recent studies associated with solar-powered space construction facilities indicate the potential of integrating certain propulsion requirements into the system. Thus, the regenerative fuel cell concept could serve as an orbiting utility substation. It is anticipated that this concept will be proven with a field test of an engineering model in 1986 and that the technology will be available for orbital emplacement by the late 1980's or early 1990's. Figure 1 illustrates how this system integrates electrical and life support functions.

The responsibility for this technology development is shared by JSC and the Lewis Research Center (LeRC). JSC has the acidic technology with the solid polymer electrolyte membrane and LeRC has the alkaline technology that is derived from the Shuttle capillary matrix fuel cell. LeRC is developing an alkaline "breadboard" article for testing at JSC.

The outstanding features of the solid polymer electrolyte concept include the extremely long-life capability of the electrolytic membrane, the superior efficiency of the electrolysis cell, and the ability to operate at high pressure. The alkaline capillary matrix concept is presently superior in fuel cell efficiency and shows promise of improved efficiency in the electrolysis mode with recently developed catalyst/electrode configurations.

A program was initiated in 1979 with the objective of bringing the regenerative fuel cell energy storage concept into technological readiness by 1986. One task was to perform an in-depth state-of-the-art study to define the various elements of the system. That task was completed with the publication of a state-of-the-art report in November 1979.

Figure 1.—Integrated regenerative energy storage.



Space Constructable Heat Pipe Radiators

The primary means for rejecting heat from orbiting spacecraft is through a space radiator system that rejects heat from a fluid circulating through it by radiation to the space environment. Current systems use a mechanically pumped coolant circuit to transfer heat over the radiating surface. Because system operation is vulnerable to complete failure from a single meteoroid penetration, reliability over long mission durations is low. High reliability in a pumped fluid system can be achieved, but the system is generally heavy because of the required redundant plumbing, pumping, and valving hardware. Long-duration high-power space missions will include excessively heavy heat-rejection subsystems unless significant technical improvements can be made. Therefore, a long-life heat-rejection system that can be constructed and deployed onorbit is required to support future long-term high-power missions such as large space structures, geostationary platforms, or space-habitable modules.

The solution to this problem is to develop a radiator system that can be assembled from a small number of relatively large elements (limited only by the size of the Orbiter payload bay) so that overall system complexity is minimized. A space-constructable radiator system, the keystone of which is an innovative high-capacity heat pipe design, will fulfill this requirement. This design, if successfully developed, will allow future large heat-rejection systems to be built up to virtually any desired size (heat load capability) using a relatively small number of components. The large heat pipes with radiator fins attached would be "plugged in" to contact heat exchangers that provide heat from a centralized heat-transport loop (fig.1). Such systems would be relatively insensitive to the micrometeoroid environment of space as the puncture of any module would cause only the loss of that module's 2-kilowatt capability, rather than the loss of all or a significant portion of the entire system. This type of system would lend itself to onorbit maintenance by simply unplugging damaged heat pipes and substituting new ones. The damaged pipes could be returned by the Shuttle for refurbishment and later reuse. The relative simplicity of this design could lead to the eventual manufacturing of the heat pipes in space for use on very large-scale structures.

The initial effort of this task has been concentrated on a feasibility demonstration of the simple dual-passage high-performance heat pipe design that forms the basic component of the system. This design permits high heat-transport capability without impacting heat-transfer efficiency. It combines the advantages of axial grooves, such as simple construction and large liquid and vapor areas, with the high heat-transfer coefficients of circumferential wall grooves.

The basic design of the improved high-performance grooved heat pipe contains two large axial channels, one for vapor and one for liquid (inset, fig. 1), that permit the axial transport and radial heat-transfer requirements to be handled independently. The small slot separating the channels creates a high capillary pressure difference that, coupled with the minimized flow resistance of the two separate channels, results in the high axial heat-transport capability. The high evaporation and condensation film coefficients are provided separately by circumferential grooves in the walls of the vapor channel without interfering with the overall heat-transport capability of the axial grooves.

Results of thermal bench tests of small-scale (30-inch-long) laboratory elements have confirmed the basic operating characteristics of the dual-passage design and indicated its feasibility for the desired application. Current effort calls for the fabrication and testing of a breadboard model (approximately 20 feet long) of the heat pipe to further demonstrate its heat-transport capabilities, followed by a demonstration of the manufacturability and performance capability of a full-scale (approximately 60 feet long) heat pipe. Development of the heat pipe will be followed by a preliminary design of a complete radiator system flight prototype during calendar year 1981. Design, fabrication, and checkout of a prototype test article comprising a representative portion of a complete system is planned for calendar year 1982, followed by thermal-vacuum testing in January 1983.

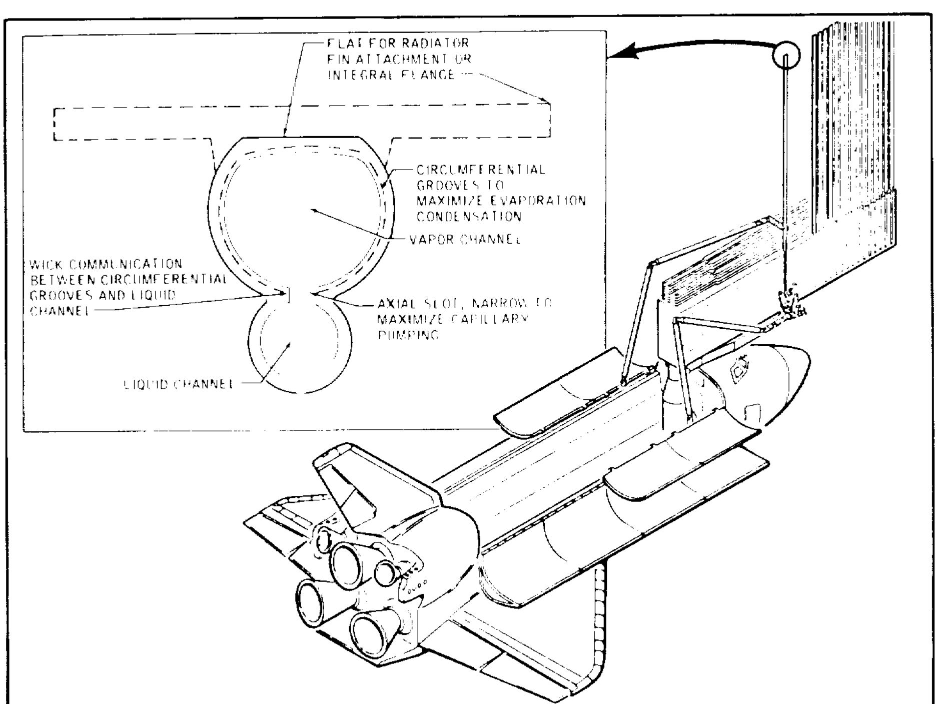


Figure 1.—Mockup of onorbit assembly of heat pipes with high-performance groove concept for efficient large-scale heat rejection.

Space Plasma Interaction Experiments for Large Power Systems

The interactions between the space plasma environment and surfaces elevated to high voltage (especially combinations of conducting and insulating surfaces such as solar arrays) are complex. These interactions must be understood to develop the design criteria necessary to build large high-voltage power systems for space.

In determining design criteria for space development testing, the large vacuum chamber at JSC can provide a vital intermediate "quasi-space" test with scaling parameters intermediate between the large ratio of object size to sheath size for testing associated with large space systems such as the solar power satellite (SPS) system and the small ratio testing in the small chambers. The technology to be developed is important to an increasing number of programs presently being identified for Shuttle era operations. Large-scale high-voltage interactions with the space plasma environment are inherent in such diverse systems as electric (ion thruster) propulsion, the various SPS subsystems and large-scale space energy systems, geomagnetic induction power supply, and various high-energy electron/proton beam experiments proposed for magnetospheric and space manufacturing studies. In addition to these intentionally exposed high-voltage devices, it has been observed that many supposedly passive surfaces acquire high-voltage potentials from time to time due to space environmental interactions, particularly in geosynchronous orbit.

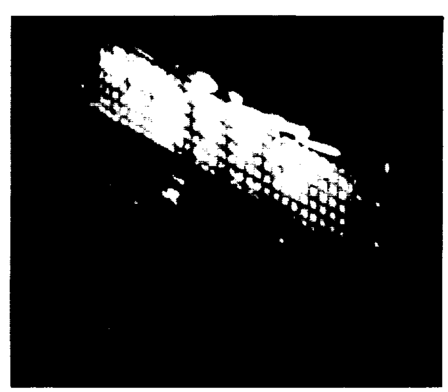
The program employs the unique 20-meter-diameter Space Plasma Laboratory facility at JSC to provide simulated space plasma conditions for testing large models. Adequate room is available for free-space development of the high-voltage plasma sheaths without the usual limitations inherent to laboratory testing due to wall effects and scaling errors. The work is conducted in close coordination with existing laboratory and flight projects at the Lewis Research Center and is one part of the proposed joint Air Force/NASA Environmental Interaction Technology Investigation.

Plasma may be generated either stationary or with a flow velocity to simulate the proper motion of a satellite through the ionosphere with the magnetic field variable from 0.1 to 3 gauss. The large sizes involved (both the test object and the high-voltage sheath) will allow direct measurement of variations of plasma parameters within the sheaths for detailed verification of analytical model behavior predictions. The Space Plasma Laboratory experimental program is intended to provide a direct link between smaller scale experimental data, analytical models, and space-flight systems. The intermediate scale experimental capability is important to avoid the large errors often encountered when attempting to scale hypothetical plasma behavior beyond an existing smaller scale data base.

From April to July 1980, the large vacuum chamber at JSC was used to perform several experiments in a simulated low-Earth-orbit/ionospheric space plasma environment. In addition to extending earlier studies (1977 and 1979) of large-scale plasma interactions with 10-square-meter high-voltage test panels, initial engineering verification tests were performed using a prototype Power Extension Package (PEP) solar array module in "flight" configuration. The 15- by 80-inch array, consisting of 174 ultrathin 6- by 6-centimeter solar cells mounted on a 2-mil Kapton substrate, is designed to produce 75 watts from each module. Each module weighs less than 3 kilograms and is designed for mechanical mounting by means of 40-mil hinge pins along each long edge, allowing series or parallel connection of successive modules to obtain 10 to 25 kilowatts total power.

The prototype PEP array was performance tested under conditions of solar thermal-vacuum and low-Earth-orbit plasma, both separately and in combination, to fully explore and verify its response under actual space operational conditions (fig. 1). The results verify satisfactory performance under combined solar and plasma conditions with plasma leakage current losses less than 2 percent at array voltages up to +280 volts (+80-volt solar array output plus 200-volt bias). Arcing to the plasma was observed at voltages over 500 but was shown to cause no

Figure 1.—Power Extension Package solar array under combined solar, thermal-vacuum, and simulated low-orbit plasma test exposure in chamber A.



damage to the array (fig. 2). Insulation of the exposed electrical interconnects to reduce plasma interactions was observed to be counterproductive, resulting in increased arcing and total plasma leakage currents for operations above 100 to 200 volts. Further investigation is required to determine why insulating the conducting surfaces causes increased arcing to the plasma at high voltages.

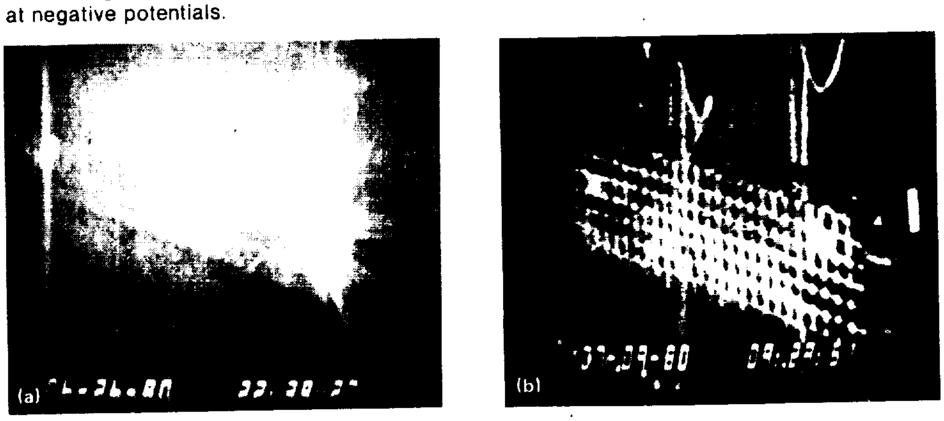
A total of 100 hours of experiment time was conducted using three 10-square-meter simulated solar array panels biased up to several kilovolts in a simulated low-Earth-orbit plasma environment. Measurements were obtained of the following:

1. Total electric current/power loss to the ambient plasma
2. Space charge limited plasma sheath size, development, and current limitation
3. Ion-current focusing by panel high-voltage sheath
4. Transient arc discharges
5. Effects of insulation of exposed conductor area on panel surface on the total current leakage and arcing to plasma

An additional 20 hours of experiment time was used to obtain similar measurements using the 0.75-square-meter PEP (flight) solar array. This included 10 hours with the array under active illumination at 1 solar constant.

An existing computer program (PANEL) was adapted to allow computation of high-voltage space charge sheath parameters around large arrays in a low-Earth-orbit plasma environment. The goal is for the resulting computer program to provide the analytical part of the planned iterative analytical/experimental approach to developing design criteria and computational capability for designing large high-voltage systems for use in low Earth orbit. Application to test results in chamber A show good correspondence in previously unexplained "focusing" patterns observed on the large arrays.

Figure 2.—Solar illumination has been turned off to allow low-light television cameras to view the faint plasma arcing. (a) Electrical arcing to plasma from the PEP solar array at −600 volts bias. The extensive point arcing shown resulted in no permanent degradation of electrical performance or physical damage. (b) PEP solar array at +600 volts bias. Note change in nature of discharge to a widespread corona-like pattern, rather than the point discharge behavior seen at negative potentials.



Advanced Manned Vehicle Onboard Propulsion Technology

The present man-rated spacecraft propulsion systems use a toxic, corrosive, and expensive hypergolic propellant combination of nitrogen tetroxide/monomethyl hydrazine. For future highly reusable manned spacecraft propulsion systems, such as a second-generation Space Shuttle auxiliary propulsion system, the hypergolic propellant combination will probably be phased out in favor of a noncorrosive, nontoxic, and less costly propellant combination. Preliminary studies indicate that the liquid oxygen/hydrocarbon propellant family provides the most attractive alternative and that an increase in system complexity will be unavoidable with these cryogenic propellants.

The present spacecraft auxiliary propulsion technology data base is too limited to allow selection of an optimum system and propellant combination. The objectives of this effort are to identify viable auxiliary propulsion system designs and propellant combinations to replace hypergolic propellant systems and to develop the technology base that will allow an orderly and cost-effective selection and subsequent development of a second-generation Shuttle auxiliary propulsion system.

Initial analytical and subscale experimental efforts will be conducted over a wide range of operating conditions to provide basic propellant combustion and thrust chamber cooling characteristics for promising propellant combinations. Preliminary system design and trade studies will involve (1) determining the inherent design, performance, and operational characteristics of promising propellant combinations and system concepts, (2) providing a common basis to compare the weight, mission performance, cost, and operational characteristics of promising propellant combinations and system concepts, and (3) identifying critical areas where full-scale component level technology efforts would be most beneficial.

High-speed color photography of single-element combustion has recently been used to qualitatively characterize the basic combustion trends of different propellant combinations and injector element designs over a wide range of operating conditions.

Resistance-heated tubes that simulate actual engine operating conditions have been used to characterize the thrust chamber regenerative cooling capability of propane.

Subscale injectors of approximately 1000 pounds force will be tested to characterize the combustion performance and stability of promising propellant combinations.

Single-Element Combustion Photography

Liquid oxygen was tested with rocket propellant-1 (RP-1), propane, methane, and ammonia in seven different single-element injectors. A total of 127 hot-fire tests was conducted over a chamber pressure range of 125 to 1500 psia. Different basic element designs were evaluated including (1) unlike coherent jet (fuel on oxidizer) impingement and (2) unlike spray (preatomized) impingement.

Striation of the propellant spray patterns (reactive stream separation) was apparent for all of the fuels and injectors except ammonia. The degree of reactive stream separation was observed to increase with increasing chamber pressure, increasing fuel temperature, decreasing unlike propellant impingement angle, and unlike spray impingement elements as opposed to coherent jet elements.

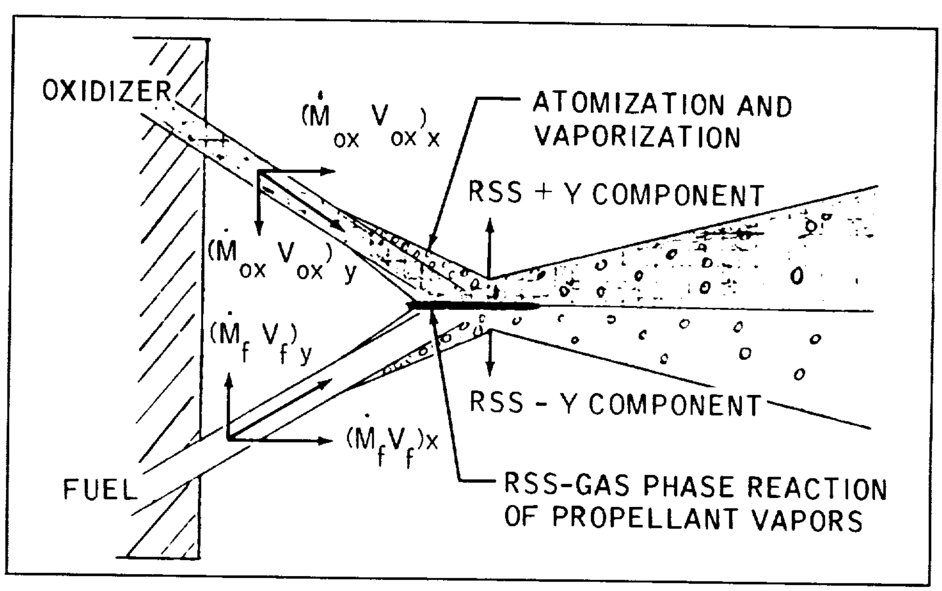
The same mechanistic model developed for hypergolic propellants is postulated to explain the trends observed with liquid oxygen/hydrocarbon propellants. In this model (fig. 1), the reaction of oxidizer and fuel vapors before the impingement of the main body of the injected propellants counteracts the hydraulic forces of the unlike propellant streams, thus affecting the subsequent mixing process.

Subscale Combustion and Heat Transfer

Twelve heated tube tests have been conducted with propane. The resulting forced convection heat transfer coefficients were 30 to 50 percent higher than predicted. The nucleate boiling heat flux capability of propane was shown to be 80 to 100 percent higher than originally predicted. Propane coking of the inside of the heated tubes occurred at lower wall temperatures (~500° F) than originally predicted (~800° F).

Future efforts will include fabrication and testing of subscale injectors and a preliminary system design and trade study.

Figure 1.—Vaporization-controlled liquid oxygen/hydrocarbon reactive stream separation model.



Advanced Synthetic Aperture Radar Technology

The 24-hour nearly all-weather high-resolution features of advanced synthetic aperture radar (ASAR) provide an Earth resources applications tool not available with any other remote sensor. The need for an orbiting ASAR for monitoring of surface water, soil salinity and moisture, vegetation classification, ocean surface winds and waves, and snow and ice has been identified during several meetings sponsored by NASA. An L-band ASAR was flown on the Seasat and a modified L-band radar is planned for the Office of Space and Terrestrial Applications-1 Shuttle payload. Single-frequency ASAR with swaths up to 100 kilometers typifies today's technology. The envisioned ASAR mission set for the 1980's includes Shuttle imaging radar, Venus-orbiting imaging radar, ice-monitoring satellites, and Earth resources synthetic aperture radar. The functional requirements for this mission set include swaths in excess of 150 kilometers, multifrequency, multipolarization, and multi-incidence angle capability with amplitude calibration to approximately 2 decibels. The purpose of this program is to demonstrate the technology for a multimode ASAR that can be operated at selectable frequencies, polarizations, and incidence angles and can generate imagery with the required accuracy. A multimode aircraft ASAR will be fabricated and flight-tested for this demonstration. The system will be parameter controlled (fig. 1) and fabricated to provide design approaches that are flexible and automated and that can be adopted for the anticipated missions in the 1980's (fig. 2). This technology can also be used in designing ASAR for spacecraft that will satisfy multimission objectives at substantial cost savings; e.g., Earth resources and ocean surveys in the same mission.

One of the goals of the the ASAR program is to identify technology areas for future development. Some effort will be expended during the system development period to study the areas for future capability expansion including wide swath, real-time onboard processing, pixel elevation, and complex polarization signature.

The tasks associated with the implementation of the project will be accomplished in three phases.

Phase I will consist of the following tasks:

1. Mission requirements survey
2. System trade-off studies: multiantennas (time sharing), multibeam scan ASAR, arrays versus reflectors, long antennas and beam shaping, calibration techniques, transmitter survey, and computer simulations
3. System implementation trade-offs
4. Multimode aircraft ASAR specification and functional design

A design document will be developed and a formal functional design review will be held at the conclusion of this phase.

Phase II will consist of the detailed design, fabrication, and tests of the system. This phase will include comprehensive design reviews to assess the detailed design of the subsystems prior to final commitment to fabrication.

Phase III will consist of the integration of the ASAR system with the aircraft and of the aircraft test flights and data acquisition. This phase will also include the detailed analysis of the test flight data and the system performance assessment. A comprehensive final report will be prepared that will include recommendations for the spacecraft system design.

The user community will be involved in the system specification and data evaluation phases of the project.

The ASAR was a fiscal year 1980 new start and is scheduled for completion in 1983. In fiscal year 1980, a survey of Earth observation user requirements was completed. Based on these requirements, a conceptual design was developed. A review of technology development was also undertaken to survey the state of the art in subsystem development. Subsequently, a specification document was prepared for the system and the computer simulation program for the design verification was updated. In addition, studies were conducted in the area of wide-swath transmitter and antenna design and data processing. The detailed design and control logic software development has begun and plans for antenna procurement have been made.

Figure 1.—Parameter-controlled advanced synthetic aperture radar system.

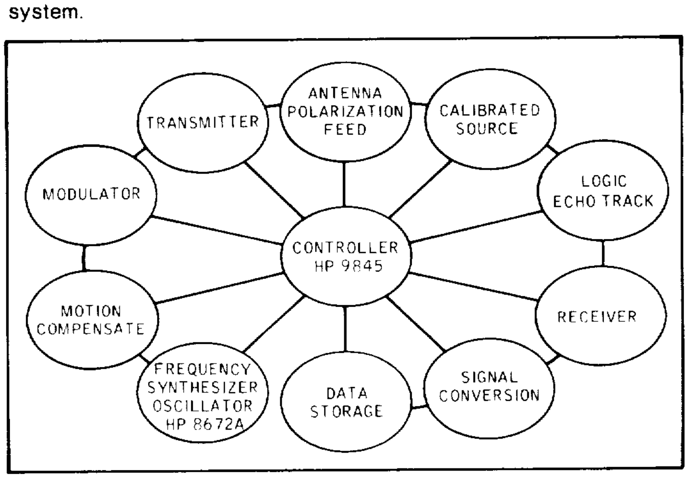
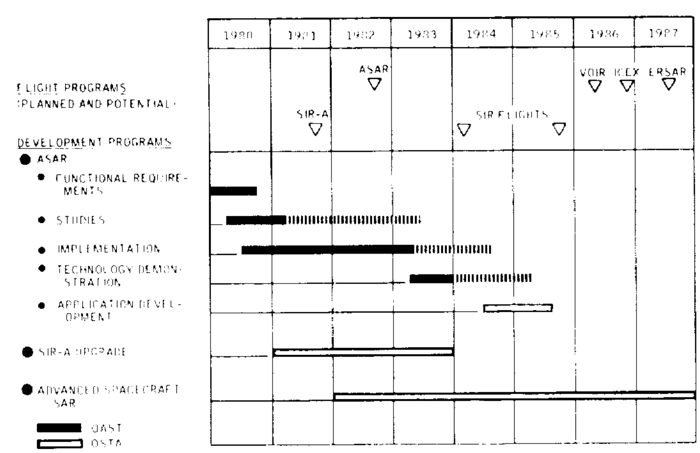


Figure 2.—Advanced synthetic aperture radar development programs.



Large Space Systems Technology

The Large Space Systems Technology Program is concentrating on future space systems that are larger than the Orbiter cargo bay and will therefore require the development of new technology, techniques, and components to enable onorbit construction or deployment. Some of the conceptual requirements for large space systems are large deployable microwave antennas, multipurpose science and applications platforms, and large reflectors for missions such as the narrowband communications satellite experiment, the passive microwave receiver, the very long baseline interferometer, and the satellite power system test article.

JSC has been developing the overall capability to construct large systems in space. This capability is complementary to the space construction plans of the system as directed by the Large Space Systems Technology Program Office at Langley Research Center. The activities at JSC include platform systems studies, simulation of the assembly of erectable structures, and subsystem technology for automated fabrication in space.

Simulation of the assembly and erection or deployment of space elements under zero-gravity conditions can be performed in the Manipulator Development Facility at JSC. From previous platform system studies, the following two areas for follow-on work were identified.

Advanced Space Platform Technology Study

A number of significant technical issues are involved in the buildup of a large space platform. Some of the key mechanical problems include berthing of the servicing vehicle or assembly modules, handling the assembly modules with the Remote Manipulator System (RMS), and connecting electrical or fluid lines between assembly modules.

The approach was to formulate requirements for mechanisms based on platform system concepts. The platform configurations have similar requirements for berthing platform segments and payloads. Although recognizing that requirements would be limited in scope, conceptual designs could be generated for berthing mechanisms, umbilical interfaces, and end effectors for the RMS.

A list of berthing system requirements was derived based on Orbiter constraints, platform interface requirements, and RMS performance. From these requirements, the design requirements for a berthing-latch interface mechanism were generated. Six concepts were developed and evaluated. A hexagonal frame concept (fig. 1) was designed and a full-scale functional model was fabricated for tests in the coming year. A preliminary design for an umbilical interface mechanism was completed and fabrication of a demonstration model of the adaptive end effector is underway.

Forming and Welding of Composite Materials

Graphite fiber reinforced thermoplastics have many desirable material properties for the fabrication of structures in space. As well as having a high strength-to-weight ratio and modulus of elasticity, the material shows very little thermal distortion. The capability to form and join the material is a new technology.

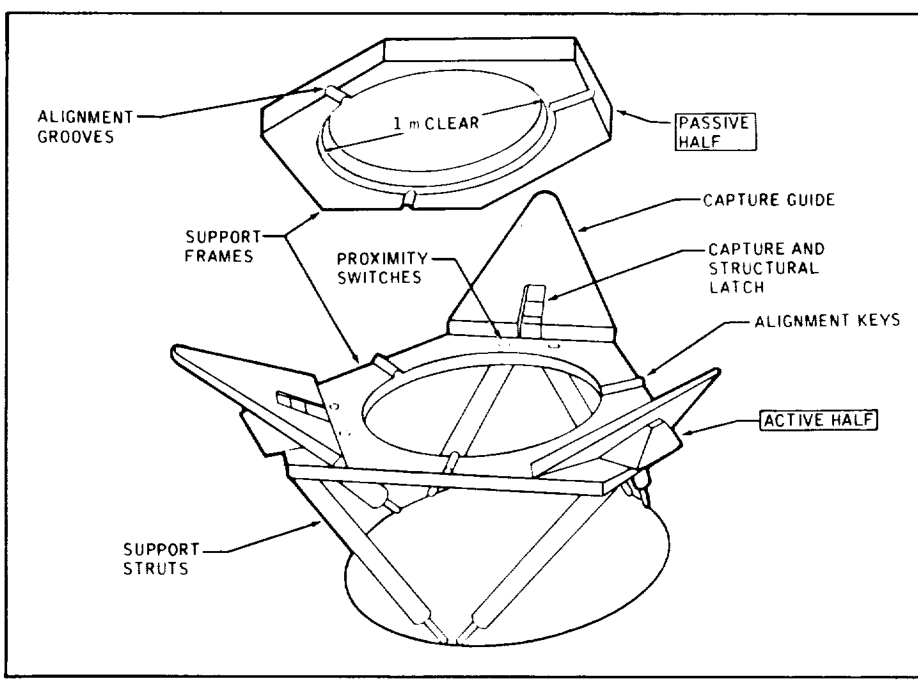
The approach adopted was to build a prototype test truss from caps formed from strip material and joined by ultrasonic welding. Extensive modifications to an existing bench test machine provided a forming capability. Commercial ultrasonic welding machines were used to join the material.

Ultrasonic welding of the composite material was achieved with excellent results after initial failures with vacuum welding. The prediction was that the commercial welder would operate successfully in a vacuum even though it was not designed for that environment. The welding failure was caused by a corona effect in the transducer and was corrected by removing a label from the vent hole.

The effect of gravity on the weld was evaluated by welding 45° and 90° angles. Some reduction in strength that could have been corrected by a change in weld schedule was noted.

Cap elements were roll-formed for the building elements of the prototype truss. The truss was assembled on a jig using ultrasonic welding. Valuable data on torsional stiffness, transverse stiffness, structural damping, and compressive strength were obtained in tests at JSC.

Figure 1.—Hexagonal frame concept for the berthing-latch interface mechanism.



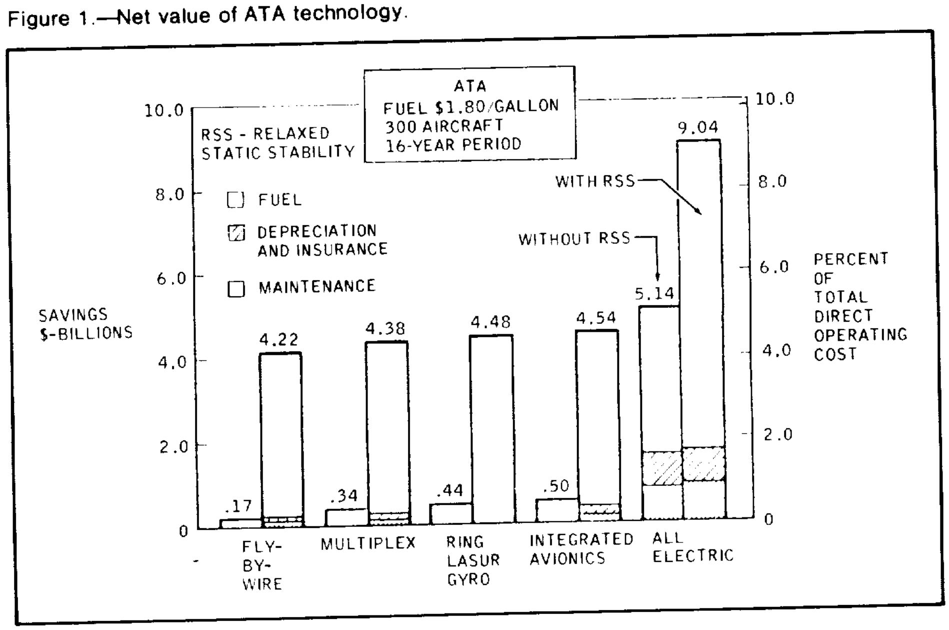
Application of Advanced Electric/Electronic Technology to Commercial Aircraft

Advanced electronics technologies similar to those used in the Space Shuttle have potential application to commercial transport aircraft. These technologies include (1) redundant digital fly-by-wire flight control and stability augmentation, (2) comprehensive computer monitoring and management of vehicle systems, and (3) digital data multiplexing. Electric actuation for aircraft control surfaces, although not currently in use in the Space Shuttle, is suitable for aircraft applications as are fiber optics communication and data transmission, advanced sensor concepts such as laser gyros, and high-voltage electrical power systems. These advanced electric/electronic systems are potentially more energy-efficient than current mechanical, hydraulic, and pneumatic system designs used in commercial aircraft. For example, reductions in aircraft "bare-airframe" stability can be permitted if a digital fly-by-wire rather than a mechanical flight control system is used. Reduced stability requirements will, in turn, decrease aircraft weight and aerodynamic drag, resulting in lower fuel consumption. Also, fluid transmission losses in hydraulic systems will increase as the size of the airplane and length-of-line runs increase. Electric actuation systems using high-voltage electrical transmission offer a significantly more energy-efficient weight-reducing alternative, particularly for the large wide-body transports.

A study to define the potential payoff from the incorporation of these advanced technologies into commercial aircraft has been completed by the JSC. Three types of aircraft selected for the study included a commuter transport weighing 28 606 pounds, a short-haul transport weighing 40 427 pounds, and an advanced wide-body transport weighing 459 437 pounds. Five candidate electronic technologies that were applied to each vehicle included digital fly-by-wire flight control with and without reduced stability requirements, data multiplexing, ring laser gyros, an integrated avionics/data processing system, and an all-electric secondary power system. Baseline system designs were defined for the three aircraft and weight, cost, and reliability estimates were made to establish a valid basis for comparison. Preliminary designs of the advanced technology systems were similarly defined for each vehicle. Investment, research and technology, and operating costs of the aircraft with these advanced systems were then derived and incrementally compared to similar costs for the baseline vehicles.

The principal results of this study for the wide-body advanced transport aircraft (ATA) are summarized in figure 1. The net value of technology (the difference between the cost of technology and the savings resulting from it) and the total percent reduction in direct operating cost for each technology are shown for the ATA with and without reduced airframe stability. These data are based on an assumed fleet of 300 aircraft and a fuel cost of $1.80 per gallon. Current industry estimates project fuel prices between $2 and $3 per gallon in the early 1990's. As can be seen in figure 1, the all-electric secondary power system ATA shows the highest cost savings, totaling more than $9 billion over a 16-year period. This is a large payoff and supports further work by NASA in the development of these technologies for aircraft applications. The benefits, when realized, will result in higher productivity for the airplane industry, lower airfares for the passenger, and significant energy savings for the United States. A contractor's report, "Application of Advanced Electric/Electronic Technology to Conventional Aircraft," summarizing the results of this study has been published.

Figure 1.—Net value of ATA technology.



Nonterrestrial Materials for Space Use

Future space activities may involve the construction of very large structures in space. Because significantly less energy is required to launch materials from the Moon than from the Earth, these large-scale space activities may benefit from the development of manufacturing industries in space that obtain the bulk of their raw materials from the rocks and minerals of the Moon. Two activities have been completed and a third has been redirected.

Handbook of Lunar Materials

The physical and chemical properties of lunar rocks, soils, and minerals are basic data needed for feasibility and design studies of advanced processes for refining lunar materials. This need has been filled by the preparation and publication of a document, "Handbook of Lunar Materials." It is available as NASA Reference Publication 1057.

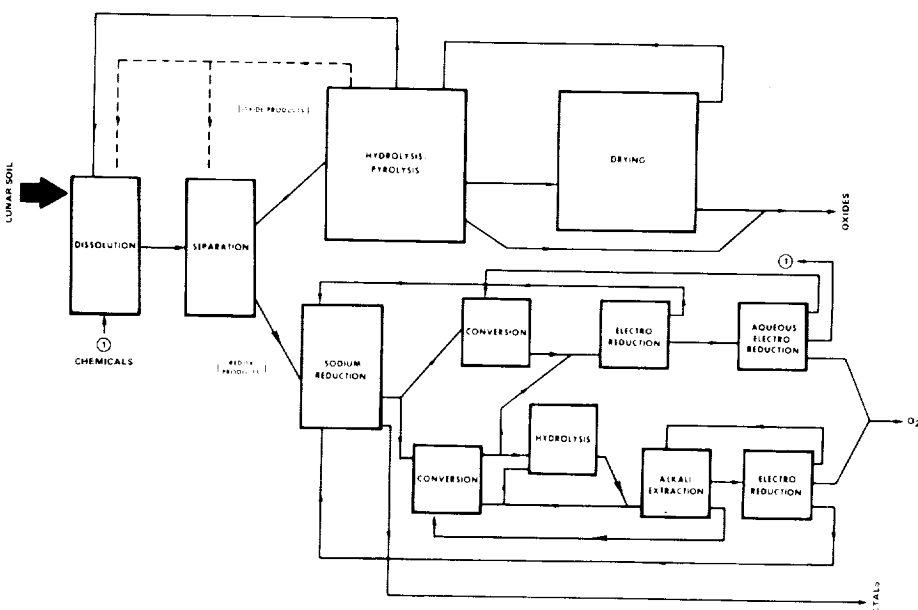
Nonterrestrial Materials for Large-Scale Space Construction

Large-scale construction activities in space might benefit if metals, ceramics, glass, and other materials could be produced from lunar rocks and soils. These potential resources present significant technical challenges, particularly in the area of refining. The low-grade and nonspecific nature of these "ores," the necessity to close all chemical cycles, and the desire to construct chemically efficient processes that produce as much as possible from as little as possible are the sources of these technical challenges. The focus of this study has been the definition of the chemical and physical processes that could be used to produce construction materials from lunar "ores."

Prior efforts concentrated on the quantification of the mining and ore beneficiation processes and on the screening of various chemical processes for refining lunar materials. A fluorosilicic acid process (fig. 1) that uses hydrolysis and electrolysis to separate and concentrate the products from refining dilute ores was developed. The study results are presented in a contractor report, "Extraterrestrial Materials Processing and Construction."

The fiscal year 1980 efforts were directed toward (1) preparing a more detailed design and definition of the fluorosilicic acid process, (2) holding a workshop on applied electrochemistry, and (3) determining the use of products and intermediaries in the fluorosilicic acid process for ceramic manufacture. The study results, workshop reports, and all technical papers are included in the contractor report.

Figure 1.—Schematic diagram showing the major process elements and flows in the fluorosilicic acid process proposed for use in refining lunar materials.



Refining of Nonterrestrial Materials

Although processes used to extract useful materials from lunar ores may be defined on paper by using thermodynamic and engineering computations, the actual viability of a process can only be tested in the laboratory. Two aspects of such testing have been explored this year.

The first aspect relates to the extraction of oxygen by high-temperature electrolysis of gaseous process effluents, especially the extraction from carbon dioxide, which is an effluent from some types of refining. Previous research has shown that thermal decomposition followed by oxygen pumping across the solid electrolyte appears to be the limiting step. Therefore, a new test design that permits the use of ultraviolet light stimulation has been designed and built. Tests are planned for the fall of 1980.

The second aspect relates to the definition of the dissolution and phase separation steps of the fluorosilicic acid process (fig. 1) in terms of experimental variables. The process steps were mapped onto a pF-pH diagram and compared with known solubility data. These were then reduced to a hierarchical set of unknowns that need to be specified to define the process better. A set of alternates for the process elements was also defined as were figures of merit. An in-house status report of the results is available.

Fire-Resistant Low-Smoke-Generating Thermally Stable End Items for Aircraft and Spacecraft

The general objectives are to apply fire-resistant materials technology to crash and ramp fires in commercial aircraft and to conduct systems testing of new and modified fire-resistant materials in configurations such as aircraft lavatories, galleys, seats, fuselage sections, and the general cabin area. The basic objectives of the program are as follows:

1. To demonstrate that the introduction of fire-barrier materials in the exterior wall will prevent an external "design" fire from entering closed and intact habitable areas for the minimum 5-minute period needed for passenger evacuation
2. To demonstrate that a closed and intact cabin will not reach a temperature of 400° F (considered a lethal temperature level for humans) nor contain smoke or toxic gases at temperatures up to 400° F for a specified "design" fire
3. To demonstrate that a "design" fire in the area of a cabin opening will not propagate throughout the cabin area during the minimum 5-minute period

The program was initiated to identify, develop, and characterize fire-resistant materials to meet the spacecraft flammability specification requirements of the Federal Aviation Administration, the aircraft manufacturers, and JSC. A fire-retardant rigid polyimide foam system was developed for internal applications. Using this technology and expanding the program to include other applications, significant progress was made in developing fire-resistant low-smoke-generating thermally stable polyimide end items.

Concurrent with the polyimide developments, a program was formulated to fabricate 8- by 12-foot aircraft fuselage section panels using baseline and advanced materials and to test them for burnthrough properties over a pit of burning jet fuel simulating a postcrash fuel fire.

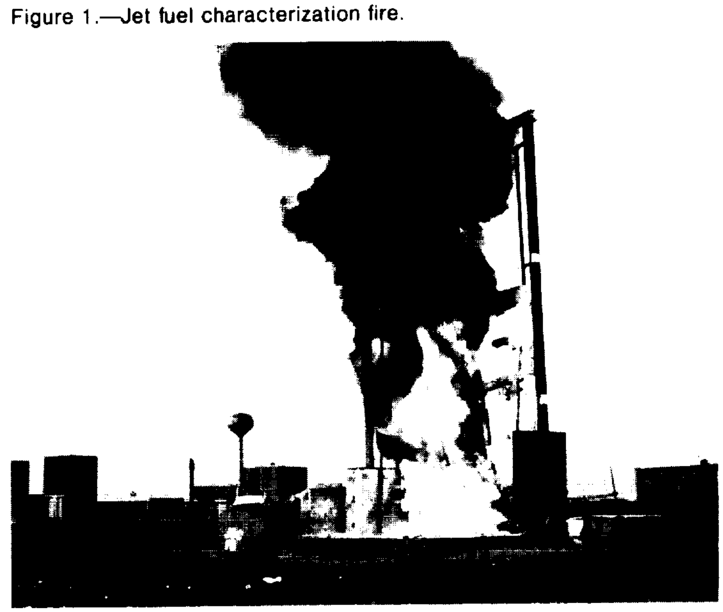
Fire-resistant low-smoke-generating resilient seat cushion polyimide foam is available in laboratory quantities for flight tests. Pilot plant production of the foam is expected by early summer 1981. The latest formulation of the resilient foam has the lowest (90 percent) compression set. It has been tested by a prime aircraft seat manufacturer for indentation load deflection and processability and was found satisfactory. The vendor has now requested two different densities of the seat foam to make several passenger seat backs for flight tests. This resilient seat foam has also been sent to another prime aircraft seat manufacturer for fabrication into prototype seats to be fire tested by two research centers.

The recent advances in the polyimide resilient foam technology resulted from increasing the power in the 6- by 6- by 12-foot microwave oven from 15 to 20 kilowatts. This power increase permitted production of large-size foam "buns" and also accomplished foaming and curing in one process. In addition, the spray-drying time for the base resin has been reduced from 18 hours to 30 minutes and the quantity of resin produced has been increased to 39 pounds per day.

Formulations of polyimide thermal-acoustical foam insulation incorporating 20 percent milled fiberfrax fibers did not shrink in length or width but ablated in thickness without burnthrough and gave a satisfactory fire-barrier time. The acoustical properties, however, were not met. A newly developed Fluorel/fiberglass laminate did meet the acoustical requirements and also showed promise as a wallboard. The combination of Fluorel/fiberglass laminate and polyimide foam as the thermal-acoustical insulation in a wallboard will be tested for effective thermal-acoustical fire-barrier properties. Multiple-density foam wallboards still require further development in the area of edging compounds with good screw-withdrawal properties before they can be produced commercially. Two rigid polyimide-foam-filled honeycomb floorboards with improved adhesive to bond the face sheets are being fabricated for functional testing in a 747 jet aircraft. A previously installed panel failed after 2633 hours because the face-sheet bond was inadequate.

The aircraft fuselage panel burnthrough test program was modified to fabricate and test standard wide-body jet aircraft fuselage sections. These will be tested over a pit of burning fuel previously calibrated to give a burn time of specific length and thermal output. The jet fuel characterization fire for these tests is shown in figure 1. The test stand includes an instrumented stainless steel panel used to calibrate the jet fuel quantity for a burn time of specific length and thermal output. If the wide-body jet materials perform satisfactorily, these materials will be fabricated in a narrow-body jet aircraft fuselage panel and retested.

Figure 1.—Jet fuel characterization fire.



Toxicity Testing and Evaluation of Candidate Aircraft Materials

Each year in the United States, thousands of lives and millions of dollars in property are lost by fire. To reduce this loss, new fire-resistant materials and chemical additives have been developed that significantly reduce the flammability of conventional materials. Recent evidence, however, indicates that materials containing fire-retardant additives may produce severely toxic gases in a fire. These gases could be extremely critical because of their potential to induce behavioral incapacitation and thus prevent escape. Therefore, the screening of materials for fire safety has been expanded to include not only tests of flammability but also of behavioral toxicity. A major difficulty facing material manufacturers is that there is no standardized test for behavioral toxicity.

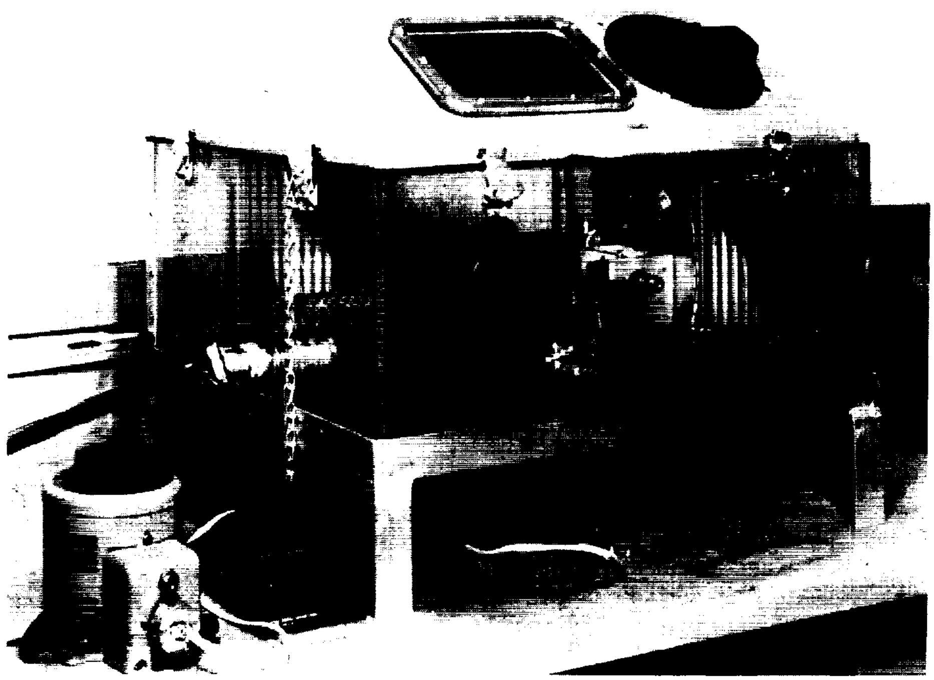
As a part of NASA's fire-retardant-materials engineering program (FIREMEN) at JSC, operant behavior technology has been used in the toxicity testing of aircraft cabin materials. A recent experiment illustrates how this technology could be employed in the screening of materials for potential toxicity.

Small uniform samples of either a conventional fire-retardant polyurethane or a newly developed polyimide foam were pyrolyzed at three different temperatures in a chamber housing test animals trained to press a lever to terminate brief electric shocks (fig. 1). During each pyrolysis test, air samples were withdrawn from the chamber and analyzed for carbon monoxide and hydrogen cyanide. Throughout the test, the lever-pressing behavior of the animals was monitored by computer. To ascertain the relative toxicities of the two polymers, the behavioral effects induced by their pyrolysis products at each temperature were compared and analyzed.

The results of this experiment indicated that the behavioral toxicity of these two polymers varied differentially with pyrolysis temperature. At the lowest temperature, the greater resistance of the polyimide foam to thermal decomposition resulted in lower off-gas concentrations and consequently in fewer behavioral effects. At the highest pyrolysis temperature, just the opposite effect was found. These results help to identify some of the complexities involved in ranking materials according to potential behavioral toxicity. The ranking of these two polymers based only on either the high or the low pyrolysis temperature would not have been accurate.

In addition to the behavioral toxicity tests of these polymers, the JSC FIREMEN program has included (1) comparisons of the susceptibility of different behaviors to toxic incapacitation, (2) full-scale fire tests of materials in a 737 fuselage, and (3) comparisons of full-scale and laboratory toxicity tests.

Figure 1.—Experiment setup to test pyrolysis toxicity of candidate aircraft materials.



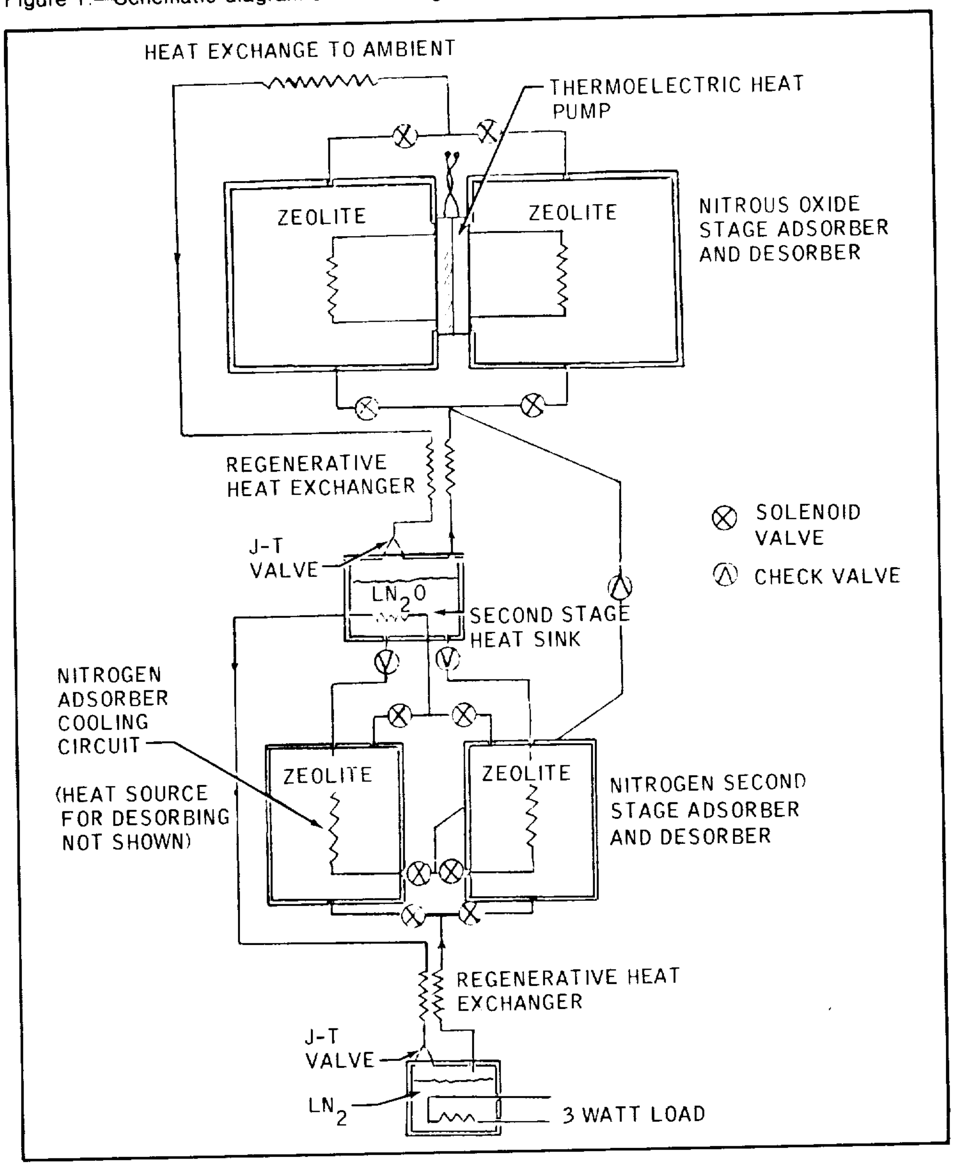
Adsorption Pumping Cryogenic Refrigeration

The objective of this project is to develop and demonstrate operation of a new type of cryogenic refrigeration called the Molecular Adsorption Refrigeration System (MARS). The device (fig. 1), which uses an adsorption pumping cycle, is nonmechanical (has no moving parts) and will provide a highly reliable source of cryogenic cooling. This cooling could be cryogenic cooling for long-wavelength infrared detectors for long-term orbital, deep space, or aircraft missions. This system could also provide conventional cooling for spacecraft and/or terrestrial uses such as automotive air conditioning where waste heat could be the power source.

The adsorption pumping cycle is similar to the better-known liquid absorbent cycle that makes use of the ammonia absorption properties of water. In the liquid absorbent cycle, the application of heat to the mixture releases the ammonia through an expansion valve and lowers the temperature. Conversely, the MARS cycle uses a mineral called zeolite (also called molecular sieves) that has a crystalline structure with storage cavities that electrostatically attract charged gas molecules to the inner walls. The refrigerant is subsequently driven out of the zeolite and pressurized by the application of heat, which may be waste heat or solar energy. Expansion through a Joule-Thomson valve liquefies the gas and produces cryogenic temperatures. Closed-loop and continuous operation is effected by the use of other containers of zeolite, one of which adsorbs the cooled refrigerant while another is preheated to be switched in when the gas is exhausted from the container in use.

The Molecular Adsorption Refrigeration System is capable, in the current design, of producing 5 watts of cooling power. To date, principles of operation and attainment of goals have been demonstrated in the laboratory using an engineering evaluation model that is the culmination of the development effort. This model, the design of which is based on the theory and the models developed in the course of the work, provides proof of the Molecular Adsorption Refrigeration System concept and the availability of valuable design tools for future effort. A limited amount of investigative work has also been accomplished using a naturally occurring zeolite, called mordenite, as opposed to the original synthesized zeolite. The apparent superior properties of the new zeolite, along with the verified theory, mathematical model, and experimental insights gained in the accomplishment of the project, will permit significant increases in performance with corresponding decreases in power, weight, and volume of future designs. This system will be evaluated as a potential air-conditioner for automobiles using waste heat from batteries or from an internal combustion engine.

Figure 1.—Schematic diagram of a two-stage nitrogen liquefier using adsorption pumping.



Office of Space and Terrestrial Applications

Significant Tasks

61 Forest Resource Information System

Funded by: Resource Observation, Applied Research, and Data Analysis (UPN-677)
Project Manager: R. E. Joosten/SH2
Task Performed by: Purdue University Laboratory for Applications of Remote Sensing
Contract NAS 9-15325

64 AgRISTARS: Supporting Research Project

Funded by: Resource Observation (UPN-691)
Project Manager: William E. Rice/SA
Task Performed by: NASA, U.S. Department of Agriculture, and U.S. Department of Commerce

66 AgRISTARS: Foreign Commodity Production Forecasting Project

Funded by: Resource Observation (UPN-691)
Project Manager: William E. Rice/SA
Task Performed by: NASA, U.S. Department of Agriculture, and U.S. Department of Commerce

68 Wildland Vegetation Resource Inventory

Funded by: Resource Observation, Applied Research, and Data Analysis (UPN-677)
Project Manager: K. J. Hancock/SH2
Task Performed by: ESL Corporation
Contract NAS 9-15740

70 Texas Natural Resources Inventory and Monitoring System

Funded by: Applications Systems Verification Test (UPN-658)
Project Manager: Leo Childs/SK
Task Performed by: Lyndon B. Johnson Space Center
Lockheed Electronics Company, Inc.
Contract T-6984G

71 Orbiter Camera Payload System

Funded by: Shuttle Experiments (UPN-666)
Technical Monitor: B. H. Mollberg/ED8
Task Performed by: Itek Optical Systems Division
Contract NAS 9-15671

72 Extended Scene Radar Calibration

Funded by: Resource Observation (UPN-677)
Technical Monitor: R. G. Fenner/ED6
Task Performed by: Lyndon B. Johnson Space Center

73 SIR-A Antenna Integration to OSTA-I Pallet

Funded by: Resource Observation (UPN-666)
Technical Monitor: Harold Nitchske/ED6
Task Performed by: Lyndon B. Johnson Space Center
Ball Brothers Aerospace Corporation
Contract NAS 9-15512

Forest Resource Information System

The Forest Resource Information System (FRIS) was initiated as an Application Pilot Test in October 1977 to demonstrate and verify the utility of Landsat computer-aided classification technology to industrial forest management problems in the Southeastern United States. The primary goal was to implement and establish an independent operational information system in which Landsat data is a viable component and also to determine if space technology is financially attractive and easy to use and can maintain the confidence of management for operational functions by an industrial user. The Southern Timberland Division of the St. Regis Paper Company owns or controls over 2.3 million acres throughout Florida, Georgia, Alabama, Mississippi, Louisiana, and Texas (fig. 1). By participating with NASA in the Application Pilot Test project, St. Regis made a philosophical and fiscal commitment to share in the overall management responsibility and in the total cost to implement such a system.

A cooperative agreement between St. Regis and NASA is the instrument of record that defined the responsibilities of both parties. NASA shares in the project management by providing for the contractual support (the Laboratory for Applications of Remote Sensing (LARS) of Purdue University) to develop specific quantifiable forest resource information from Landsat multispectral-scanner (MSS) data and correlate this to the inventory data furnished by St. Regis on specific test sites. The contractor will develop classifications analysis procedures and software and provide for the technical training of St. Regis project personnel. NASA will also provide for the technical coordination of St. Regis and contractor project personnel during the four-phased project (fig. 2).

The technology developed for this project will be documented and transferred into the public domain for possible use in the wood products industry. St. Regis will also furnish a final report on the usefulness of the system and a cost and benefit analysis study.

The past year established several highlights: (1) the transfer of the LARSFRIS software to a St. Regis computer system, (2) the establishment of the FRIS Center in Jacksonville, Florida, by St. Regis, and (3) the implementation of the FRIS design as established by the project.

The LARSFRIS software was transferred to the St. Regis National Computer Center in Dallas, Texas. This software consisted of two main elements: the LARSYS preprocessing software and the classification programs for the analysis of remote-sensing data. The preprocessing programs consist of three major processors. These processors convert the standard Landsat MSS digital tapes to a LARSYS format, perform systematic geometric corrections, and provide the capability to register temporal scenes of Landsat data sets and to register the Landsat data to a map base.

Figure 1.—Land holdings of the Southern Timberland Division of the St. Regis Paper Company.

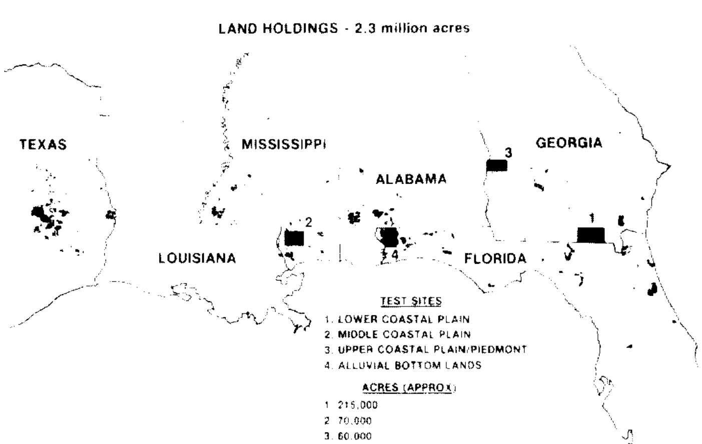
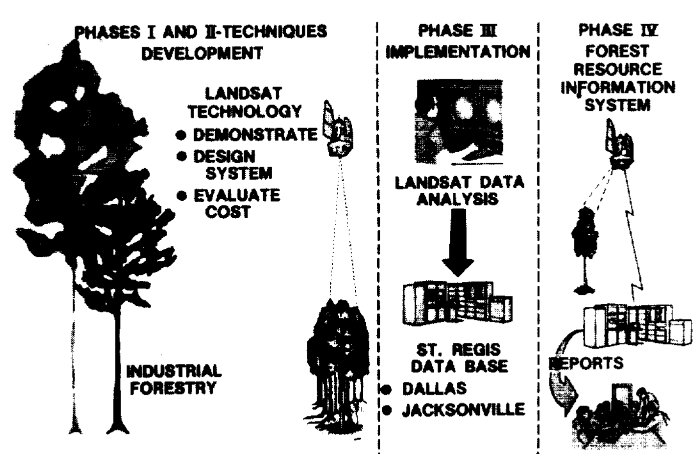


Figure 2.—The four phases of the St. Regis Project.



A total of 20 processing functions has been transferred to the Dallas facility for converting Landsat data into information useful for monitoring and inventorying forest resources (figs. 3 and 4). This image processing subsystem comprises a subset of the LARSYS 3.1-version software package that currently resides in NASA's Computer Software Management and Information Center (COSMIC) of the University of Georgia, the LARSYSDV (development) modules, and two new functions developed during this project. The total subsystem, which will be identified as LARSFRIS, was converted to operate on the St. Regis IBM 3033 system.

In January 1980, the St. Regis Paper Company provided the official acceptance of the project demonstration phase. This action provided the necessary capital expenditures to implement the FRIS in a production mode in the Southern Timberlands Division. In April 1980, the Southern Timberlands Division established the FRIS Center in Jacksonville, Florida. The FRIS Center's objectives are to complete the development of the system, to implement it on an operational basis, and to maintain and enhance the total resource information system to meet the needs of the division.

Figure 3.—Landsat forest-type map of St. Regis Paper Company, Fargo, Georgia, Test Area, prepared in 1979 from 1976 data.

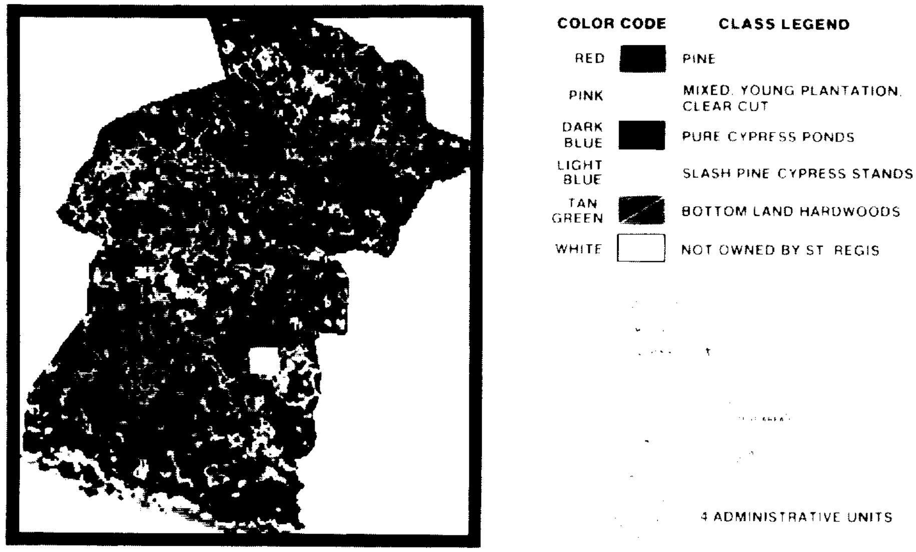
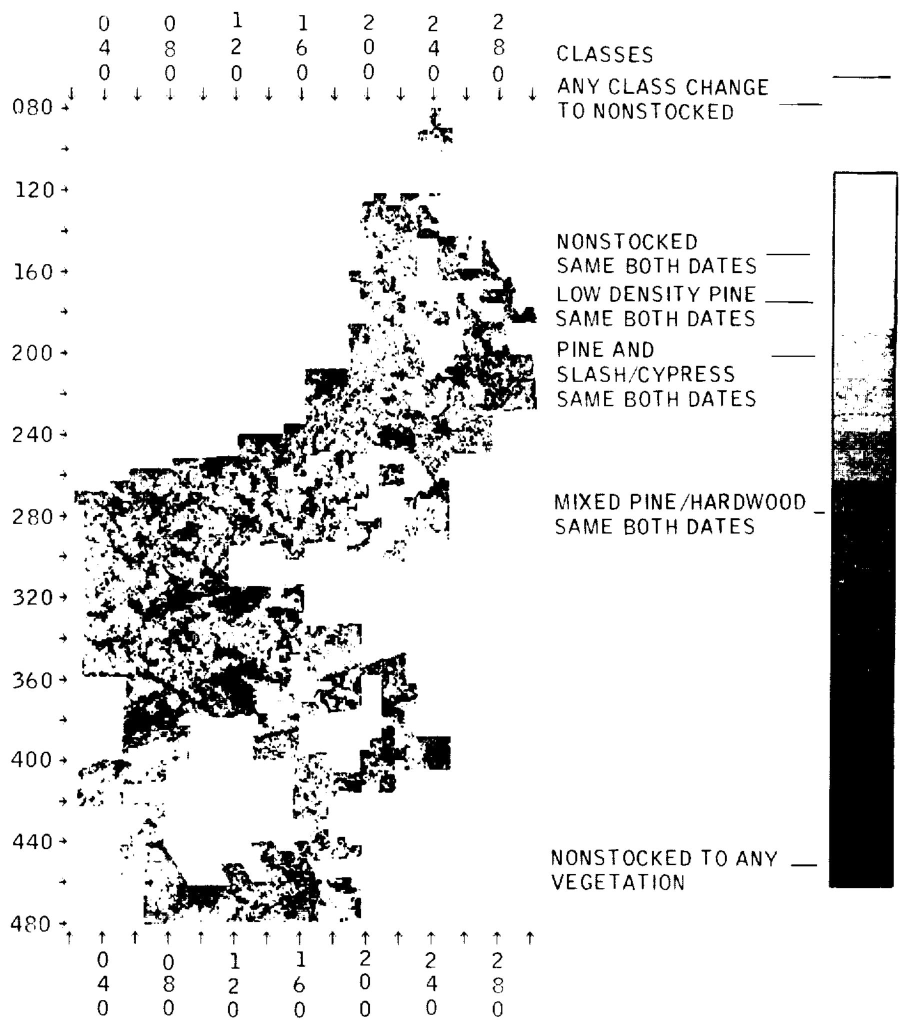


Figure 4.—Example of a change map showing the areas that changed between the 1977 and 1979 classifications.



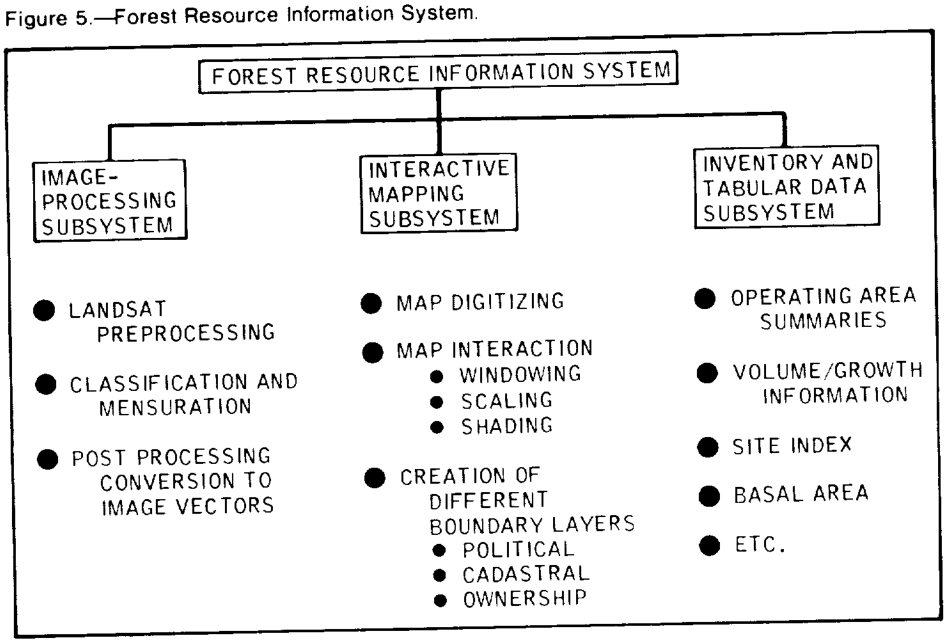
The FRIS will have three major components (fig. 5) basically representing the involvement of two major technological advances. The image-processing subsystem represents the role of satellite remote sensing for data collection, land cover analysis, monitoring of changes of forest resources, update verification and inputs to land acquisition, long-range planning, and forest inventory. The second subsystem is a new computerized mapping capability to establish the data base and revise and update forest resource data maps and is an interactive methodology to merge digital-, polygon-, and tabular-type information to produce output products. The third subsystem consists of descriptive inventory data and simulation and planning models that were already established by St. Regis and are now part of the total information system.

New hardware purchased by St. Regis for the Jacksonville center includes a minicomputer for integrating inventory, map, and satellite data bases. The minicomputer will accommodate local users and serve as a terminal to the computer center at Dallas. The minicomputer will also support future remote graphic stations within the Southern Timberlands Division. The interactive graphics terminal cluster consists of a digitizing table to establish and update map data files and two cathode-ray tubes to be used for editing, manipulation, and display of map and tabular information. A drum plotter will be used as an output medium for all maps and drawings. Also, a color-image display will be used as an interactive device for Landsat registration activities, classification analysis, and display of results including a map overlay capability. Additional equipment includes alphanumeric terminals and a line printer.

The IBM 3033 computer in Dallas will process most of the more tedious applications in a batch mode, and the system in Jacksonville will provide the interactive interface for the data management and retrieval functions. Most of the basic inventory and planning models that use simulation and linear programing techniques are on the Dallas system and will be completely compatible with the LARSFRIS software. The total system will perform various functional activities and will be a dynamic easily accessible management tool for meeting operational requirements.

Documentation of the software transferred by LARS to St. Regis will be available through COSMIC. Final reports, currently in progress, from LARS and St. Regis will also be placed in the public domain. In May 1981, St. Regis and NASA will conduct a Space Technology and Industrial Forest Management conference in Jacksonville, Florida, to present the FRIS Application Pilot Test concept and discuss its attractiveness to private industry for managing forest resources.

Figure 5.—Forest Resource Information System.



AgRISTARS: Supporting Research Project

The Supporting Research project is one of eight projects in the AgRISTARS Program. The purpose of the project is to provide an integrated research effort that supports several other AgRISTARS projects. Directly supported are the Foreign Commodity Production Forecasting, the Early Warning/Crop Condition Assessment, and the Yield Model Development projects. Indirect benefits accrue to the Domestic Crops and Land Cover, the Soil Moisture, and perhaps the Renewable Resources Inventory projects. The Supporting Research project continues the previous focus on techniques related to production estimation of wheat, barley, corn, and soybeans in foreign regions with planned extensions to rice, cotton, sorghum, and sunflowers in future years; the project also contains enhanced efforts in agronomic remote sensing.

The technical effort in this project is divided into the following areas.

1. Area estimation research: includes machine processing, manual processing (labeling/image interpretation), and preprocessing (image registration and image display)
2. Agronomic remote sensing: includes crop development stage estimation and spectral inputs to yield estimation
3. Supporting field research

The area estimation research plan includes the development of technologies for estimating crop proportions in small (5 by 5 mile) segments of Landsat multispectral-scanner (MSS) digital imagery, for estimating crop proportions in larger areas such as Landsat MSS full frames, and for segment estimates in Landsat D thematic mapper data. Currently, active research is aimed at the MSS full-frame estimation; research on use of thematic mapper data is at a background level but a substantial effort will begin in fiscal year 1981.

Many crops appear spectrally similar in Landsat MSS data at a given point in time; separations of these crops are only possible by use of multidate sequences of MSS imagery, which allow individual crops (e.g., wheat) to be recognized on the basis of their temporal spectral development. Even this approach, which was the basis of the Large-Area Crop Inventory Experiment (LACIE) efforts, does not allow 100-percent accuracy in crop recognition, both because of the significant overlap of the individual crop temporal spectral development patterns ("signatures") and because of the visibility in crop signatures due to such factors as planting date, variety, and weather. The approach to this problem has been predicated on the following judgments.

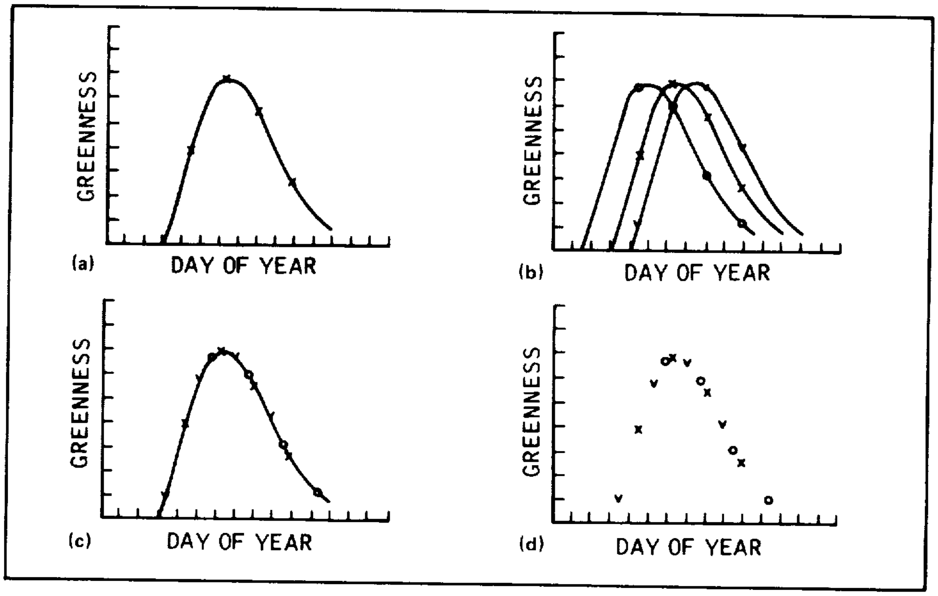
1. The requirement to assess the crop identity at a sufficiently large number of locations to make an accurate estimate of crop proportions cannot possibly be done economically unless it is automated.
2. The current lack of quantitative understanding of how crop signatures are affected by external factors requires the use of a human analyst to adjust the parameters of ("train") the automated processing system to the local conditions.

In practice, the analyst has manually identified ("labeled") training samples from the Landsat image to be machine processed. Several important accomplishments in this area have occurred in the past year.

Previously, machine processing has been used primarily to reduce the error in an analyst-based estimate because the analyst cannot economically identify all pixels in the Landsat MSS image ("sampling variance") while propagating the effect of other analyst-induced errors. In the past year, however, several machine processing approaches have been identified in which other analyst-induced errors are substantially attenuated. The first such technique has been delivered to the Foreign Commodity Production Forecasting project. All these techniques have been enabled by the previous development of computer algorithms capable of automatically isolating and characterizing the statistical crop signature distributions present in a segment of MSS data. Further improvements in this area are anticipated.

Analysis of multidate MSS data has been a cumbersome process for several reasons: (1) Each Landsat observation contributes four distinct measurements on each pixel, (2) different segments of data have different acquisition histories, and (3) variations in planting date from field to field cause substantial variations in individual crop signatures on each acquisition date. Simplified representations of multidate MSS data that offer new insights into the crop identification and assessment process, substantially reduce the cumbersomeness of the data, allow us to eliminate the planting date influence, and reduce the sensitivity to acquisition dates (fig. 1) have been developed. These tech-

Figure 1.—Multidate multispectral scanner data. O's and X's are Landsat observations on overpass dates. (a) Typical crop profile. (b) Variations due to planting date. (c and d) The effects of shifting all observations to a single crop emergence date.



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niques are regarded as being the foundation of a probable breakthrough in MSS processing in that it will be possible to characterize a crop by agronomically meaningful descriptions (e.g., planting date and growing-season length) rather than by a sequence of MSS observation values.

Previously, the labeling process has been a highly labor-intensive process in which the analyst has been called upon to make not only those decisions which he is uniquely qualified to make but also a large number of relatively mundane decisions. Many of the more mundane have become sufficiently quantitative to enable their automation in the labeling procedure. This will have the major advantages of both reducing the cost of labeling and making it possible to objectively study the effect of variations in the labeling process.

In LACIE, registered multidate MSS data were provided by the Goddard Space Flight Center LACIE processor. This system, which provided registration to a 1974 state-of-the-art value of 1 pixel rms (a marginal value for many of the applications), is now being phased out. The technical design of a new JSC registration system that will replace the LACIE processor and provide the foundation for a sequence of improvements in registration accuracy has been completed.

In LACIE and in the Multicrop Research Program, research was largely concentrated on crop area estimation techniques, with a relatively low level of research directed at agronomic remote sensing through fiscal year 1980. A major goal of the Supporting Research project is to advance the state-of-the-art technology in agronomic remote sensing to a quantitative rather than qualitative level; resources directed to this area will be substantially increased in fiscal years 1981-85. Despite the limited level of resources in fiscal year 1980, two significant accomplishments have occurred. The first was the discovery that, at least for corn and soybeans, the crop development stage is closely related to the accumulated versus the projected area under the crop development curve and that we could project backwards in time along the crop development curve to determine the emergence date (fig. 2). The importance of this is twofold: (1) when the spectrum of the crop development stage can be measured, rather than simply estimated from meteorological or historical data, the performance of a meteorologically driven yield model can be substantially improved; and (2) the crop development stage models can now be run on a per-field basis to improve the accuracy of labeling. The second significant accomplishment was the conceptual development of an advanced yield model in which MSS data are used to determine the crop leaf area index and, hence, the fraction of incident sunlight intercepted. This yield model would be combined with Metsat (meteorological satellite) measurements of insolation to derive solar inputs required by process-level yield models (fig. 3).

The remaining major technical area in the Supporting Research project is supporting field research, which conducts experiments involving the acquisition and analysis of data sets containing both spectral and agronomic measurements, frequently under conditions of controlled variability. Major recent accomplishments include (1) an experiment that shows the effects of various factors (e.g., row width, row direction, solar elevation angle, and soil color) on corn and soybean reflectances, and (2) the development of a low-cost radiometer system that will permit substantial expansion of the supporting field research program without an equivalent cost increase.

In summary, the first-year 1980 effort in Supporting Research has resulted in substantial technical progress and has placed the Supporting Research project in a good position to initiate the work to be performed in subsequent years.

Figure 2.—Spectral profile crop development stage estimation.

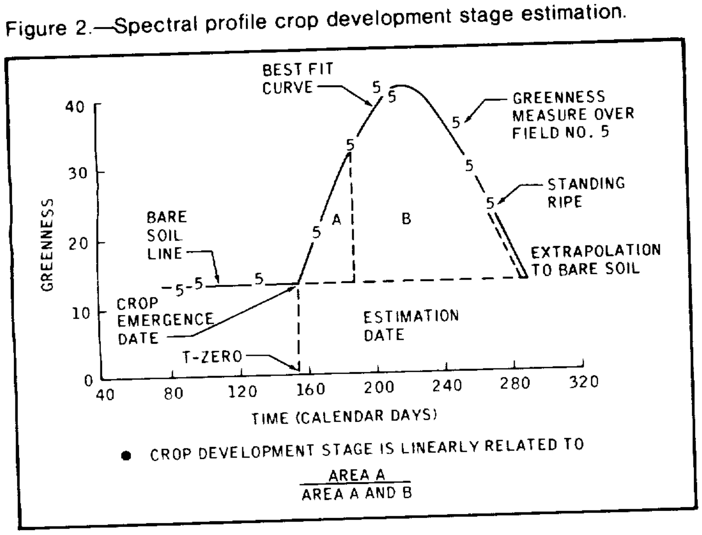
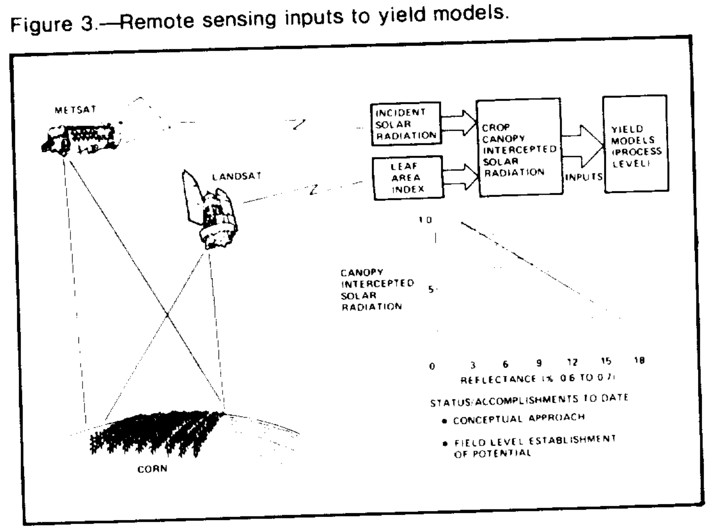


Figure 3.—Remote sensing inputs to yield models.



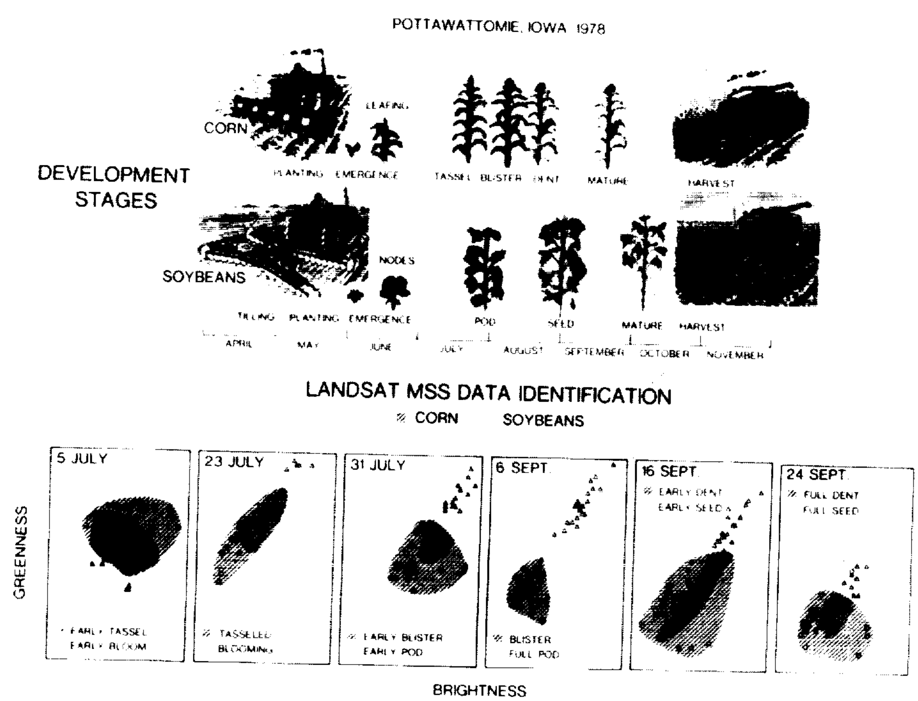
AgRISTARS: Foreign Commodity Production Forecasting Project

The Foreign Commodity Production Forecasting project of AgRISTARS builds on 6 years of joint experience by the U.S. Department of Agriculture, NASA, and the National Oceanic and Atmospheric Administration in foreign crop production forecasting and remote-sensing research and development and on more than 15 years of crop-related aerospace remote-sensing technology in the United States. Previous triagency research of the application of Landsat multispectral-scanner and weather data has established a suitable basis for the Foreign Commodity Production Forecasting project (fig. 1). For example, previous accomplishments have (1) shown that regression-yield models for wheat have worked well under both average conditions and under important conditions that significantly departed from the average; (2) shown that small grains can be reliably estimated in important areas; (3) demonstrated the value of exploratory experiments in foreign areas to identify each region's unique commodity characteristics in addition to research in the United States where detailed ground truth is available; (4) provided understanding of real problem areas, quantified their impact, and developed generalized approaches for their solution; (5) provided an understanding of the need for improved spectral, spatial, and temporal resolution of satellite sensors and systems; and (6) shown that data loads associated with the technology can be handled. In addition, at the outset of the AgRISTARS, the Foreign Commodity Production Forecasting project has the following advantages of previous research:

1. Teams of scientific personnel experienced in this technology and its application within the participating agencies
2. Universities and industries that can now perform a more significant role in research and development
3. In-place research and development data systems
4. Existing data bases that will allow the effective use of retrospective data in the development and evaluation of technology over many of the crop regions to be investigated
5. Components of technology that will serve as building blocks for further research
6. The considerable research already conducted by LACIE and the LACIE Transition Project to isolate the wheat/barley/small-grains issues and effect solutions
7. Experience in development of corn and soybeans technology based on the Corn Blight Watch Experiment
8. The Crop Identification Technology Assessment for Remote Sensing (CITARS) experiment over Illinois and Indiana
9. The USDA research in Illinois and Iowa
10. An 18-month experiment during fiscal years 1978 and 1979 over the U.S. corn and soybeans belts

The Foreign Commodity Production Forecasting project will build upon the technical capability of this previous research to further advance the applications of remote sensing to foreign production forecasting through research and development. It will be test oriented toward resolving the remaining issues in direct observation of wheat and barley in the presence of other small grains; extending the technology to additional crops and regions; using improvements in spectral, spatial, and temporal characteristics of satellite sensors such as the seven-band 40-meter-resolution Landsat D thematic mapper; developing improvements in early season production estimation technology; developing approaches that tend to be more cost-effective; and quantifying the value of still further improvements in the technology (e.g., sensors, crop identification, pattern recognition, registration, etc.).

Figure 1.—Spectral separability of corn and soybeans, Pottawattomie, Iowa, 1978.



The scope of this project involves wheat or barley or both over selected regions within Canada, U.S.S.R., India, Australia, and Argentina; corn and soybeans over selected regions within Argentina and Brazil; beginning technology extension to rice in India; and exploratory investigations in the United States for cotton, sorghum, and sunflowers. Production estimation technology will be developed and evaluated for each crop and region combination. Technique development and problem solving will be carried out in "similar" U.S. crop regions (where good ground truth is available) in parallel with the foreign crop regions, where independent data and statistics are not as timely or reliable. The quality and availability of government statistics vary from country to country and from region to region within a country. Assessment of achievable performance in foreign regions will depend on the performance assessment in similar U.S. regions as well as comparison to independent foreign estimates.

AgRISTARS during fiscal year 1980 continued those activities that were carried out in the LACIE Transition Project. In particular, efforts were continued on advancing techniques to perform crop identification and classification on corn and soybeans and wheat and barley. During the fiscal year, the supporting research and technology community, primarily the Environmental Research Institute of Michigan (ERIM) and the University of California at Berkeley (UCB), was given the major role in corn and soybeans classification technology and the JSC Earth Observations Division assumed the lead in wheat and barley technology.

At JSC, the principal classification effort was to translate transition-year corn and soybeans crop identification and classification techniques into wheat and barley techniques. The systematic objective labeling logic developed for corn and soybeans was modified for wheat and barley and the increased use of spectral aids was incorporated into the logic. The techniques developed during the transition year for wheat and barley were also incorporated into this new labeling logic approach. The "new" wheat and barley logic and procedure were tested twice during the fiscal year. The first was a six-segment "shakedown" test to identify procedural and logic problems; the test results were encouraging and only minor modifications were made. Using the new procedure, called the "reformatted" wheat and barley procedure, the U.S. wheat and barley exploratory test was then conducted using 11 segments. The results indicated some previously undetected problems with the procedure and modifications are currently being made before its use in the fiscal year 1981 U.S. Wheat and Barley Pilot Test. Simultaneously with the U.S. wheat and barley exploratory test, an evaluation of a second wheat and barley procedure, the "integrated" procedure, was conducted; this less systematic more labor-intensive procedure was also evaluated.

The corn and soybeans efforts of ERIM and UCB have involved modifying the JSC-developed corn and soybeans decision logic procedure developed in fiscal year 1979 and incorporating the use of spectral and spatial transformations developed by the supporting research and technology community. These developmental efforts have been continuously reviewed by JSC, and JSC has conducted a preliminary review of the corn and soybeans labeling logic. The first end-to-end test of the procedure and logic developed by ERIM and UCB is planned for early in fiscal year 1981 as part of the 1981 U.S. Corn and Soybeans Pilot Experiment.

In the area of sampling and aggregation, a new weighted aggregation approach has been developed and tested that establishes a more valid technique for handling the "nonresponse" areas, or areas not adequately represented because of poor satellite acquisition histories. Poor satellite acquisition can result from cloud cover, operational constraints, or equipment malfunctions. Simulated aggregation software was developed to permit simulating the performance in area and production estimation over a region, assuming different values for within-stratum variance and for nonresponse. Sample frame development for foreign areas to be addressed in later AgRISTARS experiments is progressing well. Indicator regions have been selected in Brazil, Argentina, the U.S.S.R., and Australia and sample segments have been selected to support the exploratory experiments in these countries.

Wildland Vegetation Resource Inventory

The joint NASA and Bureau of Land Management (BLM) Application Pilot Test was accomplished through an off-site contract (ESL Incorporated of Sunnyvale, California) to NASA to test and implement an interactive Wildland Vegetation Resource Inventory System based on remotely sensed data and oriented to the BLM state and district office management requirements. The project was planned in three phases with test sites in Alaska, Arizona, and Idaho.

The Alaska phase, May 1977 through July 1978, mapped vegetation types and developed accuracy relationships using various scales of aerial photography and ground data applied to Landsat digitally processed data. Landsat spectral classes were developed with a maximum likelihood classifier; these classes were then described through photointerpretation of large-scale (1:1200) color aerial photography coupled with selected plots of ground-truth data to correlate the photointerpretation with ground conditions. An example of a classification of the Alaska Test Site is shown in figure 1. BLM resource personnel were trained in the theory and application of resource measurement and estimation procedures and how, when, and where remote-sensing techniques should be applied to provide cost-effective resource inventories and assessments.

The second phase, September 1978 through June 1980, modified the system developed during the Alaska phase and tested it in the desert ecosystem of Northwestern Arizona.

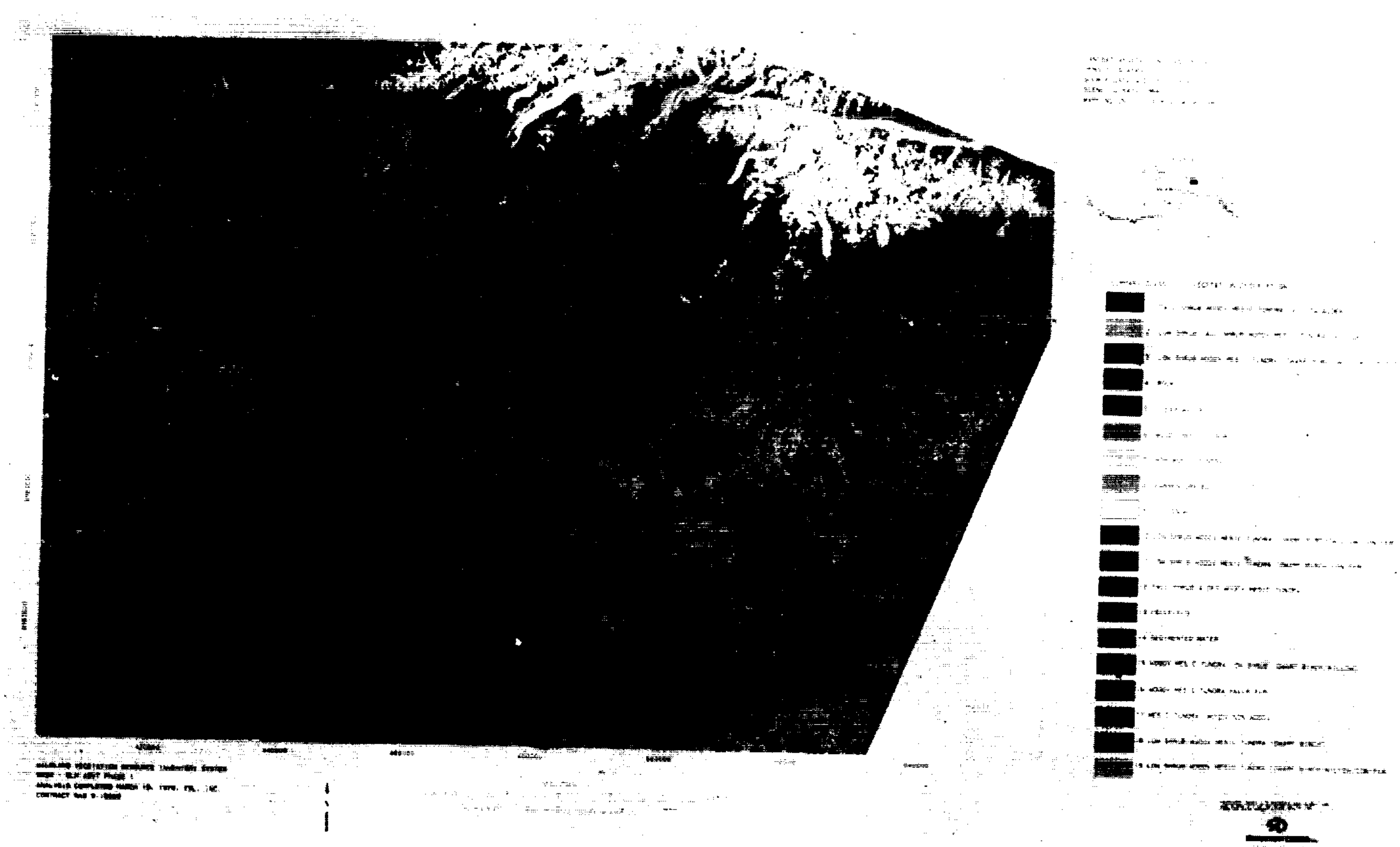


Figure 1.—Landsat vegetation classification of the Alaska Test Site.

This phase went one step further by demonstrating a multi-resource inventory with productivity estimates for range forage, timber production and woodland volume (fig. 2 and table I). Training of BLM resource personnel continued. Concurrent with the contractor Phase II activities, BLM tested its in-house expertise, with assistance from the Earth Resources Observation Satellite (EROS) Data Center, by accomplishing a Landsat vegetation resource inventory over the same test site in Arizona.

The final phase of the NASA support began in December 1979 and involves project documentation, implementation and documentation of software, and support for a final project conference in early 1981. The Application Pilot Test is scheduled for completion in March 1981.

BLM purchased a minicomputer system in the fall of 1979 and established a Remote-Sensing Branch at the Denver Service Center for operational support of ongoing projects. BLM is presently using these capabilities during the final project test phase at the Idaho Test Site. The results of this remote-sensing effort, to be completed in late 1980, will provide inputs for preparation of an environmental statement.

The overall success of the Application Pilot Test is evidenced by the remote-sensing processing and analysis capabilities established at the Denver Service Center and the inclusion of remote-sensing requirements in the BLM budget submission.

Figure 2.—Landsat vegetation classification of the Arizona Test Site.

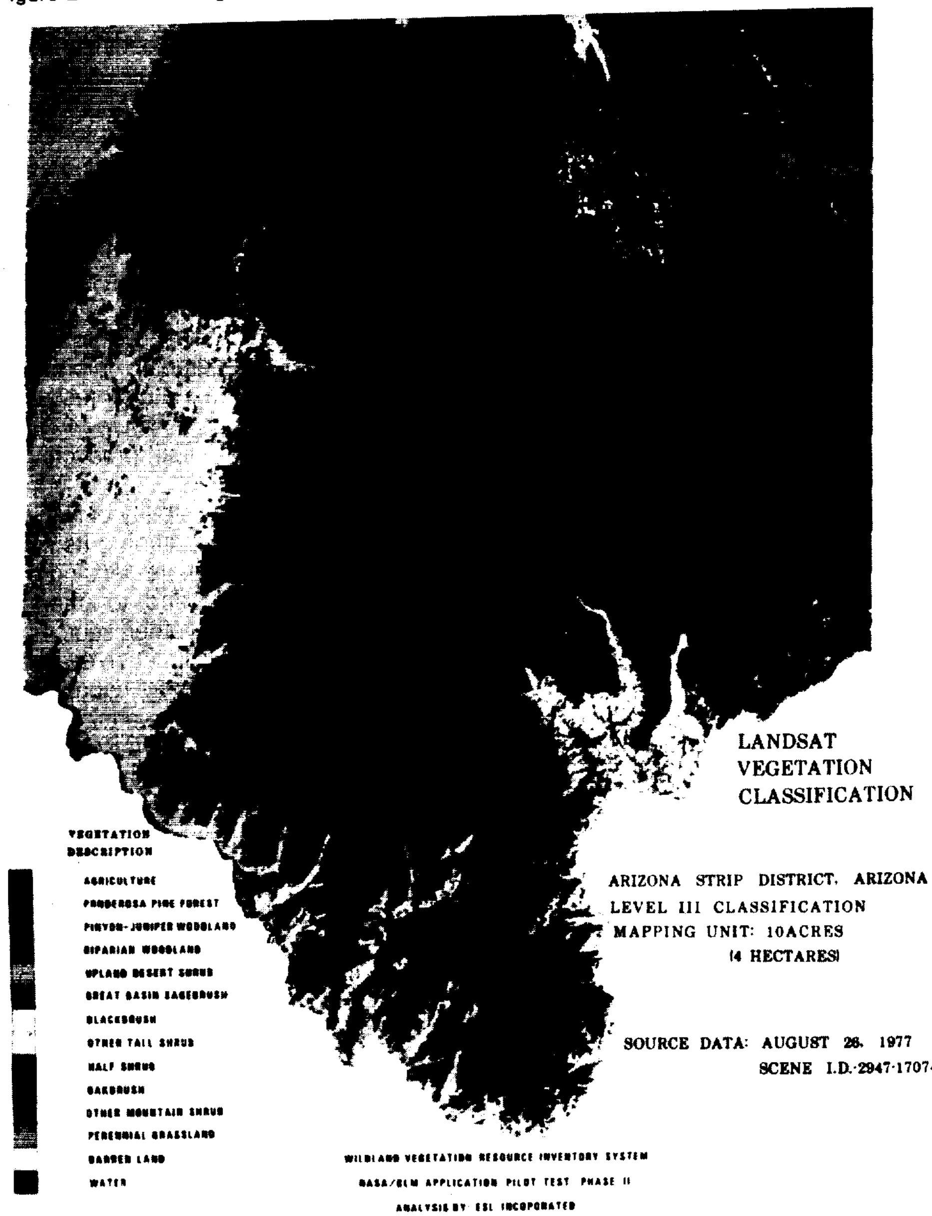


TABLE I.—JUNIPER CUBIC VOLUME ESTIMATES[a] FOR SELECTED ARIZONA TEST SITE ALLOTMENTS

ALLOTMENT	TOTAL AREA, ACRES	TOTAL VOLUME, $FT^3 \times 10^3$	VOLUME, FT^3/ACRE	STANDARD ERROR	RELATIVE STANDARD ERROR	AVERAGE SIZE, FT
Wolfhole	13 308	2215 [b](1479, 2951)	178.4 [b](119.1, 237.7)	45.9	0.26	14.0 [b](8.9, 19.1)
Wolfhole Mountain	14 727	2770 (1756, 3785)	188.2 (119.3, 257.1)	53.5	.28	15.6 (9.8, 21.5)
Blackrock	37 323	4831 (3119, 6543)	147.2 (95.1, 199.4)	40.6	.28	12.4 (6.6, 18.2)
Total	65 358	9817 (8533, 11 101)	163.7 (142.3, 185.2)	16.7	.10	13.6 (7.8, 19.4)

[a]Estimates apply to BLM land only.
[b]Numbers in parentheses are 80-percent confidence intervals.

Texas Natural Resources Inventory and Monitoring System

The purpose of this project is to develop, test, and evaluate approaches and procedures for integrating Landsat and other remote-sensing data with more conventional data sources (e.g., census, maps, and field surveys) to augment and make more effective the existing information data base supporting Texas natural resources management agencies. The major goal is to integrate the use of Landsat and other remote-sensing data into the day-to-day decisionmaking processes of the Texas resources management agencies. To accomplish this goal, the utility and cost-effectiveness of the information derived from remotely sensed data must be evaluated in an operational environment using ongoing management requirements of selected state agencies as evaluation criteria.

This project is a joint effort of the JSC Earth Observations Division and a consortium of 13 Texas agencies known as the Texas Natural Resources Information System. The project started in June 1978 and is expected to span 3 years. The project will develop, test, and evaluate a Texas Natural Resources Inventory and Monitoring System based in part on information derived from remote sensing. The system will consist of three components: a remote-sensing information subsystem, a geographic information subsystem, and a natural resources analysis subsystem. Figure 1 illustrates the type of output products that will be produced.

The major responsibility of NASA is to assist Texas in upgrading its existing experimental remote-sensing data analysis capability and to interface this capability with other sources of natural resources information available to the state. The software capability is being developed in two parts. The first part was completed by NASA in early fiscal year 1980. The major responsibility of Texas includes developing the remaining remote-sensing software; expansion of the existing geographic information subsystem; development of the natural-resources analysis subsystem; and preparation, testing, and evaluation of output products.

To carry out the responsibilities of both parties, a Memorandum of Understanding was instituted. Responsibility for management of the project is shared by a Texas Project Manager and a JSC Deputy Project Manager.

The technology developed for this project will be documented for transfer to the public domain through NASA's Regional Technology Transfer Centers and the Computer Software Management and Information Center (COSMIC). Texas will also furnish a final report on the utility of the system and a cost and accuracy analysis study.

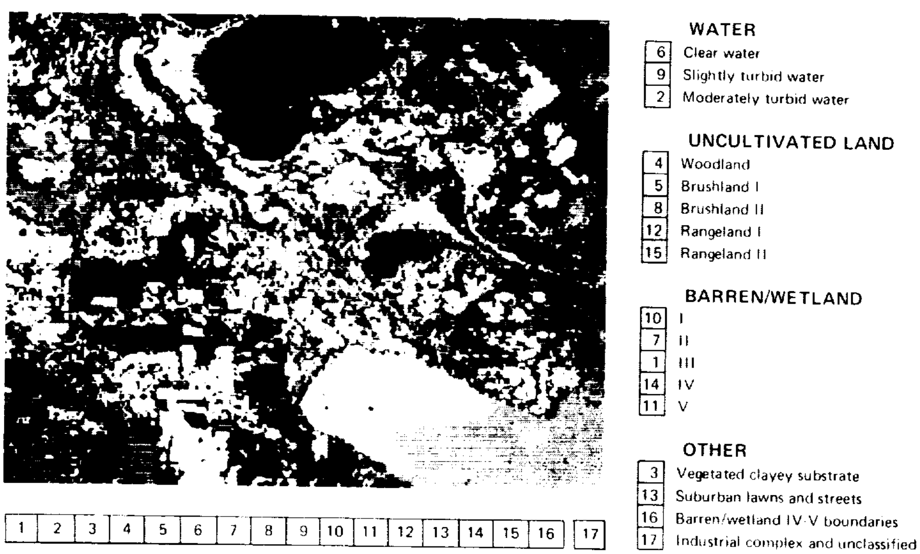
Accomplishments during the past year are as follows.

1. Development of remote-sensing data analysis software and procedures to support use of the color graphics terminal for the display and enhancement of Landsat multispectral-scanner (MSS) digital data. The system is capable of displaying raw or classified Landsat 1, 2, and 3 MSS digital data as well as performing limited data enhancements including contrast stretching, band ratioing, and edge sharpening.

2. Applications were identified by state agencies for the five test sites in the areas of coastal zone management, forestry, water resources, mineral resources, and wildlife management. Remote-sensing data were collected at four test sites. This broad-based application testing will help demonstrate the statewide applicability of remote-sensing technology.

3. Development of the geographic information subsystem and the natural resources analysis subsystem was initiated. These subsystems will provide the means for integrating and analyzing the information to support the specific state agency applications.

Figure 1.—Computer classification.



Orbiter Camera Payload System

The Orbiter Camera Payload System was a fiscal year 1978 new start and is funded through fiscal year 1984. This camera system is composed of a large-format camera, an electronics control assembly, a high-pressure gas supply system, and a flight support structure. The system is designed for operation in the Orbiter cargo bay (fig. 1) to obtain high-resolution vertical stereoscopic photographs of the Earth's crustal and surface features from orbital altitudes. The large-format camera (fig. 2) produces photographs of high geometric fidelity for cartographic applications where precise height and position of surface points are required. In addition to the cartographic applications, the stereoscopic photographs will be of particular value to the geological explorer (fossil fuels and minerals), the engineering geologist, and other investigators of renewable and nonrenewable resources.

During fiscal year 1980, all development and manufacturing tasks were completed and all phases of testing were nearly completed. Factory testing and calibration of the cartographic lens assembly (fig. 3) was completed. The final two quarters of fiscal year 1980 have been devoted to subsystems verification and full system environmental and functional testing. A thermal-vacuum retest has been scheduled for the first month of fiscal year 1981, and delivery of the fully operational flight system and ground-support equipment is scheduled for November 1980.

A tentative mission assignment for the Orbiter Camera Payload System has been made using the space available on Space Transportation System (STS) mission 26. This mission is planned for a launch to a 28° inclination in September 1984. For this mission, the camera system will be configured as part of the proposed Office of Space and Terrestrial Applications (OSTA-3) payload. This mission will be conducted as an engineering evaluation flight of the Orbiter Camera Payload System and will derive mission planning and postmission data analysis support from the Large Format Camera Interagency Working Group.

Figure 1.—Orbiter cargo bay.

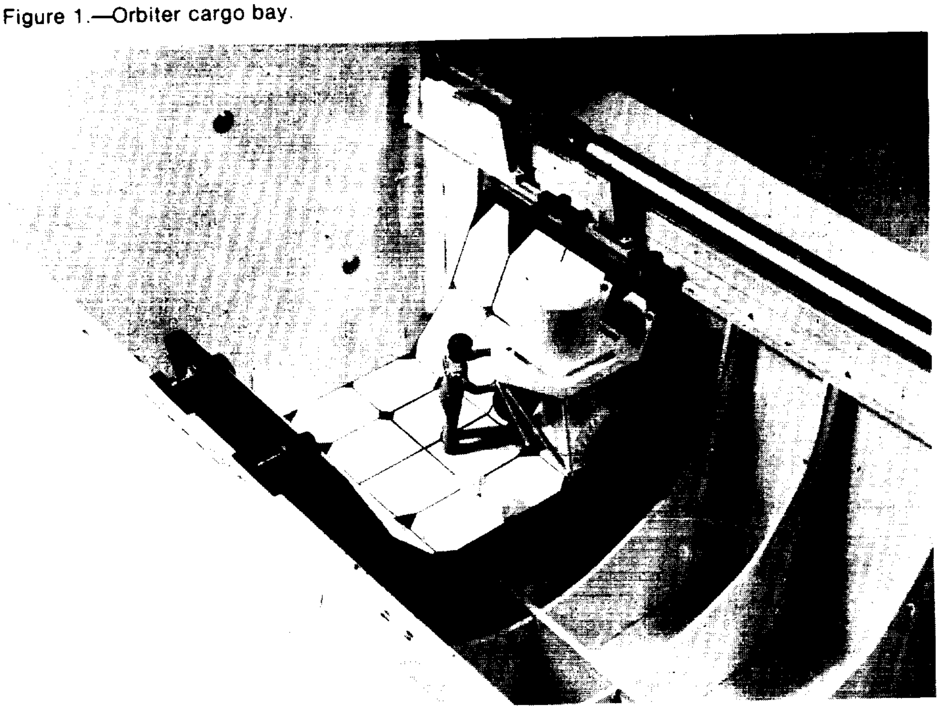
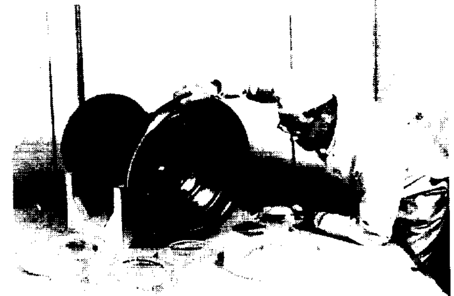


Figure 2.—Large format camera (LFC).

Figure 3.—Cartographic lens assembly.



Extended Scene Radar Calibration

The extended scene radar calibration effort was initiated to verify the precision and accuracy of scatterometers and imaging radars used for remote-sensing investigations on JSC aircraft. The precision and accuracy of microwave sensors must be verified to ensure that day-to-day variations in their data sets are truly remotely sensed phenomena rather than sensor variations.

The experiment approach was to carefully measure the radar reflectivity of large homogenous test areas (extended scene) with a highly calibrated ground scatterometer system. These test areas were then overflown by the aircraft sensors and the two data sets analyzed with respect to precision and accuracy to provide a measure of calibration to the aircraft sensors for extended scenes. Data sets are taken at 1.6, 4.75, and 13.3 gigahertz.

The effort was initiated in 1977, with test sequences performed in 1978 and 1979. In 1979, the effort was expanded to cover the effects of row spacing on radar reflectivity or backscatter curves. In fiscal year 1980, a test series was again performed at Northrup Strip, White Sands Missile Range, and Jornada Experimental Range in New Mexico. The Northrup Strip data will be used as baseline data for radar calibration. The Jornada data were gathered to study the effects of row height on radar reflectivity. Figure 1 is a plot of the backscatter difference between cross-row and along-row radar data of 1.6 gigahertz for two different field conditions. The first data set was taken over rows that were 25.4 centimeters high. The second set was taken over rows that were 15.0 centimeters high. Row spacing was the same in both sets. The peaking effect caused by the rows is present in both but gets smaller with reduced row height. Analysis of the aircraft data also showed that the peaking was not present in cross-polarized data. Figure 2 shows the new configuration of the ground scatterometer system. During fiscal year 1980, a new tower/trailer combination was integrated into the system, providing a greater degree of transportability.

Figure 1.—Comparison of angular response of the modulation function.

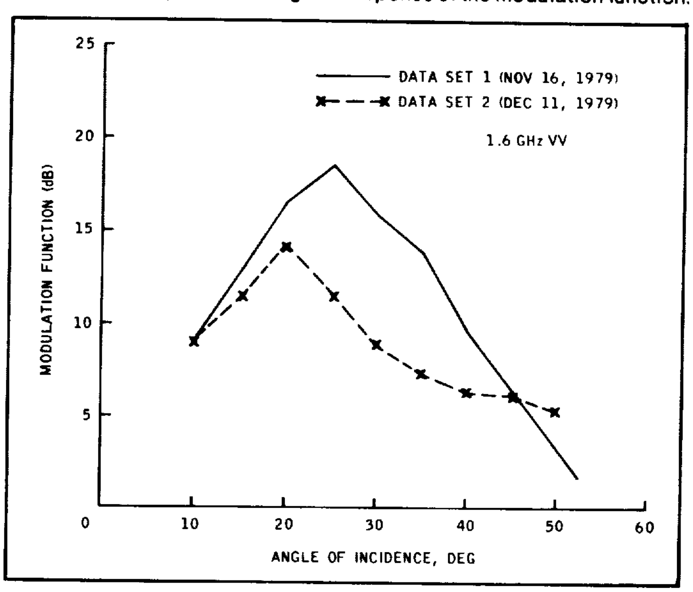
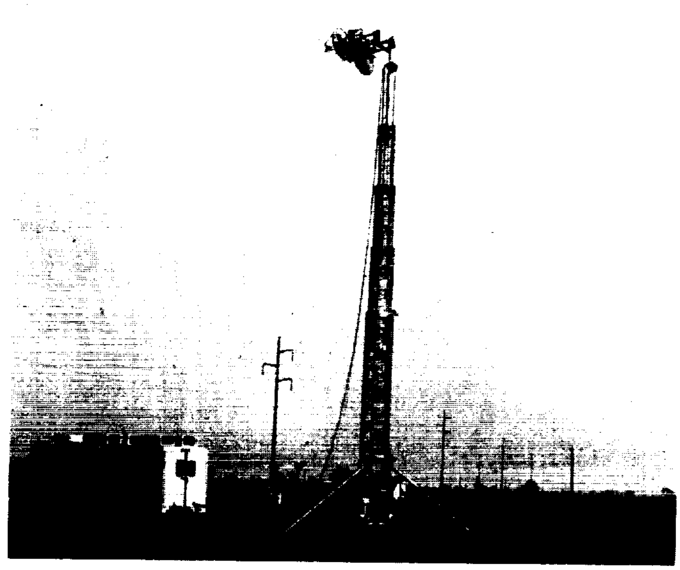


Figure 2.—Ground scatterometer system.



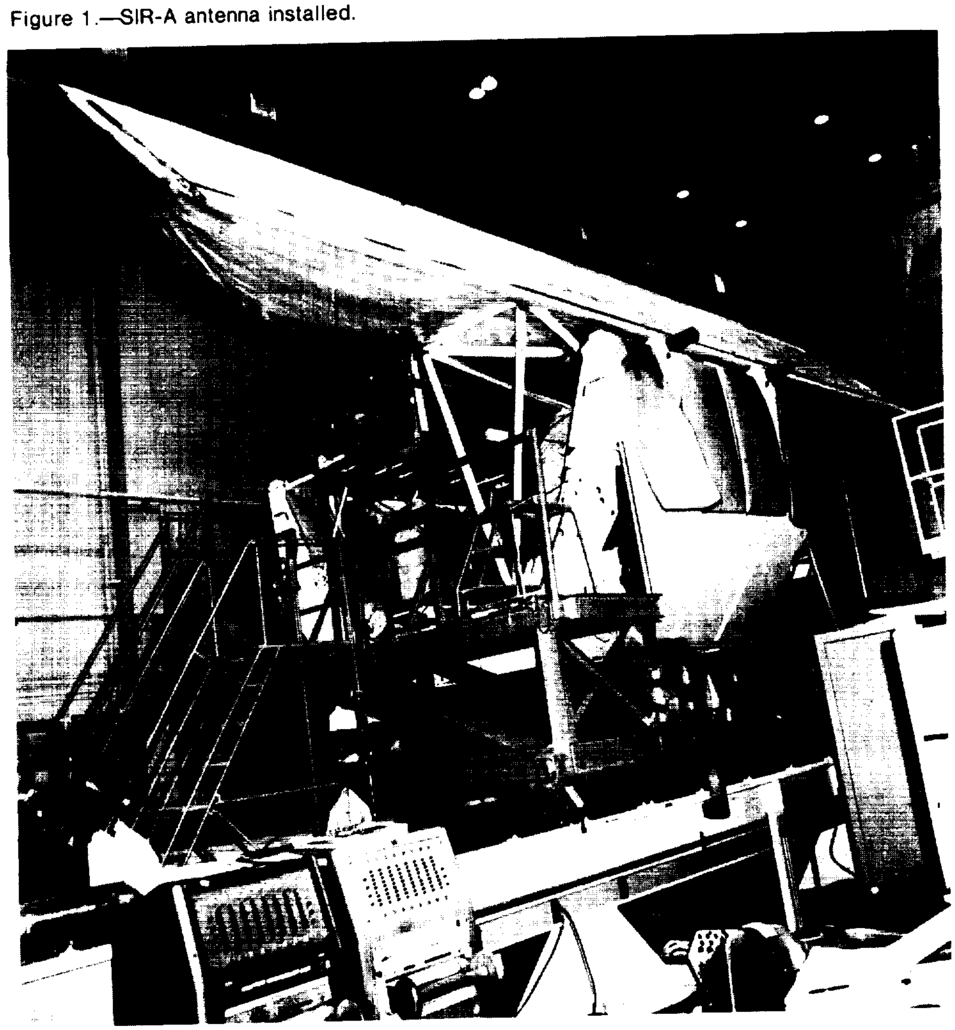
SIR-A Antenna Integration to OSTA-1 Pallet

The Shuttle Imaging Radar (SIR) A—developed to evaluate the potential of spaceborne imaging radar as a tool for geologic exploration and, in general, for mineral exploration, petroleum exploration, and structural mapping—is part of the Office of Space and Terrestrial Applications (OSTA) 1 payload to be flown on the Space Shuttle (SS) 2 mission. The SIR-A antenna was developed by the JSC to be used with the SIR-A electronics developed by the Jet Propulsion Laboratory.

The SIR-A antenna, manufactured by Ball Aerospace Systems Division, consists of seven microstrip array panels mounted on a triangular support structure. The antenna is attached to the OSTA-1 pallet by an aluminum truss structure (fig. 1). The nondeployable 9.44- by 2.1-meter antenna is mounted in the payload bay in a fixed position at 47°. Thermal protection is provided by the multilayer aluminized mylar covering the support structure and by the Beta cloth covering the total system.

The 400-pound antenna system was installed on the OSTA-1 pallet in the Operations and Checkout Building at the Kennedy Space Center in January 1980. Verification of proper fit was made. However, the planned course alinement was deferred because of an out-of-plane condition of the pallet caused by the pallet support method used in the engineering model stand. Course alinement is anticipated to be completed when the OSTA-1 payload is located in the cargo integration test equipment stand. Electrical testing of the antenna has been successfully completed. These tests consisted of (1) a continuity check of reflection and loss through the antenna and (2) a coupling check of antenna/electronics and the interface by injecting a signal into the antenna and monitoring the radar system output.

Figure 1.—SIR-A antenna installed.



Office of Space Sciences

Significant Tasks

87 **The Dynamic Crystallization of Basalt**

Funded by: Planetary Geochemistry and Geophysics (UPN-153)
Technical Monitor: G. Lofgren/SN6
Task Performed by: Lyndon B. Johnson Space Center

88 **Antarctic Dry Valleys: Terrestrial Analog of the Martian Surface**

Funded by: Mars Data Analysis Program (UPN-155)
Technical Monitor: E. K. Gibson/SN7
Task Performed by: Lyndon B. Johnson Space Center

89 **The Chemistry of Micrometeoroids**

Funded by: Spacelab Payloads (UPN-834)
Technical Monitor: F. Horz/SN6
Task Performed by: Lyndon B. Johnson Space Center

90 **Remote Sensing of Lunar Rock Composition by Thermal Infrared Measurement**

Funded by: Planetary Astronomy (UPN-196)
Technical Monitor: A. E. Potter, Jr./SN3
Task Performed by: Lyndon B. Johnson Space Center

91 **Advanced Hyperthermia System**

Funded by: Life Sciences (UPN-199)
Technical Monitor: SD and ED
Task Performed by: Memorandum of Understanding
Lyndon B. Johnson Space Center
Stehlin Foundation for Cancer Research

92 **Linear Accelerator for Human Vestibular Research**

Funded by: Life Sciences (UPN-199)
Technical Monitor: M. F. Reschke /SD
Task Performed by: University of Michigan
Contract NAS 9-15663

93 **Nuclear Cardiology Imaging System**

Funded by: Life Sciences (UPN-199)
Technical Monitor: D. L. Teegarden/SN
Task Performed by: Lockheed Engineering and Management
Services Co., Contract NAS 9-15800

94 **Mobile Biological Isolation System**

Funded by: Life Sciences (UPN-199)
Technical Monitor: A. Mandel/SD
Task Performed by: ILC Dover
Contract NAS 9-15946

Martian Weathering Simulation

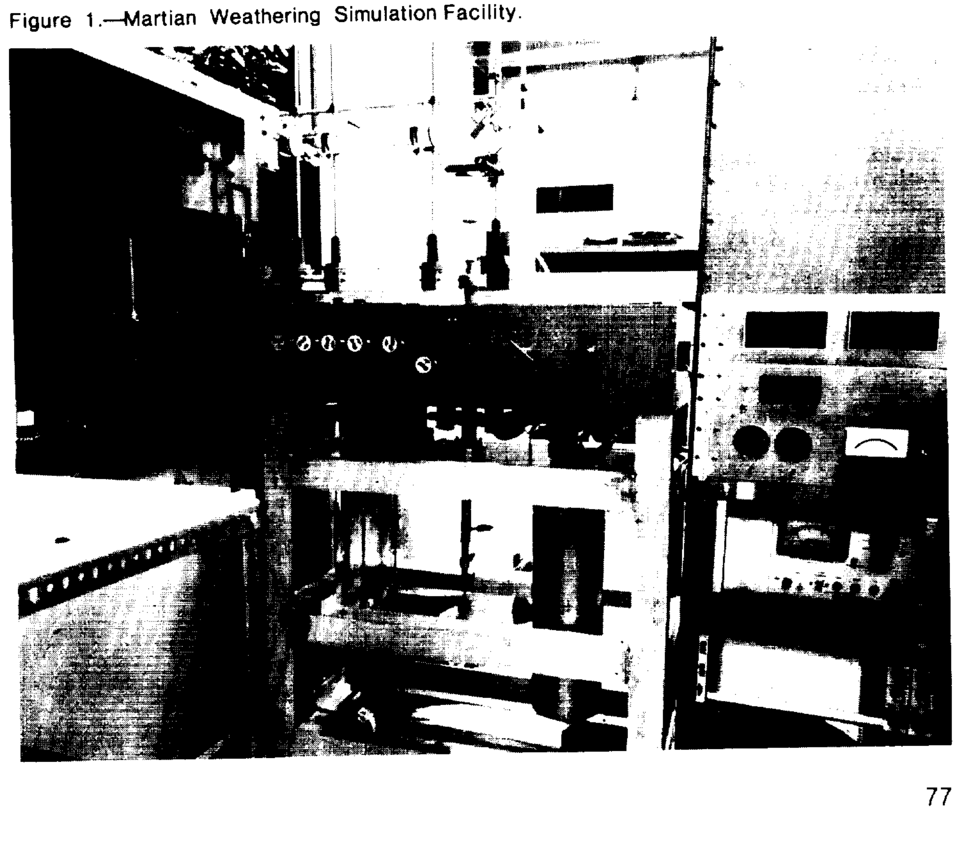
Weathering is a surface process that is universal to all planetary bodies. The difference among planetary bodies is in the form weathering takes in response to its energy source. For planetary bodies having atmospheres, such as the Earth, the energy source is the secondary dissipation of electromagnetic radiation that arrives at the surface and heats the atmosphere. For planetary bodies having virtually no atmosphere, such as the Moon, the energy source is the direct transmission of energy in the form of meteorites, radiation, and atomic and nuclear particles impinging on the surface. For planetary bodies having thin atmospheres, such as Mars, the energy source embodies aspects of both of the above limiting cases.

Data on planetary surface materials obtained remotely (such as from Earth-based telescopes or spacecraft imagery), in situ (such as by the Viking landers), or directly (such as by analyses of returned surface samples) have been influenced by weathering processes. Only when the extent and nature of weathering processes (and of other surface processes such as erosion, transportation, and lithification) are sufficiently understood can the data on surface materials be properly interpreted and used to construct models about the constitution and evolution of a planetary body. The accuracy and predictive capability of the models are directly related to how well the changes introduced by weathering are recognized and understood.

At the present stage of the scientific study of Mars, it is of primary importance to establish to what extent the remote sensing and Viking lander data on surface material reflect primary versus secondary (weathered) surface material. One important avenue to use in determining and evaluating the nature and influence of weathering on Mars is through laboratory simulation experiments. In such experiments, terrestrial materials, including both primary and secondary rock types and synthetic materials, are weathered in a simulated Martian environment.

A Martian Weathering Simulation Facility (MWSF) is operational at the Johnson Space Center (fig. 1). The apparatus in this facility can simulate superficial conditions on Mars in terms of temperature (below $-10°$ C), atmospheric pressure and composition (mainly carbon dioxide at $\sim$ 6 torr), electromagnetic radiation environment (ultraviolet through infrared), and the normal Martian variations in these parameters. One of the studies performed in this facility is that of the kinetics of magnetite oxidation in the presence of ultraviolet radiation. Previously, researchers thought that magnetite would efficiently oxidize to ferric oxide phases under Martian conditions of ultraviolet radiation. This process was thought to be the dominant one that has resulted in the apparently high-oxidation state of the Martian surface. However, experiments performed in the Martian Weathering Simulation Facility revealed that this process does not proceed at a perceptible rate. What appears to happen is that Martian surface materials are heated by the infrared in sunlight and the oxidation proceeds rapidly under the effect of this heating.

Figure 1.—Martian Weathering Simulation Facility.



New Results from a Lunar Core

An Apollo 15 lunar core recently analyzed in detail has revealed some interesting results. This core (15010/15011) is a double-drive tube that was taken by Astronauts Dave Scott and Jim Irwin at Station 9A about 20 meters from the rim of Hadley Rille (fig. 1). The 55-centimeter-long core was carefully dissected, described, and photographed at JSC, a process which took nearly 2 years. Samples from the core were then analyzed by principal investigators at JSC and elsewhere by a variety of techniques and instruments. The dissection revealed nine separate stratigraphic units which differed slightly in color or texture. The core contained a number of small rocks, especially toward the bottom of the core (fig. 2).

This core has several interesting features related to its sampling location near the edge of the rille. Most of the rock, mineral, and glass fragments are derived from basalt, reaffirming the interpretation that basalt flows underlie much of the site and comprise the edges of the rille. The largest rock fragment shown in figure 2, for example, is a basalt fragment. However, fragments of highland rocks are present throughout the core and are surprisingly slightly more abundant toward the bottom. Figure 2 also shows a whitish fragment which is probably an anorthositic breccia. Such fragments are probably derived from the Appenine Front some 4 kilometers away from the core site.

The soil in the core is relatively coarse-grained with a mean grain size of about 95 micrometers; it is slightly coarser toward the bottom. The ferromagnetic resonance profile for the core reveals that whereas the core is slightly more mature in its upper half

Figure 1.—Map of the Apollo 15 site showing the location of the four cores. When completed, analyses of these cores will provide three-dimensional control for the Apollo 15 regolith.

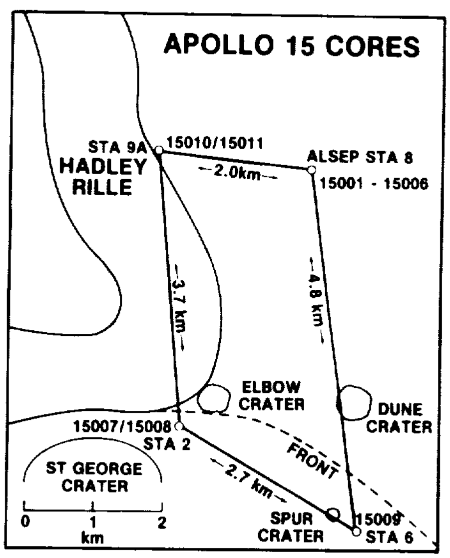
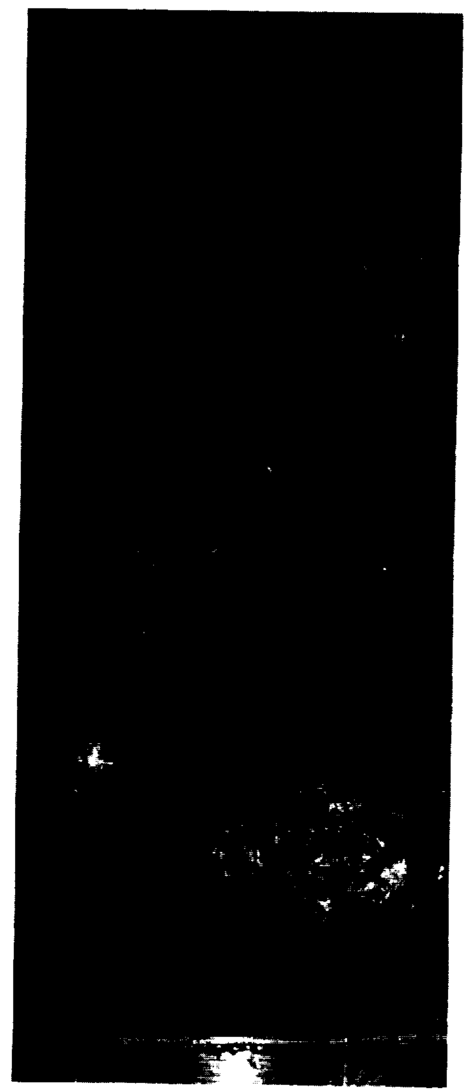


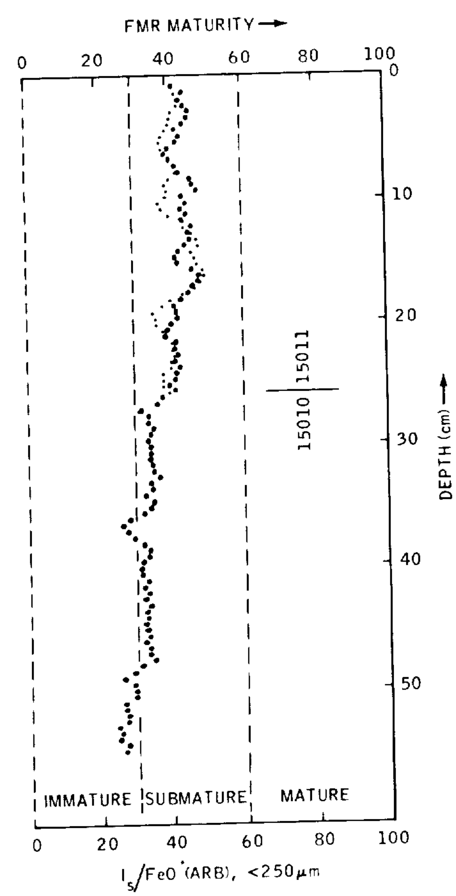
Figure 2.—Photograph of the bottom of partly dissected core 15010/15011. Three rock fragments are visible. The lowermost is apparently an anorthositic breccia; the other two are basalts.



(fig. 3), it does not have the well-developed maturity profile commonly found in other lunar cores. This limits the time the core material was in place to 100 million years or less. Furthermore, rare-gas data reveal that the core does not have a significant production profile of cosmogenic species such as ^{3}helium, ^{21}neon, ^{38}argon, ^{80}krypton, and ^{126}xenon. This means that the core material was not irradiated by cosmic rays for very long, certainly no longer than 100 million years. Yet individual samples from the core were exposed to cosmic rays for 300 million years or more. This indicates that most of the core material was preirradiated somewhere near the lunar surface before the material was incorporated into the stratigraphic section sampled by the core. The formation of the present stratigraphic sequence occurred less than 100 million years ago, which is a short time compared to the age of the basaltic bedrock (approximately 3.3 billion years). The lack of a well-developed soil profile shown by the ferromagnetic resonance data (fig. 3) is also supported by grain-size data, solar wind gas data, and agglutinate abundances.

The unusual features of this core include the relatively immature state of the entire core, the lack of well-developed maturity profiles, the relatively homogeneous characteristics of the core throughout its length, and the relatively short period of time that the core material resided in its present position as sampled by the astronauts. These features require an unusual set of circumstances, and the explanation is probably closely tied to the unusual location of this core. The steep Hadley Rille has apparently acted as a sink for regolith that has been stirred and ejected by meteorite impact, preventing the regolith from becoming very thick near the edge of the rille. The regolith at the core site is estimated to be only about 1-meter thick compared to a more normal thickness of about 5 meters on the flat terrain near the Lunar Module. The thinness of the regolith near the edge of the rille causes a relatively rapid turnover, prevents maturity profiles from developing, and prevents the development of very mature soils because they are rapidly diluted or covered by fresh ejecta. The sampling location, therefore, is the cause of the core's rather unique properties and it provides new insight into lunar regolith processes. This core may also be the best prototype for some types of asteroidal regoliths characterized by extreme thinness and may help to explain the lack of mature soil features in most regolith-derived meteorites. Core 15010/15011 is consequently an extremely important part of the Apollo sample collection.

Figure 3.—Ferromagnetic resonance (FMR) profile of soil maturity throughout the length of core 15010/15011. No part of the core contains mature soils commonly found in other cores.



Complexity of the Lunar Crust

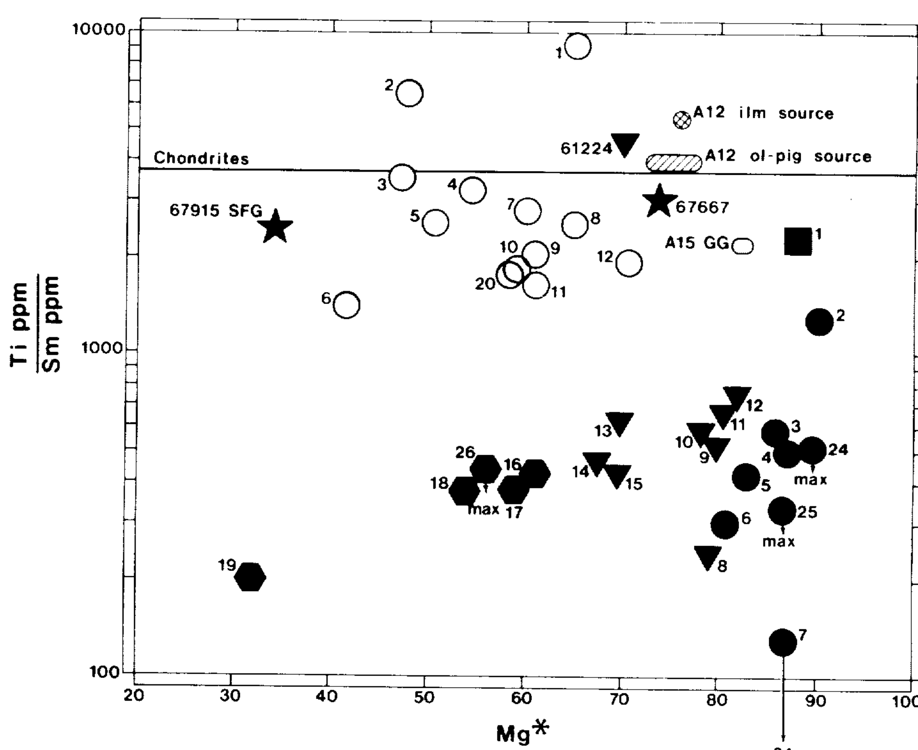
Much of the Moon's evolution has involved igneous processes; i.e., those in which silicate liquids (magmas) are produced by the melting of the Moon. These liquids can crystallize to their own compositions as many lavas do on Earth; or the crystals that form can subsequently accumulate and form rocks, at the same time changing the composition of the liquid. Different crystal types affect the liquid in different ways, influencing the minerals that later crystallize from the liquid. For instance, the mineral olivine, which is magnesian, depletes the liquid in magnesium and subsequent minerals are less rich in magnesium than they would otherwise have been. Even though the olivine may no longer be seen, its effects can be inferred by inspecting the rocks that accumulate from the later minerals. Magnesium is a major element and olivine is a major phase, but the same kinds of effects can be seen for trace elements and trace minerals. The ratios of titanium/samarium and scandium/samarium have been used as tracers of the history of lunar-highlands igneous rocks. Samarium is not easily absorbed into any major minerals; hence, as crystallization proceeds, its abundance in the liquid increases. If ilmenite crystallizes, then the titanium in the liquid decreases and rocks accumulating later have low titanium/samarium ratios. Scandium/samarium is a similar indicator of pyroxene crystallization.

The Moon does not have the same composition throughout its depth; instead, like other planets, it has a crust different from the interior. It was realized early in lunar sample analysis that the Moon has a plagioclase-rich crust (an unexpected result) and that this crust had formed not long after the formation of the Moon itself. Plagioclase is a light mineral and the general interpretation is that the concentration of plagioclase in the outer regions of the Moon was a result of its crystallization and flotation from a massive "ocean" of molten silicate. We now know that there are many igneous rock types in the lunar highlands other than the very plagioclase-rich ones, and the compositions of the breccias (the impact-produced broken and melted rocks that dominate the highlands) suggest that they are a very substantial part of the crust. These rocks are more magnesian than are the plagioclase-rich ones (anorthosites) and hence are known as the "magnesium-suite" rocks. To understand the crust and its evolution, it is necessary to understand the relationships between all the rocks. The titanium/samarium ratios of the rocks (fig. 1) show that the anorthosites crystallized from a liquid from which ilmenite had not crystallized. However, the magnesium-suite rocks crystallized from liquids from which ilmenite had at some time been removed. This makes the origin of the magnesium-suite rocks complex because ilmenite is a mineral that crystallizes only at an advanced stage of the crystallization of a silicate liquid; yet all the other characteristics of the magnesium-suite rocks suggest that they crystallized at an early stage of crystallization (including the fact that they are rich in magnesium) and certainly earlier than the anorthosites.

The conclusion is that the magnesium-suite rocks and the anorthosites are not very closely related, but that the magnesium-suite rocks are related to each other because they have the same peculiar characteristic of low titanium/samarium, unlike terrestrial, meteoritic, or other lunar rocks. The scandium/samarium ratios show a similarly perplexing depletion of pyroxene in the magnesium-suite parent liquid.

Because the magnesium-suite rocks are too dense to have floated over a silicate liquid, the formation of the lunar crust must have involved a more complex origin than simply the flotation of rocks over a magma "ocean" (although this probably did happen to produce the anorthosites). There are several possibilities, but none yet seem to be quite right. Further work with trace elements will probably solve the problem rather than just demonstrate its existence.

Figure 1.—The titanium/samarium ratios of Moon rocks.



Meteorite Types in the Antarctic Meteorite Collections

During the past year, meteorites with masses greater than 150 grams collected by the joint Japanese-American Antarctic expeditions for the field seasons of 1977-78 and 1978-79 have been classified at the JSC and at the Smithsonian Institution. Traditionally, meteorites have been classified in the broadest sense by the amounts of metal and silicate they contain. Thus, irons are composed chiefly of metallic nickel-iron but may contain silicate inclusions. Stones are composed mainly of silicates but may contain more than 24 percent nickel-iron. The stones can be divided into two groups based on their textures: chondrites and achondrites. Chondrites contain chondrules, which are spherical to subspherical bodies composed mainly of silicates, and range in size from less than 0.1 millimeter to more than 0.5 centimeter. Chondrites are classified by their chemistries and mineralogies. The amphoterites (LL group) are regarded as a subgroup of the olivine-hypersthene chondrites (L group) by some researchers, but others regard them as a separate type of ordinary chondrite with equal stature to the olivine-bronzite chondrites (H group) and the olivine-hypersthene chondrites (L group). The carbonaceous chondrites are generally characterized by a high content of volatile elements and compounds that include water, sulfur, and rare gases. The most widely accepted classification of petrologic types of chondrites is based on their chemistries, mineralogies, and textures. This model was proposed in 1967 by VanSchmus and Wood and assumes a progressive thermal metamorphism (type 6 being the most highly metamorphosed) to account for the textural and chemical variations.

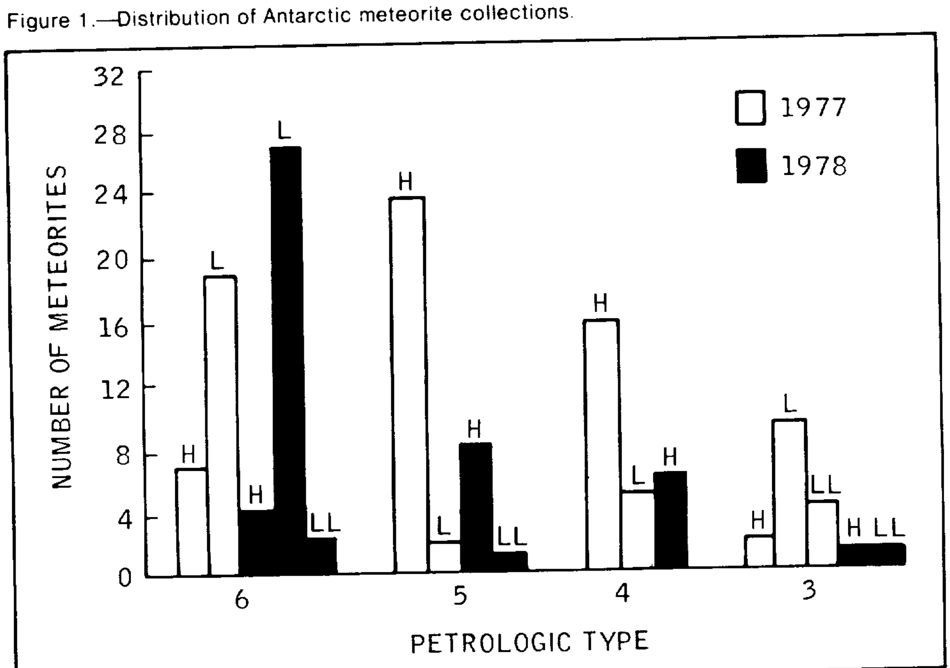
Stony meteorites without chondrules are termed achondrites. The achondrites are generally divided into two groups based on calcium content. Calcium-poor achondrites include the aubrites, diogenites, chassignites, and ureilites. The calcium-rich achondrites include eucrites, howardites, angrites, and nakhlites. The shergottites are considered to be eucrites by some researchers but the majority believe that they are sufficiently distinct to retain the term shergottite.

The complete classified collection of the 1977-78 season consists of 103 meteorites including 7 irons, 2 carbonaceous chondrites, 5 achondrites, 49 H-group chondrites, and 39 L- or LL-group chondrites. Achondrites represent five individual classifications: mesosiderite, ureilite, diogenite, eucrite, and winonaite. One petrologic type 2 and one petrologic type 3 carbonaceous chondrites are present.

The 1978-79 collection of 69 specimens has been classified and includes 31 L- or LL-group chondrites, 19 H-group chondrites, 10 irons, 8 achondrites, and 1 carbonaceous chondrite. Achondrites are represented by 5 polymict eucrites, 1 aubrite, and 2 ureilites. The carbonaceous chondrite is petrologic type 2. The histogram (fig. 1) shows the distribution of the ordinary chondrites in the 1977-78 collections by chemical group and petrologic type.

The distribution of chemical groups within each petrologic type of ordinary chondrites is similar for both collections. The petrologic type 6 specimens are dominated by the L-group chondrites, and the petrologic types 4 and 5 meteorites are overwhelmingly represented by the H-group chondrites. Because of the distinct groupings and similarities between intraspecimen and interspecimen comparisons, it is believed that the samples represent a limited number of falls.

Figure 1.—Distribution of Antarctic meteorite collections.



The 1979-80 collection is comprised of 83 meteorites including 1 iron, 75 chondrites, and 7 achondrites. The chondrites are estimated to range in mass from less than 20 grams to more than 3 kilograms. The iron has a mass of approximately 10 kilograms and is known to have silicate inclusions that are believed to be of orthopyroxene composition. Of the seven achondrites, one is classified as a eucrite, one as a howardite, and three as either polymict eucrites or howardites. Their masses range from 86.4 grams to 7.1 kilograms. One achondrite (2.8 kilograms) is classified as an anomalous diogenite based on its petrographic characteristics. The last achondrite (7.9 kilograms) is classified as a shergottite and is one of the four known shergottites in the world. It will certainly be of great interest to the scientific community because much speculation about its origin still remains.

Young Meteorites from an Earthlike Parent

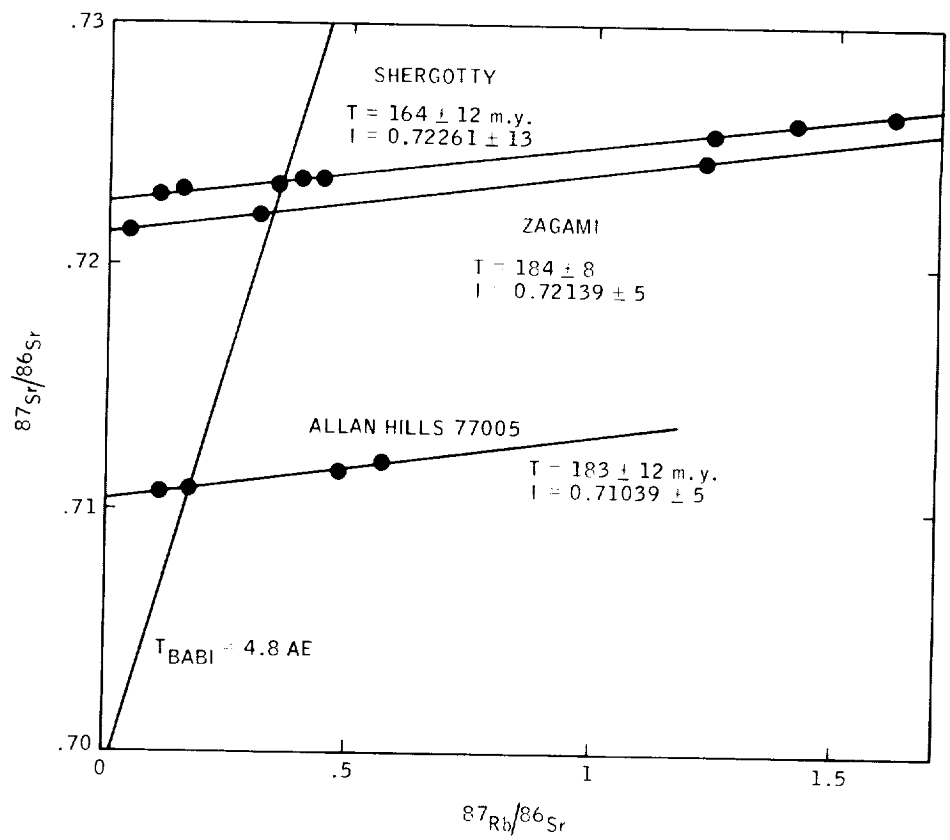
Meteorites have long been objects of curiosity. Centuries ago, stones that fell from the sky created sufficient interest among observers to ensure their preservation as evidence of a poorly understood natural phenomenon. Only relatively recently have scientists possessed the analytical tools with which to understand the origins of these visitors from space. As a result of intensive laboratory studies, it has been shown that most meteorites are both ancient and primitive. Chemical analysis reveals that the majority of stony meteorites are undifferentiated; i.e., the relative abundances of nonvolatile elements in these meteorites are close to the relative abundances of the same elements in the Sun. Such meteorites are said to be primitive. Radiometric dating of primitive undifferentiated meteorites shows that they are nearly 4.6 billion years old. Most other meteorites and some lunar rocks also are about 4.6 billion years old. Although no terrestrial rock is this old, "model ages" can be calculated for the bulk Earth; such ages are also about 4.6 billion years old. Thus, 4.6 billion years is believed to be the age of the solar system.

Meteorites tell us more about the solar system than just its age, however. Each meteorite type was formed by a specific set of processes. Some of the most interesting meteorites are the basaltic achondrites. They are called basaltic because they are texturally and chemically similar to terrestrial basalts, which are solidified melts from the interior of the Earth. Spacecraft exploration has shown that basalts occur on the surface of the Moon and on the other terrestrial planets as well as on Earth. Because basalts are melt products from the interiors of planets, their chemical compositions vary with the variations in the bulk composition of their parent planets. The ages of basalts are also controlled by the properties of their parent planets. Thus, large planets that contain large quantities of heat-producing elements and that cool slowly have produced basalts over most of the solar system history. Earth, Mars, and Venus are examples of such planets. Smaller planetary bodies have cooled enough so that basaltic volcanism has ceased. The Moon is an example of such an object; basaltic volcanism on the Moon ceased about 3 billion years ago. Most basaltic achondrites have ages of about 4.6 billion years, showing that their parents were hot near the beginning of the solar system but cooled very rapidly. The early heat source remains a matter of some speculation; however, rapid cooling is consistent with the widely accepted concept that the asteroid parents for these meteorites are small planetary bodies.

Some basaltic achondrites, the nakhlites and the shergottites, have young radiometric ages. Identification of their parent planets remains a tantalizing puzzle. Young basalt ages normally imply a large planet. But which planet, and how were rocks hurled from its surface into space so that they might later fall on Earth? The natural transport of rocks from the surface of one large planet to the surface of another seems so improbable that most scientists have sought other explanations. A favorite alternative hypothesis is that the meteorites were really formed about 4.6 billion years ago, like other achondrites, and have simply had their radiometric clocks reset by the heat accompanying asteroid or meteoroid collisions in space.

Work directed towards solving the nakhlite/shergottite puzzle is currently underway at the JSC and elsewhere. The emphasis has been on the shergottites, only two of which were known to exist at the beginning of the study. One, called Shergotty, fell in India in 1865; another, called Zagami, fell in Nigeria in 1962. A third shergottite-like meteorite was found in the Antarctic in 1977; it is called Allan Hills 77005. A fourth shergottite-like meteorite has recently been identified among meteorites found in the Antarctic in 1979; it is called Elephant Moraine A79001. Radiometric dating of the first three meteorites has repeatedly yielded young ages. Figure 1 shows results obtained by the rubidium-strontium method. In the representation of figure 1, the rock ages are proportional to the slopes of

Figure 1.—Geochronological results obtained by the rubidium-strontium method.



the lines and correspond to the data received when each meteorite was measured for the various minerals. The rubidium-strontium ages (T) of all three meteorites are identical within analytical uncertainty. An average age is 177 million years. The slope of the line labeled T_{BABI} = 4.8 AE is close to that expected for a "normal" meteorite with an age of ~ 4.6 billion years (1 AE = 1 billion years).

Ages obtained for the shergottites by the ^{40}argon/^{39}argon and samarium-neodymium method (two other radiometric techniques) are older than the rubidium-strontium ages. These results, in addition to petrographic evidence of shock metamorphism of the mineral phases, strongly suggest that the rubidium-strontium age has been reset by a major collision. This conclusion does not solve the shergottite puzzle, however. The samarium-neodymium model ages of the shergottites range from 2.8 to 3.6 billion years. These model ages give an upper limit to the time since the concentration ratio of two rare earth elements, samarium and neodymium, was last significantly changed. Because the chemical behaviors of samarium and neodymium are very similar, it is extremely difficult to change the samarium/neodymium ratio of rocks except by special igneous processes. Thus, if the shergottites were really 4.6 billion years old, they should have 4.6 billion years samarium-neodymium model ages. Thus, whereas the rubidium-strontium ages clearly suggest a "metamorphic" resetting, the samarium-neodymium model ages also clearly suggest a "young" igneous event. Exactly when the igneous event occurred is not presently known with certainty. A lower limit of 6×10^8 years ago is obtained from samarium-neodymium analyses of minerals from the Shergotty meteorite. Geochemical considerations suggest that the "whole rock" samarium-neodymium age of the three analyzed shergottites, about 1.35 billion years, is both an upper limit and a good approximation of the shergottite age. This interpretation will be strengthened if analyses of the newly recovered shergottite also yield the same whole rock age. Perhaps coincidentally, the nakhlites also have been dated as being 1.3 billion years old. In the case of the nakhlites, the same age has been obtained by the rubidium-strontium, samarium-neodymium, and ^{40}argon/^{39}argon techniques. The nakhlite age must be considered as representing an igneous event.

The most direct interpretation of the radiometric age data for the nakhlites and shergottites is that igneous melts were formed on a planetary body about 1 billion years ago. The only known objects that produced melts of about the right age and composition are Earth and Mars. The volcanism presently observed on the Jovian satellite Io is too sulfur-rich to be linked to the achondrites. Although the nakhlites and shergottites have chemical affinities to terrestrial basalts, they cannot be terrestrial rocks because they have been exposed in space for about 2 million years as shown by the presence of nuclear reaction products formed by exposure to cosmic rays. Indeed, the "cosmic-ray exposure" ages of the meteorites are typical for stone meteorites, suggesting origin in the region of the asteroid belt, i.e., between Mars and Jupiter. The three possible alternative origins are as follows.

1. A giant "asteroid" was totally disrupted less than 1 billion years ago.
2. The meteorites were somehow blown off the Martian surface, presumably by the impact of a giant meteoroid on Mars.
3. The meteorites came from Phobos or Deimos, the Martian satellites.

Hypothesis 1 is ad hoc and not easily tested. Hypothesis 3 is dynamically more plausible than hypothesis 2; furthermore, the Viking mission has shown that a significant portion of Phobos has been blasted away by a single meteorite impact. A Phobos origin for the nakhlites and shergottites would only push the problem back one step as Phobos is far too small to have produced late-stage melts. Perhaps tiny Phobos is a "late" satellite of Mars, having been ejected from and subsequently captured by the parent planet. In this case, hypotheses 2 and 3 merge, suggesting that Mars is the ultimate origin of nakhlites and shergottites. This possibility is now receiving serious scientific consideration, particularly in view of a remarkable chemical similarity between the shergottites and the Martian soil analyzed during the Viking missions.

Moon Rock Curation

The prime physical legacy of the Apollo Program is the lunar sample collection. That collection is not only a symbol of a major national achievement but is also a scientific resource that continues to be studied by scientists around the world. The 382 kilograms of lunar material is the responsibility of the JSC Lunar Sample Curator. Caring for the collection involves considerations for protection from natural hazards such as hurricanes and tornadoes, theft, vandalism, and chemical contamination that could produce subtle changes that would invalidate time-consuming scientific experiments.

Protection from natural hazards, theft, and vandalism is offered by the 18-inch reinforced concrete walls and the 15-ton vault doors of the Lunar Sample Building completed in 1979. To protect the samples from the most significant natural threat to the Gulf Coast, hurricane-induced storm tides and flooding, all samples are stored in containers on a specially elevated second floor of the building, 42 feet above sea level. As an added precaution, when a hurricane threatens the Houston-Galveston area, key records describing the processing and subdividing of the collection are moved into the vaults on the second floor and the vaults are sealed with special watertight covers. The ultimate precaution to protect the Apollo treasure is the storage of a representative 14 percent of the collection in a vault at Brooks Air Force Base in San Antonio, Texas, 320 kilometers west of JSC. Storing the collection in two places assures that scientific study can continue should an unforeseen disaster strike either of the two repositories.

To prevent pilfering and to keep track of the geometric relations between individual sawed pieces of rocks and of the depths of individual strata in core samples, an elaborate system of documentation is used. Each step of the splitting up of a rock or core is recorded photographically and samples are repeatedly weighed during processing. The magnitude of this documentation has grown as the collection has grown, from the 2169 samples actually brought back from the Moon to over 66 000 current samples. Each sample must be continuously tracked and accounted for. Using weight as a guide, 74 percent of the collection has never left JSC curatorial custody, 14 percent is stored in San Antonio, 3 percent is currently loaned to scientific investigators, 5 percent was loaned to investigators and then returned to the curator, and 2 percent is on display in various museums and traveling exhibits. Only 2 percent has actually been consumed by scientific investigations.

Lunar samples typically contain significant amounts of metallic iron, virtually no water, and only a fraction of a percent of alkali metals (such as potassium and rubidium found in natural terrestrial materials). Therefore, the samples must be continuously protected from the Earth's atmosphere and dust. A series of concentric barriers and containers is placed between the sample and the environment (fig. 1). When stored, each sample is enclosed in three Teflon bags or in a combination of three barriers made of Teflon bags and metal containers. The bags are filled with high-purity nitrogen gas and are inside stainless steel glove boxes filled with nitrogen that is continuously measured for oxygen and water. The cabinets are in a clean room supplied with air from which all particles larger than 0.0001 millimeter have been filtered. Employees working in the clean room wear special lint-free garments and enter through a succession of progressively cleaner change rooms (fig. 2).

As a further precaution against chemical contamination, materials touching the samples are carefully controlled. Only objects made of aluminum, stainless steel, or Teflon are allowed to come in contact with the samples, and the amount of other materials inside the cabinets is held to a minimum.

All the tools, bags, and metal containers that enter the glove boxes are specially cleaned to remove all dust and oily residues. The lunar samples have tiny amounts of lead (less than a few parts per million) with an isotopic composition that is critical in determining the age of many rocks. All the chisels, tweezers, and other steel tools used with the samples are specially washed in diluted acid to remove any adhering lead, in addition to the dust and oily residues.

In the last 2 years, simplified versions of the techniques used to curate the lunar samples have been applied to the meteorites collected from ice fields in Antarctica.

Figure 1.—Lunar samples are placed inside a series of concentric barriers and containers.

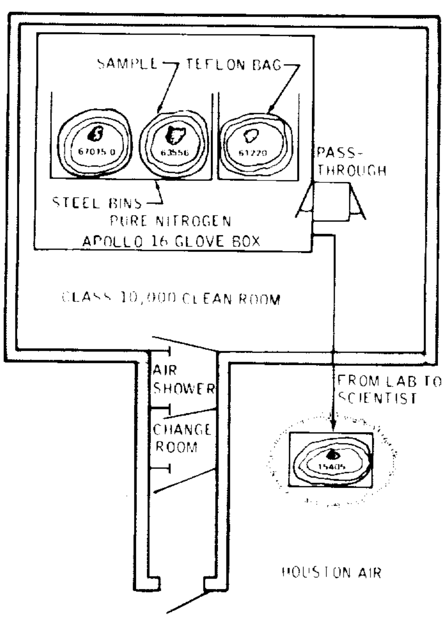
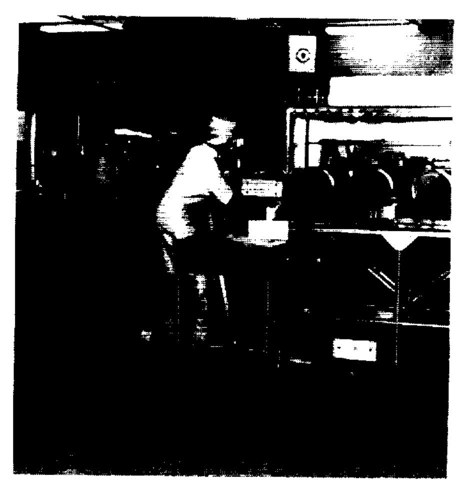


Figure 2.—Employees working in the clean room.



Origin of the Earth's Continental Crust

The formation of a differentiated crust appears to be a commonality in the development of all rocky and icy planets. This process is driven by the tendency of each planet to rid itself of excess internal energy. The origin and development of the differentiated crust on Earth, represented by the continents, is being investigated. The excess internal energy that drives the formation and development of the Earth's continents is the latent heat released by the continuous crystallization of the inner solid-metal core from the outer liquid-metal core.

The two extremes that may be considered as working hypotheses for the Earth's continental crust are (1) the mass of the continental crust separated from the mantle early in Earth's history, and (2) the mass of the continental crust has been separating from the mantle in a continuous manner all through Earth's history. The truth must lie between these two. The objective of the ongoing research has been to define the history of the separation of mass from the mantle to form the continental crust. This task is complicated because once a continental crust forms, it is modified and remodified by subsequent geologic events.

A well-known but surprising result derived from a histogram of the ages of continental rocks is that the ages form several well-defined peaks (fig. 1). This result has been interpreted as evidence for the sporadic growth of the continents; i.e., each peak in the age histogram records an episode of continental growth. The age histogram, and thus the continental growth record, has been traced back to a major event between 2700 and 2500 million years ago. This event marks the end of the period of Earth's history known as the Archean.

The Archean is the time interval from the oldest known rocks (3750 million years ago) to the major continent-making event between 2700 and 2500 million years. Examination of the oldest rocks suggests that continental material existed even earlier. The time interval of continent formation that predates the oldest rocks known is called the Proto-Archean.

Evidence has been assembled that indicates that the mass of continent that separated from the mantle during the Proto-Archean and the Archean is approximately as great as the mass that has separated since the Archean. One important line of evidence is the distribution of rocks that suggests the measured ages do not record the time a mass of continental rock was separated from the mantle but rather record the latest modification of that mass of continental rock. This is illustrated for Archean rocks in the following argument.

Although typical Archean rocks yield ages of 2700 to 2500 million years, many rocks have been discovered during the past two decades that yield ages as old as 3750 million years. These older rocks have been discovered by the skill of geochronologists that enables them to "see through" the 2700- to 2500-million-year event to an earlier event in a rock's history. There are two alternative models (fig. 2) to explain ages greater than 3000 million years. In model A, nuclei of continent material existed at 3750 million years and the common 2700- to 2500-million-year ages represent later additions of continental material. In model B, most of the 2700- to 2500-million-year-old terrain existed at 3750 million years and the younger age represents a time when that terrain was thermally modified. In a model-B world, a geochronologist would be able to discover pre-3000-million-year-old rocks in most places in the Archean that were investigated in detail. In a model-A world, geochronologists would expect to discover pre-3000-million-year-old rocks in only a few places in the Archean terrain. The experience of geochronologists is that, in most Archean regions studied in detail, pre-3000-million-year-old ages were discovered. This suggests that model B is correct. Thus, the 2700- to 2500-million-year event is one of modification of existing continental material and not one of separation of continental material from the mantle.

Figure 1.—Distribution of ages in time of Earth's continental crust.

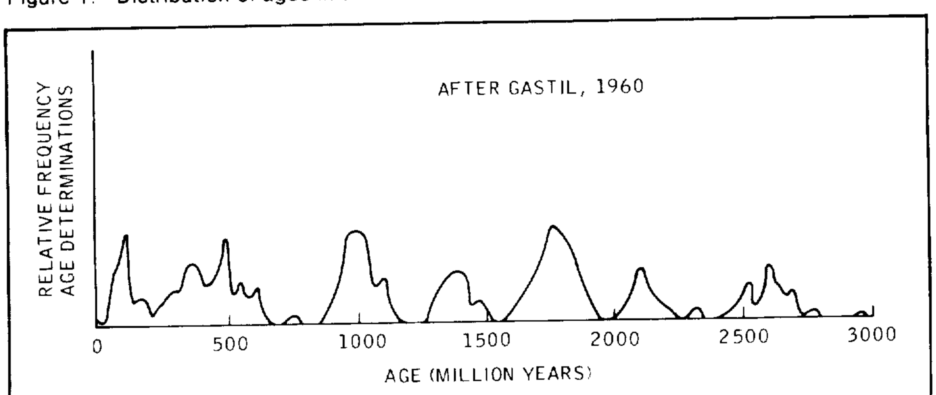
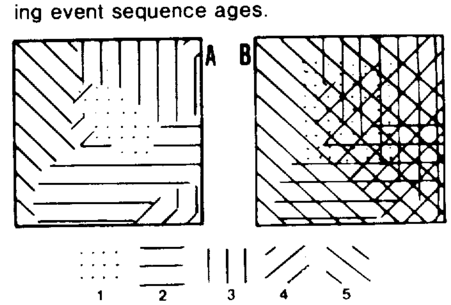


Figure 2.—Two alternative models displaying event sequence ages.



Role of Anorthositic Rocks in Early Evolution of Planetary Crusts

Significant contributions to the growth of early planetary crusts are made by extrusive and intrusive melts. These melts generally are derived from mantle material and provide the major constraint for the thermal and chemical history of the mantle during early crustal evolution. Formation of melts apparently occurs on all planets as indicated by samples from the Moon and Earth and as interpreted from remotely sensed data from Mars, Venus, and Mercury. On Earth, the occurrence of early crustal rocks is limited only to the Precambrian shield areas of the continents. The earliest preserved rocks derived from melts are the Archean volcanic and associated anorthositic intrusive rocks that formed primarily over the period between 3.7 and 2.7 billion years ago reaching a peak at about 2.7 billion years.

The work of the past year indicates that anorthositic rocks are common in Archean terrains although volumetrically minor. At least seven anorthositic complexes occur in the Superior Province of the Canadian Shield and similar units occur in similar settings in Archean terrains of other continents. Nearly all of the complexes have an unusual and distinctive feldspar texture in the anorthositic rocks in which plagioclase occurs as roughly equidimensional grains ranging from pea to grapefruit size (fig. 1). In some cases, various grain sizes are mixed; in others, grain size is homogeneous. This texture is distinctly different from that of younger rocks in which plagioclase commonly occurs in elongate laths and suggests a significantly different history.

Studies have demonstrated an unusual and consistent average composition for several Archean anorthositic complexes (table 1) suggesting that they formed from either an unusual source material or as cumulate complements of associated volcanic sequences that are derived from more typical mantle materials. If the former is true, then the unusual source material may represent heterogeneities in the mantle caused by very early separation of the Earth's crust and mantle. If so, a better understanding of the early evolution of planetary crusts may be gained.

Figures 1.—Large equidimensional crystals in anorthositic rocks. (a) Golfball-size crystals from the Bad Vermilion Lake intrusion. (b) Grapefruit-size crystals from a thick sill in Manitoba.

TABLE I.— AVERAGE COMPOSITIONS: ANORTHOSITIC COMPLEXES

	Fiskenaesset (Windley)	Limpopo, Messina (Barton et al.)	Bad Vermilion Lake (OGS maps and analyses)	Shawmere (OGS maps and analyses)	Sittampundi (Ramadurai map, Subramaniam analysis)
SiO_2	46.5	49.9	48.4	49.9	44.52
TiO_2	.4	.3	.4	.2	.11
Al_2O_3	23.2	24.3	23.5	24.1	25.77
FeO^*	5.3	4.9	6.3	3.8	5.95
MnO	.1	.1	.3	.1	.10
MgO	6.3	5.3	5.1	5.7	6.79
CaO	14.1	12.6	13.7	13.5	14.54
Na_2O	1.6	2.0	1.8	2.0	1.16
K_2O	.2	5	.1	.2	.04
P_2O_5	.05	.05	.1		05
H_2O^+	.9				59
$MgO/MgO+FeO^*$	.68	.66	58	.73	

The Dynamic Crystallization of Basalt

When the first basalts were returned from the Moon, it was evident that they were much like terrestrial basalts. There were differences, however subtle, in both chemistry and texture. One interesting difference was that the roles of pyroxene and plagioclase in the texture were reversed in some rocks. In terrestrial basalts, certain textures are defined by a fretwork of plagioclase laths enclosing either glass or pyroxene (intersertal to intergranular). In some Apollo 11 basalts, pyroxene formed the fretwork and plagioclase was interstitial or poikilitic (enclosed the pyroxene). This reversal is a direct result of a near reversal in the model amounts of pyroxene and plagioclase in the basalt.

Some Apollo 12 and 15 basalts are porphyritic basalts; i.e., large crystals of pyroxene and/or plagioclase enclosed in a finer grained matrix of more plagioclase and pyroxene. This was an important difference from the Apollo-11 basalts because phenocrysts definitely indicated a more complex preeruption history for the basaltic magma, much like basalts on Earth. The phenocrysts, however, were not like those commonly seen in terrestrial basalts. They were skeletal to dendritic and showed complex and extensive chemical zoning. Such features were not compatible with the slow growth typically associated with phenocrysts at depth in the Earth, but rather implied that the crystals grew rapidly on or near the lunar surface.

Experiments conducted in the experimental petrology laboratory at JSC confirmed that the lunar porphyritic basalts did indeed crystallize completely at or near the lunar surface. The phenocrysts did not represent a preeruption phase of the magma history. Continuation of those initial experiments has provided further insight into the histories of lunar basalts and now into terrestrial basalts as well.

One of the most important results of this continued research is the effect of heterogeneous nucleation on the subsequent textural development. When cooled at the same rates from a complete liquid, terrestrial basalts do not crystallize as readily as do lunar basalts. This is another manifestation of the chemical differences between the two groups of basalts. The lunar basalts are far less viscous and therefore crystallize more readily. Thus, it is for terrestrial basalts that the presence of heterogeneous nuclei is so important. These nuclei need not be large and in most cases are below the resolution of the ordinary petrographic microscope. Their presence can be strongly argued, however, based on the textures observed in the experiments.

Plagioclase, even though it is usually the dominant mineral in terrestrial basalts, is the most reluctant mineral to nucleate. In the basalt studied most extensively, olivine is the first mineral to appear on cooling (1198° C), followed by plagioclase (1187° C) and pyroxene (1133° C). If the basalt is melted above the liquidus at, e.g., 1215° C, so that all crystals (whether visible or not) have melted and then cooled at 2° C/hr, the product contains only olivine and pyroxene in a matrix of glass (fig. 1). The plagioclase did not crystallize and its chemical components are still contained in the glass. If the basalt is melted at a lower temperature so that not all the olivine and plagioclase have melted before cooling is initiated at the same 2° C /hr, the resulting texture is very different (fig. 2). The plagioclase is well crystallized into elongate crystals that are somewhat skeletal. The plagioclase forms a fretwork and, because the pyroxene is very fine-grained, the texture is intersertal. To obtain such radically different textures at the same cooling rate helps to explain the greater variety of textures in terrestrial basalts compared to those on the Moon. This phenomena will also help explain the existence of very thick basalt flows on Earth that have finer-grained textures than they should have based on cooling rates that can be predicted from thermal-cooling models. Either a very high density of preexisting nuclei or a total absence of nuclei (should they be reluctant to nucleate) will result in fine-grained textures at slow cooling rates.

The study of the crystallization behavior of rock magmas is continuing with the hope that at some future time the histories of rocks can be read from their textures; i.e., the physical path from their birth to their current resting places as well as their chemical evolution.

Figure 1.—Basalt melted above the liquidus so that all crystals have melted and then cooled at 2° C/hr, resulting in a product containing olivine and pyroxene.

Figure 2.—Basalt melted at a lower temperature so that not all the olivine and plagioclase have melted before cooling, resulting in a very different texture.

Antarctic Dry Valleys: Terrestrial Analog of the Martian Surface

The Dry Valleys of Antarctica probably represent the best terrestrial analog of the surface of Mars. The Dry Valleys are similar to the Martian surface in the following manner: low temperatures and humidities, diurnal freeze-thaw cycles (even during daylight hours), low annual precipitations, desiccating winds, oxidizing environment, high sublimation and evaporation rates, high-radiation environments, low magnetic fields, absence of higher life forms, and irregular distribution and low abundances of soil microorganisms. The Viking landers have shown that the surface of Mars is similar to those surfaces observed in the Dry Valleys of Antarctica (fig. 1).

In order to better study the properties of planetary regoliths, a large suite of soils, rocks, and cores was collected from Wright and Taylor Dry Valleys located in southern Victoria Land, Antarctica. The suite of samples was collected using techniques developed for collection of the lunar samples. Frozen samples were returned to JSC and their initial characterization is underway in the geoscience laboratories of the Planetary and Earth Sciences Division.

Preliminary findings indicate that the samples collected from regions surrounding evaporite ponds show sulfur abundances similar to those observed on the Mars surface at both the Viking 1 and 2 landing sites. The soils are enriched in sulfur (up to 4 to 6 percent) immediately beneath the surface and depleted above and below the enrichment zone. It is believed that the enrichment in sulfur represents deposition of evaporite minerals during the percolation of ground waters toward the surfaces. Similar processes are believed to occur on the Martian surface resulting in the salt deposits observed by the landers. Thus, there is good reason to expect that further study of the collected suite of Dry Valley soils will provide important information that will assist in the understanding of the data returned from the Viking landers.

Figure 1.—Surface observed in the Dry Valleys of Antarctica.

The Chemistry of Micrometeoroids

A significant dust population exists in the inner solar system, prominently manifested, for example, by the zodiacal cloud, visible meteoroid showers, and small-scale impact phenomena on lunar surface materials. The origin of these particles is of great planetary interest and current studies include time-of-flight spacecraft experiments, astronomical observations, lunar microcrater analysis, and dynamical studies relating to the evolution of their orbits.

The planetary interest is based primarily on the fact that a significant fraction of these particles originated from comets. Another prominent source area may be the asteroid belt and a small fraction may even be of interstellar origin. Each of the above sources may yield materials that are mineralogically and chemically different from all other extraterrestrial materials currently available for analysis in terrestrial laboratories.

Although exact proportions of these three sources in the makeup of the interplanetary dust population are presently unknown, it is generally agreed that comets must be the major contributor. On close solar approach, comets release gases as well as solids; the solids are manifested in "dust tails." Because comets primarily consist of frozen volatiles, they must have originated at different pressure/temperature conditions during solar nebula condensation than did the inner planets, which are characterized by relatively refractory elemental composition. Therefore, comparison of cometary "solids" with materials from the inner planets becomes fundamental in defining boundary conditions for the early solar system.

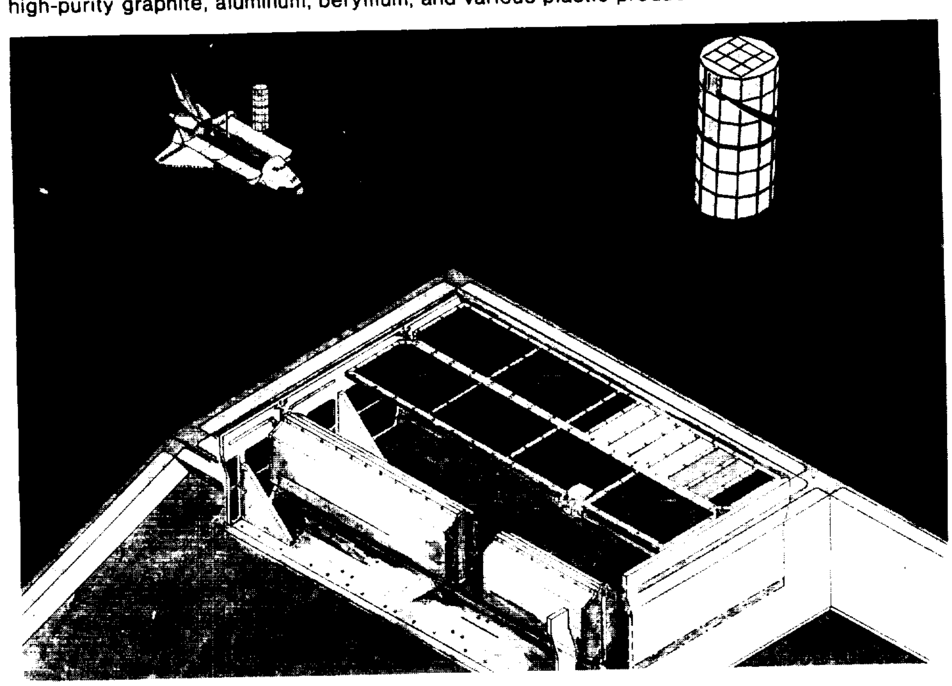
The primary objective of the chemistry of micrometeoroids experiment is to characterize the chemical composition of interplanetary dust. Secondary objectives focus on the total particle flux and some selected physical properties such as the bulk density and shape of individual particles.

Gold surfaces totaling approximately 10 square feet will be exposed to the natural micrometeoroid environment onboard the Long Duration Exposure Facility (LDEF) (fig. 1). Upon impact, the dust particles will create a hypervelocity crater and remnants of the projectile will reside in the crater bottom. Upon return to Earth, these projectile remnants will be analyzed by a variety of microanalytical techniques. The primary reasons for using gold as a collector surface consist of the requirements to have a high-purity substrate to maximize the signal-to-noise ratio during the analytical investigations and to have a chemically inert substrate. Furthermore, a substrate material that is not an important element in cosmochemical modeling and meteorite studies had to be selected. Finally, a ductile material retains projectile remnants much more efficiently than do brittle substances.

For an anticipated exposure time of about 15 months, a total of approximately 50 microimpacts are expected, ranging in size from 20 to 100 micrometers in diameter; the projectile remnants may be as small as 10^{-10} to 10^{-12} grams. They will be analyzed primarily with scanning electron microscopes and energy-dispersive X-ray techniques.

Assembly of the experiment is completed. Parts of the flight acceptance tests were accomplished and the experiment should soon be flight-rated. The Long Duration Exposure Facility launch is presently scheduled for late 1984.

Figure 1.—Schematic layout of the chemistry of micrometeoroids experiment. A clamshell-type arrangement is used to open and close the collector doors that house the gold plates. One clamshell is illustrated in an open position; the second is in a closed position. Electronic sequencers will initiate opening and closing of the doors a few days after Shuttle deployment and a few days before redocking for retrieval. This assures maximum protection from various contaminants during ground handling, launch, deployment, and retrieval. Part of one opened door shows rows of small collectors made for experimental purposes. These collectors consist of high-purity graphite, aluminum, beryllium, and various plastic products.



Remote Sensing of Lunar Rock Composition by Infrared Measurement

The existence of weak reststrahlen bands in the 8- to 14-micrometer spectrum of the Moon was demonstrated during the previous reporting year. This past year, additional measurements were made to verify the results and to develop improved methods for the detection of the weak bands.

The best technique was found to be a differential measurement. The difference spectrum was measured between two lunar sites when the local lunar Sun angle was such that they were at the same calculated temperature. In this way, spectral differences between the two sites were emphasized.

The difference spectrum between the central peak of Tycho and the Apollo 11 site is shown in figure 1, along with a laboratory spectrum of a feldspar-rich lunar soil sample.

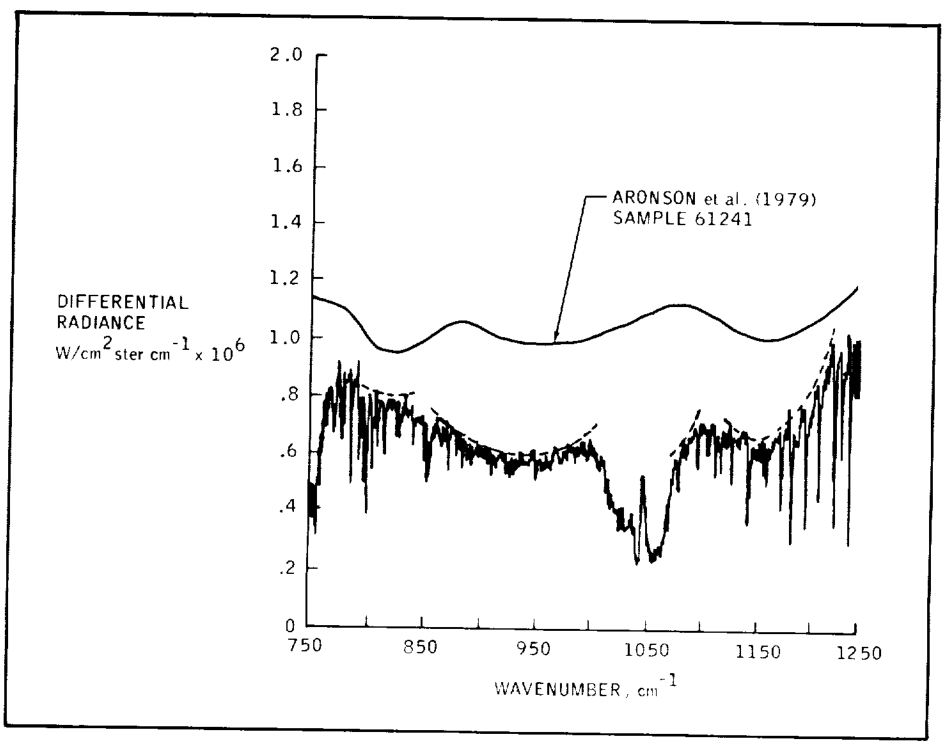
Apollo 11 was chosen as a reference site because the old glass-rich powder at this site should have few, if any, spectral features. Tycho is a relatively fresh crater and young crystalline rocks should be exposed there. Hence, most of the structure in the difference spectrum is assumed to be from Tycho.

This lunar difference spectrum was measured at a spectral resolution (1 centimeter^{-1}) high enough to permit the lunar continuum spectrum to be seen between the water lines. However, ozone lines are not resolved at 1 centimeter^{-1} and the region around 1050 centimeters^{-1} is completely screened by atmospheric ozone.

Of particular interest in this spectrum is the weak band near 820 centimeters^{-1}. This band is not found in bulk samples of feldspar but does appear in feldspar powders when the particle size is reduced below approximately 50 micrometers.

Thus, the lunar infrared spectra are determined not only by mineral composition but also by particle size. More laboratory and theoretical work on the emission spectra of powdered minerals is needed before lunar spectra of this kind can be fully interpreted.

Figure 1.—Spectrum of difference between two lunar sites.



Advanced Hyperthermia System

The advanced hyperthermia system was a joint program involving NASA and the Stehlin Foundation for Cancer Research. The objective of the project was to employ NASA expertise toward the development of an improved heating system that would be used by the Foundation in the treatment of certain types of cancer.

Over the years, it has been demonstrated that hyperthermia has been successful in certain cancer therapies. Tumor cells were found to be more sensitive to killing than normal cells when heat was applied. There is less blood flow (for heat transport) in solid tumors than in normal tissue, leading to greater heating for these tumor cells. Even partial regressions of tumors were observed where they were previously inoperable. The Stehlin Foundation for Cancer Research has been using hyperthermia over the past 15 years with dramatic results. However, the present systems have several basic disadvantages. The Foundation solicited NASA's support toward reducing or eliminating these problems. Preliminary background efforts indicated that NASA technology could be applied, and the Foundation contributed funds for the purchase of the necessary hardware.

In mid-1978, JSC signed a Memorandum of Understanding with the Stehlin Foundation for Cancer Research at St. Joseph's Hospital in Houston, Texas, outlining the responsibilities of both organizations and defining the technical support of JSC.

The challenge for JSC engineers was to improve radiofrequency heating techniques used at the Stehlin Foundation. The first step was to develop a machine for treatment of small animals (fig. 1). The small-animal experimental system that was developed provided valuable data on applicator size and shape in addition to determining tolerable temperatures. A notable feature of the system was the ability to apply up to 50 watts at five frequencies from 3 to 30 megahertz. The small-animal system also assisted in establishing human protocols and studying the effects of hyperthermia at the cell level.

After a year of tests on mice, JSC developed an advanced radiofrequency hyperthermia system for treatment of humans (fig. 2). Developing the human system involved concern about safe and reliable performance. A team of engineers, scientists, and representatives of the JSC Safety, Reliability, and Quality Assurance Division helped monitor and review the overall design and performance. In January 1980, the team delivered an experimental human treatment system to St. Joseph's Hospital.

The radiofrequency system for human treatment uses a gradual buildup of power to a preselected value. Two pairs of sequentially driven electrodes provide more concentration of radiofrequency power at the tumor and disperse heat at the skin. A feedback control that allows regulation of temperatures within a specific area to an accuracy of 0.2° C was also designed. One area of concern was the heating of the skin below the electrodes that, in some cases, caused burns. The solution was to circulate temperature-controlled water through metal tubing soldered onto the back of flexible electrodes. A data printer added to the system records temperatures and power levels as a function of time. The human radiofrequency system has been used successfully on several cancer patients.

Figure 1.—Small-animal experimental system.

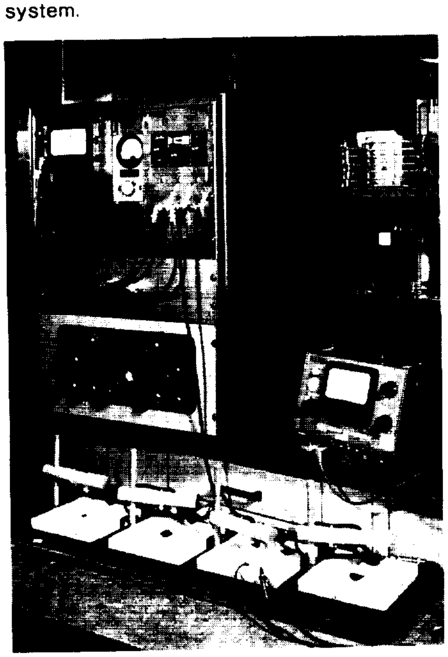
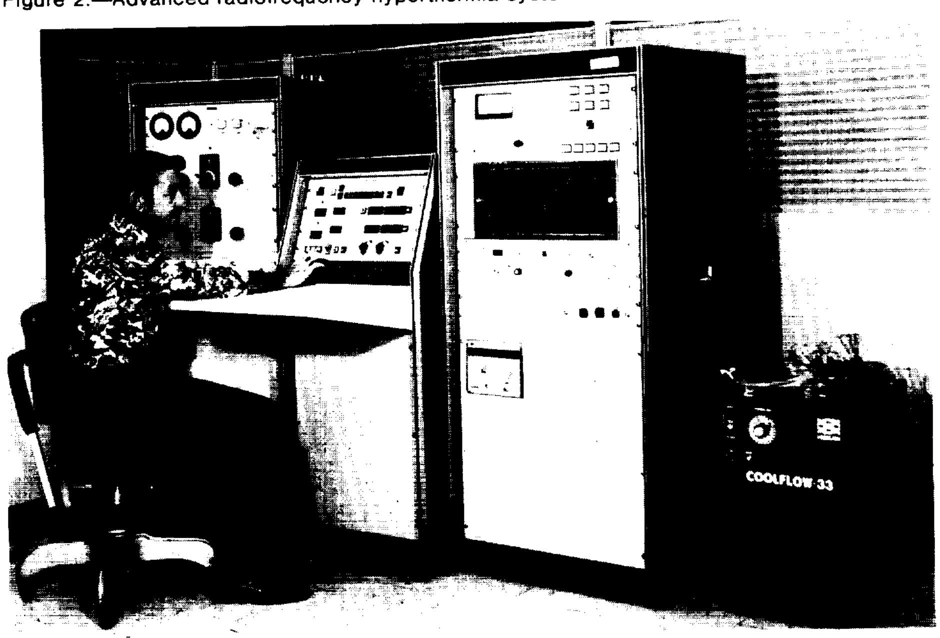


Figure 2.—Advanced radiofrequency hyperthermia system for treatment of humans.



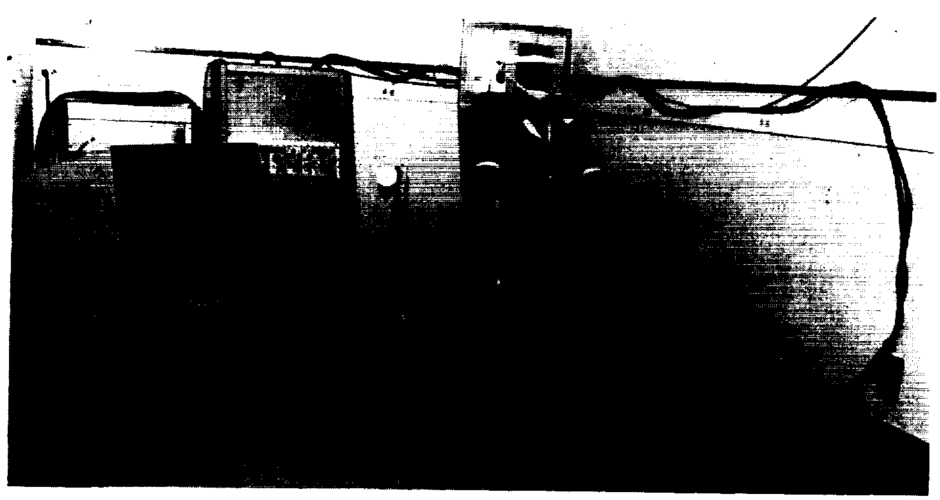
Linear Accelerator for Human Vestibular Research

NASA has long been interested in developing tests that assess the effects of extended zero-gravity space flight on the vestibular system of flightcrews. On the basis of limited flight data and fairly extensive ground-based laboratory data, it is widely accepted that alterations in the otolith receptors of the inner ear are primarily responsible for the vestibular disturbances (including space motion sickness) observed in about 40 percent of U.S. astronauts and Soviet cosmonauts. Therefore, investigations of otolith function, both in the terrestrial and weightless space flight environments, will probably significantly enhance our understanding of vestibular function in zero gravity. Such studies should also provide insight regarding the etiology of space sickness and contribute to the development of methods for controlling this potentially debilitating syndrome. Different testing procedures have been used to apply meaningful stimuli to the otolith receptors in man. These include static tilt, the use of four-pole swings, and short periods of altering g-forces achieved with parabolic flight. Although much can be learned by these techniques, it is of great value to use precisely controlled and programmable linear acceleration. It was with this objective in mind that the Neurophysiology Laboratory at JSC elected in March 1978 to develop a man-rated linear acceleration device for ground-based vestibular research.

Dr. David Anderson of the Kresge Hearing Research Institute at the University of Michigan, because of his experience in the design and fabrication of moving platform systems for the measurement of postural mechanisms in man (fig. 1), was contracted to design and develop a human linear accelerator for use at JSC. The linear accelerator system was delivered to JSC in June 1979. The system consists of several fundamental components. A platform upon which the subject seat or restraint system is located rides on two parallel steel rods. The platform is connected via a cable-drive assembly to a dc torque motor mounted at one end of the frame. The system incorporates an electronic package that contains a power transformer, a power supply, a servoamplifier, and a controller interface for connection to a LSI-11 microprocessor. The frame of the accelerator is 12 feet long and 3 feet wide and the displacement of the accelerator platform is approximately 8 feet peak-to-peak. It is capable of achieving accelerations up to 0.5g over a frequency range of approximately 0.18 to 5.0 hertz. The accelerator can be programed to deliver constant g (ramp), sinusoidal or pseudorandom linear displacement. Following delivery to JSC, the linear accelerator was "ruggedized" for use on the KC-135 zero-gravity airplane and a number of subject/operator safety devices were added. Several computer programs have been written for controlling the device in various operating modes.

Actual experimental use of this linear acceleration system has been limited during the period from July 1979 to the present. During this time, considerable effort was expended in implementing the various system improvements previously defined and in conducting various functional checkouts. The system has also been used to conduct pilot studies to evaluate the effects of linear acceleration on vestibulo-spinal reflexes in man. Plans for ever-increasing use of the system will be made to conduct linear acceleration experiments with humans. These experiments will directly support the implementation of Spacelab 1 Experiment 1NS-104, "Adaptation of Vestibulo-Spinal Reflex Mechanisms During Space Flight," as will a similar flight experiment tentatively planned for the first dedicated life sciences Spacelab. Certain phases of these ground-based support experiments will be conducted during parabolic flight, representing the first time that a precision linear acceleration device has been flown in such an environment. The linear accelerator will also be evaluated for its ability to evoke symptoms of motion sickness. If early studies of this type are successful, the device will be increasingly used to evaluate susceptibility to motion sickness and to evaluate the efficacy of antimotion-sickness medications. In general, the human linear acceleration device has added a significant dimension to the JSC Neurophysiology Laboratory's ability to investigate vestibular function, especially otolith receptor function in man.

Figure 1.—Linear accelerator system for human vestibular research.



Nuclear Cardiology Imaging System

The multiwire proportional counter (MWPC) is a modern instrument used for detection of ionizing radiation. It is widely used in research applications for accurate high-speed position measurements of ionizing radiation. A sophisticated yet simple technique for electronic readout of this instrument was developed for space research at JSC and is currently being adapted for medical imaging applications. The very high rate capability of this technique, combined with its simplicity and low cost, offers the possibility of a significant advance in certain areas of nuclear medicine where high-speed imaging of dynamic radioisotope distributions within the body is required. A prototype device currently in operation at JSC has demonstrated this potential and a refined device is nearing completion and should allow medical testing on human subjects in 1981.

Applications of the JSC multiwire proportional counter in the field of nuclear cardiology are particularly promising. In the nuclear cardiology technique, a radioactive tracer is injected and the passage of the tracer through the heart is viewed with the MWPC imaging device. By making rapid sequential images that are stored and manipulated by an on-line computer, the device can obtain measurements of great diagnostic value, such as determination of ventricular stroke volume and ejection fraction and observation of heart chamber wall motion irregularities.

The dynamic imaging capability of the prototype device has been tested using a cardiac phantom. This phantom was specially designed and constructed at JSC; it consists of a fluid-filled rubber bag with a volume that can be rapidly modulated to simulate the human left ventricle. Tests have been conducted in which a radioactive tracer was injected into the bag, which was pulsed at 60 beats per minute from a diastolic volume of 140 milliliters to a systolic volume of 0 milliliters. The MWPC camera was used to produce 16 stop-action views of the phantom (fig. 1). The radiation intensities observed by the camera are interpreted by using the color-coded bar at the right. An on-line computer was used to locate the wall perimeter of the phantom. Computer software has also been developed to determine the stroke profile (volume versus time correlation) and ejection fraction. The accuracy of these measurements has been validated for various ejection fraction values, pulse rates, and stroke volumes.

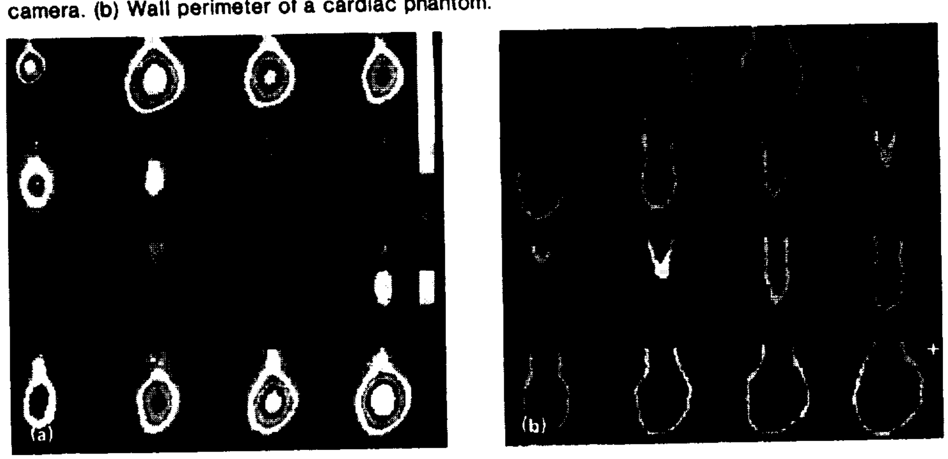
A method was recently developed for production of a radionuclide generator that provides a continuous supply of the short half-life isotope tantalum-178 ($T_{1/2}$ = 9.3 min). This makes possible the application of this isotope as a nuclear medicine tracer. Tantalum-178 is nearly optimum for use with the multiwire proportional counter. Tantalum's attractive intrinsic features include its short half-life, which permits repeat studies at short intervals, and very low radiation exposure compared with currently used clinical radionuclides. A 100-millicurie tantalum-178 generator has been produced at JSC from tungsten-178 (the generator parent isotope) which was furnished by Lewis Research Center. Eluent from this generator was used to perform the phantom tests.

In addition to the MWPC application, tantalum-178 has potential application for use with commercially available imaging devices if interference between its low-energy primary photons (54 to 65 kiloelectron-volts) and its less-abundant high-energy photons can be resolved. In collaboration with Baylor College of Medicine, good quality images have been produced by tantalum-178 using both multicrystal and Anger cameras. These cameras are the imaging devices most used in clinical nuclear cardiology. The tantalum-178 studies included static and dynamic imaging, ejection fraction, and wall motion and sensitivity measurements. The quantitative results have been compared with those obtained using technetium-99. Technetium-99 (half life, 6 hr) is the commonly used radionuclide in clinical angiocardiography studies.

Collaborative agreements have been made with E. R. Squibb Research Institute and Harvard Medical School to test NASA-produced tantalum-178 to improve the safety, reliability, and yield of the tungsten-tantalum generators. These studies will validate the use of tantalum in human studies with particular emphasis on nuclear medicine research uses.

It is expected that combined application of MWPC imaging technology and tantalum-178 to the nuclear cardiology field will open new areas of diagnostic capability and improve techniques already being extensively used with existing cameras and isotopes.

Figure 1.—The MWPC camera produced these stop-action views of the phantom as it contracted and expanded through one cycle. (a) Radiation intensities observed by the MWPC camera. (b) Wall perimeter of a cardiac phantom.



Mobile Biological Isolation System

In January 1974, a request was received from the Baylor College of Medicine outlining a need for a germ-free suit system for use by a 2-1/2-year-old child who was afflicted with a severe immunization deficiency and had lived in a germ-free carefully constructed room (bubble) since birth. The objective of the ensuing program was to develop a mobile biological isolation system for use by patients with immunization deficiency or aplastic anemia or who were undergoing chemical therapy or organ transplant, requiring their confinement to laminar-flow isolation facilities.

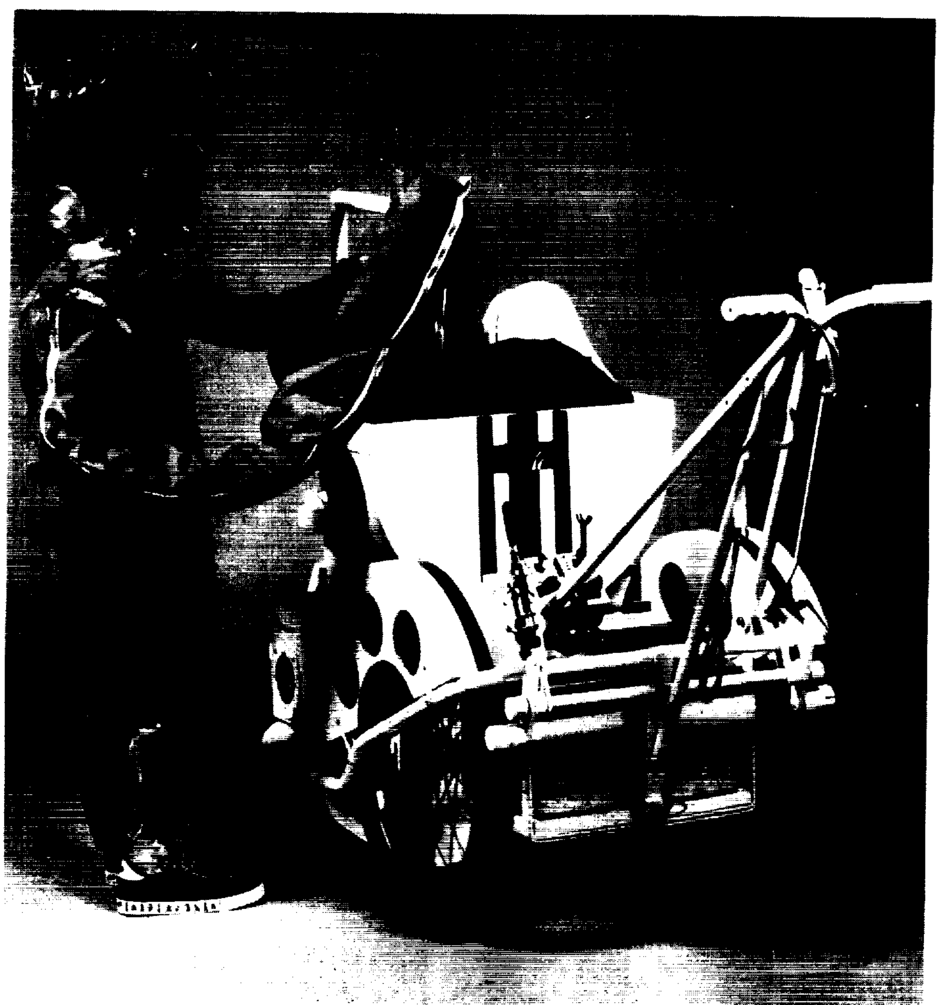
The mobile biological isolation system consists of a bioisolation unit or suit assembly and a pushcart transporter (fig. 1) that carries a life support system. The mobile biological isolation system is divided into three subsystems: suit and air supply, mechanical, and electrical power.

The suit and pressure-retention assembly is of one-piece construction and consists of a neoprene-coated nonporous nylon bladder to which are permanently attached a soft transparent plastic helmet, rubber gloves, and boots. The configuration supplied to the Texas Children's Hospital, Baylor College of Medicine, includes a permanently attached tunnel and adapter ring assembly that attaches directly to one of the patient's isolation bubbles. This allows the patient to don and doff the suit without ever coming in contact with the nonsterile outside environment or outer surface of the garment. A 2-foot sheath was fabricated on the back of the garment. After subject entry, the sheath is simply rolled shut and strapped in place.

A lightweight overgarment of porous nylon (Nomex) — similar to that used in certain outer layers of the Gemini space suit — is worn over the suit and affords additional protection against abrasion, puncture, and fire. The tunnel is sheathed with a material identical to that used for the pressure garment and this sheathed configuration serves as a tether during patient excursions. Ambient air, filtered to 0.3 micrometer via a high-efficiency particle-accumulator filter, is blown into the helmet by one of three (two redundant, one emergency backup) ventilator fan assemblies, circulated over the body for cooling, and exited at the ankles under positive pressure.

A typical lawnmower frame, wheels, handles, and brakes serve as the basic transporter unit on which mechanical and electrical equipment is mounted. A seat is provided together with a swing arm to allow the patient to ride on the transporter or to walk alongside within the 10-foot radius of the suit tunnel.

Figure 1.—The mobile biological isolation system consists of a suit assembly, a pushcart transporter, and a life support system.



The electrical power system includes two blowers, two motors, two 12-volt batteries, and the circuitry required to utilize power from a standard household electrical outlet or a motor vehicle cigarette lighter. During normal operation, the batteries are connected in parallel. The system was designed to support a 4-hour outside excursion as a minimum (fig. 2). Additional time is permissible as patient comfort and endurance allow. (Additional emergency equipment and reconfiguration options are available to the qualified operator.)

Two new larger suits are being developed for the patient at Texas Children's Hospital and are expected to be completed by late 1980. Results of growth studies were incorporated to increase the overall wear time of the suits. New materials are being used that allow stronger seams and easier fabrication. Glove material has been changed from neoprene to dipped latex to allow greater tactility and dexterity. Boots are no longer part of the leg assembly. The new concept provides a tube sock as part of the lower leg, allowing the subject room for growth and permitting him to wear better fitting shoes or sneakers. A new helmet material and design increases optical qualities and visibility. The air-spray design is also improved to allow better dispersion of carbon dioxide and to eliminate visor fogging. The outer garment has been redesigned to give a casual denim look with pockets large enough to accommodate many articles. Perhaps the greatest improvement is a change from the previous exhaust ports to a more reliable type that is easily replaceable.

Figure 2.—Supported by the mobile biological isolation system, the patient is able to go on an excursion.