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Research and Technology

Annual Report 1983

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Houston, Texas

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Research and Technology

Annual Report 1983

November 1983

Prepared by
Office of the Director of Research and Engineering
Lyndon B. Johnson Space Center
Houston, Texas

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. This document will be updated in November of each year.

The JSC Annual R&T Report is compiled by the Office of the Director of Research and Engineering. 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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Contents

1	Office of Space Flight
1	Advanced Programs Summary
7	Advanced Programs Significant Tasks
17	Office of Aeronautics and Space Technology
17	Summary
27	Significant Tasks
41	Office of Space Sciences and Applications
41	Solar System Explorations Summary
49	Solar System Explorations Significant Tasks
65	Life Sciences Summary
71	Life Sciences Significant Tasks
83	Earth Sciences and Applications Summary
89	Earth Sciences and Applications Significant Tasks
101	Index

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Space Flight Advanced Programs

Summary

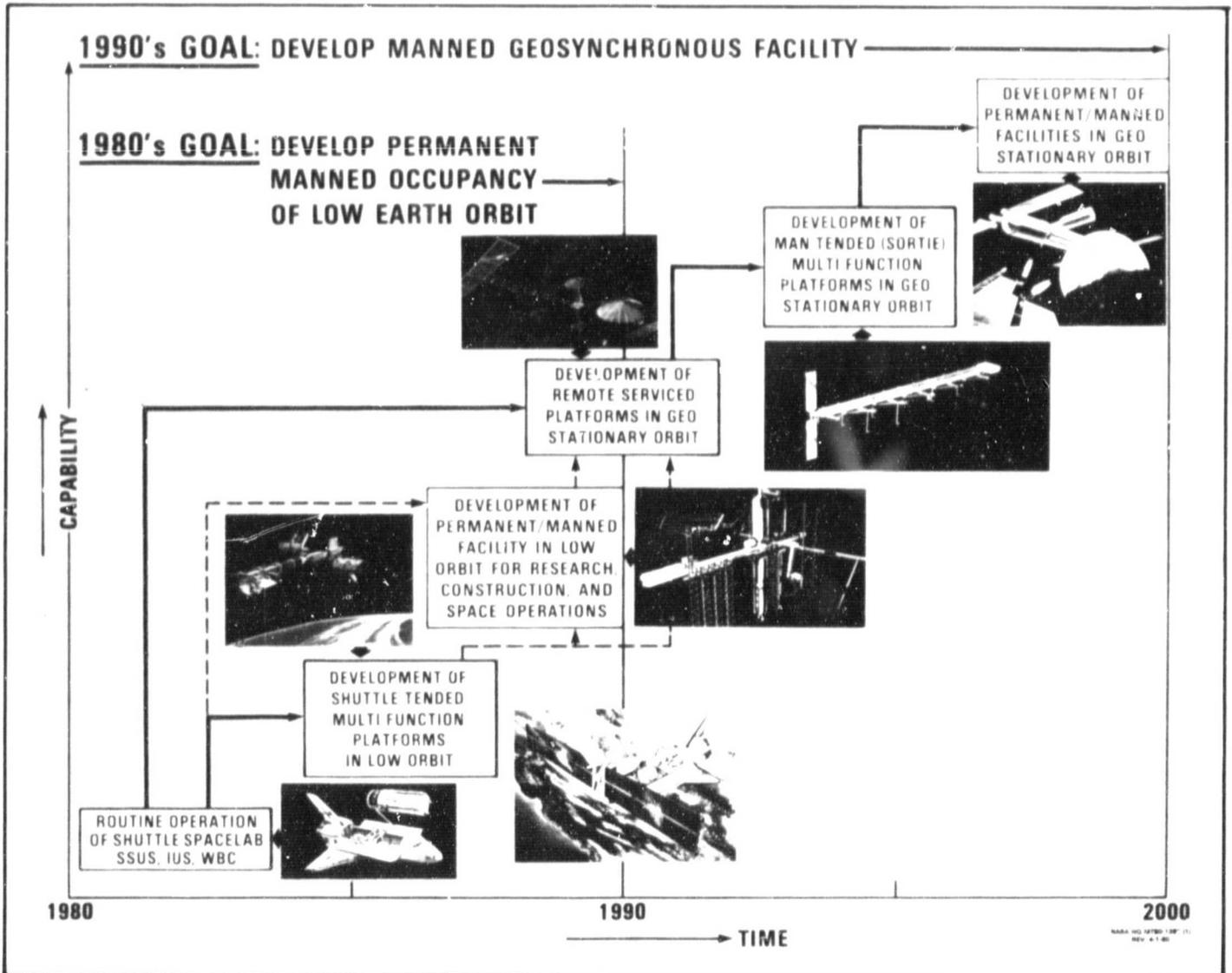
Overview

The Office of Space Flight (OSF) Advanced Program activities are directed toward enhancing and expanding the national Space Transportation System (STS). In fiscal year 1983, the second Space Shuttle Orbiter—*Challenger*— was added to

the STS inventory. Several of the key features of the STS have been demonstrated, including the first extravehicular activities, the first interim upper stage (IUS) mission, successful demonstration of the Shuttle remote manipulator system (RMS), and the integration of the Spacelab into the

STS. Although the bulk of the Johnson Space Center (JSC) work force has been directly involved in these activities, a steadily growing number of activities are underway toward the longer term goals of enhanced Shuttle orbital operations and of permanency in Earth orbit as illustrated.

Long-term JSC goals



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In the 1980's, STS missions will require enhanced Space Shuttle capabilities in the areas of satellite proximity operations and docking. New payloads such as the tethered satellite will require improved dynamics and control capabilities. Concepts such as scavenging fuel from the Shuttle Orbiter for use by other spacecraft are being envisioned as are new orbital vehicles capable of operating in conjunction with the Shuttle and the space station to ferry men and equipment to orbits beyond the domain of the Space Shuttle. All these areas of potential operation are being investigated in JSC Advanced Program studies.

The permanently manned space station is the most important new concept of the NASA space program to be added in this decade. It will complement the Shuttle, Spacelab, and upper stage components of the STS to add new dimensions to our capability to live and function in space. It will act not only as an important adjunct to the Space Transportation System but, perhaps more importantly, as a vital asset for space science and operations in its own right.

During this period, the development of the manned facility in low Earth orbit has been vigorously pursued

through both specifically focused and more generally applicable studies and designs. Virtually all OSF-funded and in-house studies conducted at JSC during the past year were related to enhancing the operations and capabilities of the STS or to supporting the development of the manned orbital space station. In some instances, the work can be applied to both objectives.

Space Shuttle Utilization

The JSC activities devoted to developing and enhancing the Shuttle capability to provide fully operational, cost-effective, and routine access to space for payload users were many and varied. Primary, of course, was conduct of the Shuttle missions, which yielded experience and added proficiency in the routines of launching, operating in orbit, recovering, and preparing the Shuttle for the next mission. The efficiency and expertise gained from this operational experience is essential to reducing costs and attaining the goal of cost-effective, routine access to space.

Another important result of the Shuttle missions conducted in 1983 was demonstration of the RMS capabilities in satellite servicing. The RMS was first used on the STS-7 mission to

deploy and later retrieve the Shuttle Pallet Satellite (SPAS), developed by West Germany, which provided the excellent picture of the Shuttle operating in space as seen by a fellow space vehicle. On the STS-8 mission, the capabilities of the RMS were thoroughly exercised through operations with the Payload Deployment and Retrieval System test article and the Payload Flight Test Article (PDRS/PFTA). As a result of these activities, the RMS has been shown to be a vital part of the STS arsenal of equipment for satellite servicing and space operations.

A study is underway to use the RMS as a configurable, flexible structure to aid in the development of modeling techniques and of closed-loop active control laws. The capability to configure the RMS to represent significant aspects of large space structures makes it a suitable test article for investigating on-orbit vibration and damping.

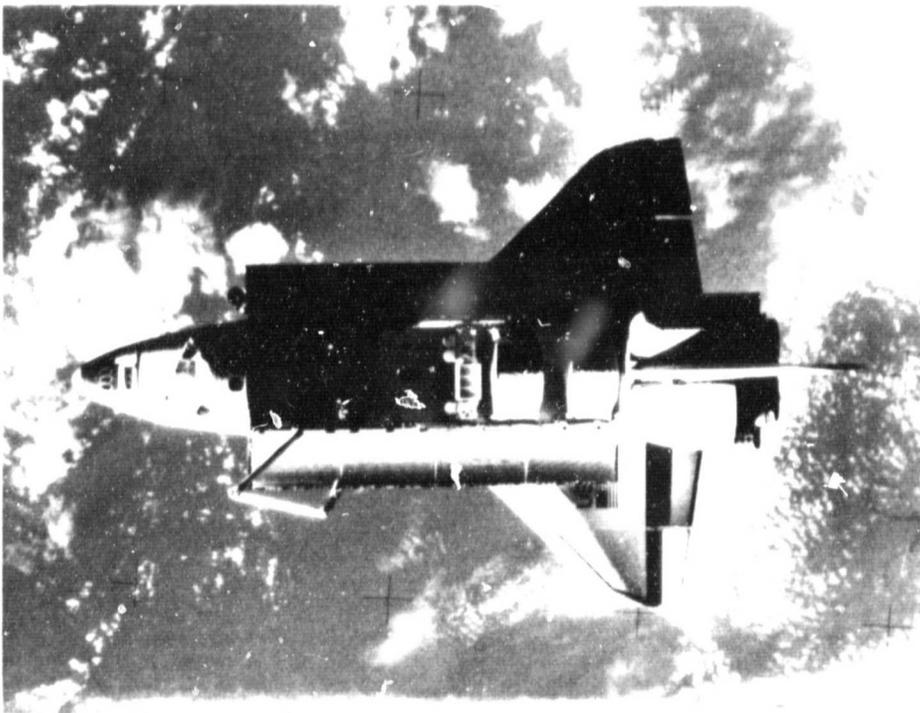
Of a less spectacular nature, but of utmost importance to STS utilization, were the OSF-funded and in-house-supported activities conducted by JSC during the year. The work on orbital refueling mentioned last year has particular interest and potential. This project, an offshoot of Advanced Programs funding, will demonstrate the on-orbit transfer of hydrazine propellant from a storage tank through a zero-g servicing system into a flight-type propulsion module. The demonstration will illustrate the practicality of extending the operating life of existing satellites, such as Landsat, by replenishing their propellants from the Shuttle.

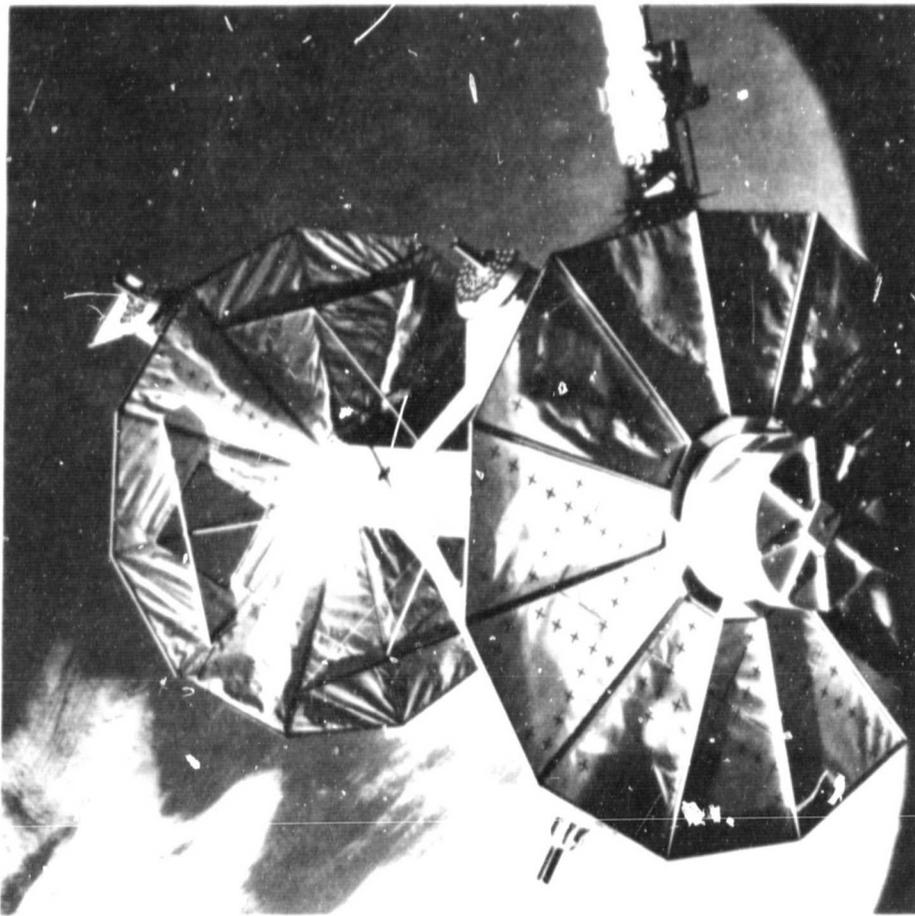
A catalog of tools and equipment, storage containers, payload carriers, and projected satellite servicing equipment was issued as the result of another funded effort. This document will aid payload developers and users in incorporating the STS capabilities for payload support in their planning, design, and operations.

Space Station

During fiscal year 1983, JSC has continued vigorous support of the NASA goal to establish a permanent manned presence in space. The activities at JSC are focused by the Space Station Project Office, with work being accomplished throughout the Center.

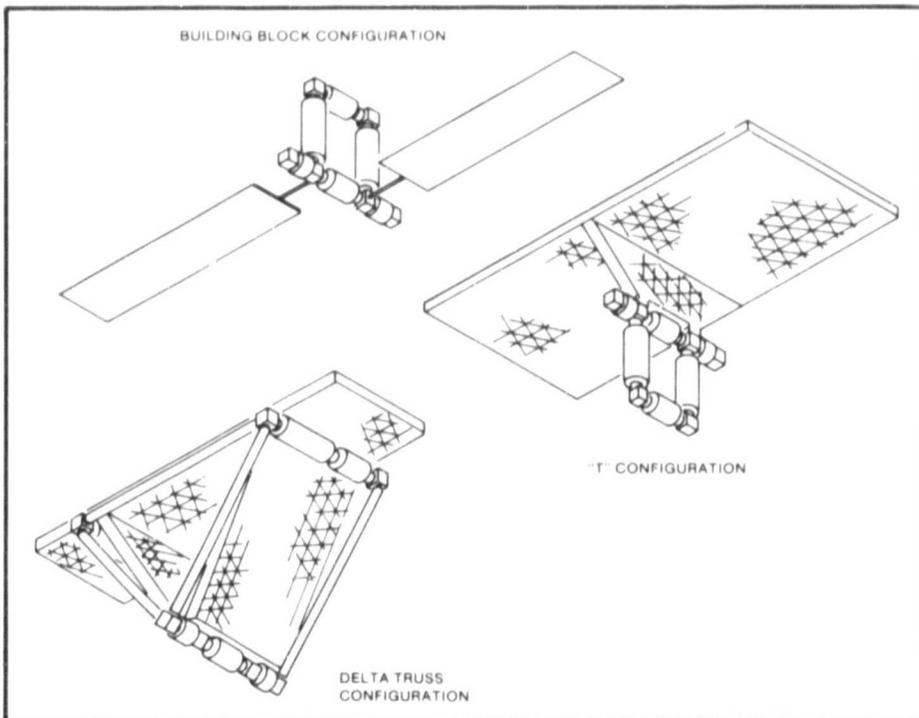
Challenger as photographed by the Shuttle Pallet Satellite (SPAS) on STS-7 mission.





The Payload Deployment and Retrieval System/Payload Flight Test Article deployed on STS-8 mission.

Space station alternate configurations



Fiscal year 1983 activities can be categorized by three major areas of emphasis. The first is a continuation of in-house system-level studies of configuration options in response to user requirements being defined through a combination of government and industry studies. To develop these configuration options, an in-house organizational structure consisting of system- and subsystem-level panels has been formed. These panels evaluate options to the subsystem level and integrate results to establish overall configuration options. The illustrations represent options currently under evaluation.

In addition to investigating the alternative overall configurations, a great amount of study has been devoted to systems definition and locations and to systems operation analysis. Sizing studies for crew, power systems, research areas, etc., have been performed as an aid in defining and bounding the space station costs.

The second area of emphasis has been support of NASA Headquarters "Space Task Group" activities. Areas of support include performance of a series of studies in support of the Concept Development Group, development of operations guidelines and procedures in support of the Operations Working Group, definition of programmatic activities required for program initiation in support of the Program Planning Working Group, and development and analysis of mission requirements in support of the Mission Requirements Working Group.

Special studies include definition of a multidiscipline Manned Research Laboratory, studies of space station food systems, and long-duration implications of these systems. Also investigated were potential low-cost habitability mockups. From an operational analysis standpoint, special studies included automatic rendezvous and docking investigations, operational control zones, and reference mission envelopes.

The third area of emphasis has been the continued definition of "test beds" required to properly assess subsystem-level technology to be incorporated in the space station. Currently, existing JSC test facilities are being used to conduct preliminary testing in the disciplines of environmental control, power, propulsion,

avionics, and habitability. Results to date indicate that a very substantial increase in understanding of technology readiness can be obtained through the use of early ground and flight test activities. Proposals have been submitted to the Space Station Task Force to develop space-station-unique test beds in the following areas: data management; guidance, navigation, and control; environmental control and life support; thermal management; electrical power; communications and tracking; onboard propulsion; space mechanisms; and fluids management.

Funded studies sponsored by Advanced Programs include the investigation of an integrated atmosphere revitalization system for use on the space station to replace the expendable lithium hydroxide system employed on the Space Shuttle. Also studied were distributed data management system concepts maximizing use of new technology such as Local Area Network techniques, fiber optics, and bubble memory systems.

Propellant scavenging from the Space Shuttle Orbiter systems appears to be a cost-effective technique for refueling orbital transfer vehicles located at the space station. The use of a tethered orbital refueling system is another intriguing companion concept.

Continuation and expansion of the JSC in-house and funded space station activities are planned for fiscal year 1984 in anticipation of initiating formal space station definition in fiscal year 1985.

Orbital Debris

Studies of the populations and hazards of manmade orbital debris (report: J in 1982 R&T Report) continue at JSC under the sponsorship of several NASA offices. A photograph taken at Lincoln Laboratory's Experiment Test Site, White Sands, New Mexico, on October 30, 1982, using their 31-in. telescope shows the final seconds of a second-stage IUS burn, 23 000 mi. away. Clearly visible by reflected sunlight is the 2000 lb of aluminum oxide dust that these rockets produce. The photograph shows the dust spread over 300 mi. in space. Preliminary calculations and limited experimental data indicate that the flux from these dust particles can exceed the natural

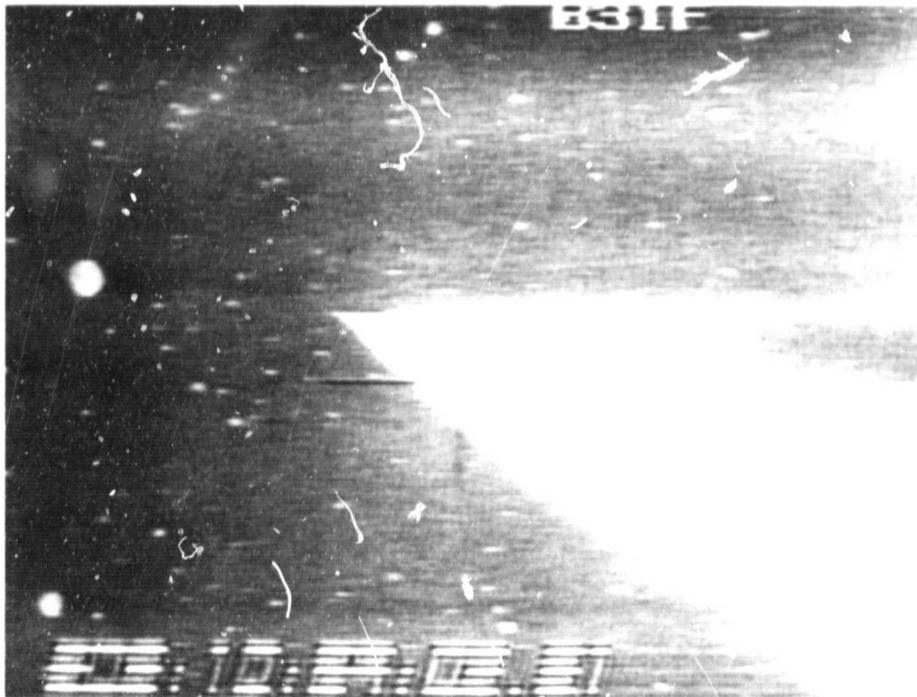
meteoroid environment. However, the amount by which the natural environment is exceeded depends on the orbital lifetime of these microscopic particles. These studies of particle lifetime are planned for fiscal year 1984.

Also visible in the photograph are 15th magnitude stars. Use of this telescope in an optical search for small

orbital debris during fiscal year 1984 is planned. Expectations are that objects as small as 1 cm will be detectable at 400 km altitude. Presentation of all these data and other information on orbital debris is planned at a "Space Debris Workshop," scheduled on June 29, at the 1984 Committee on Space Research meeting in Graz, Austria.

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Photograph of IUS exhaust cloud made using Lincoln Laboratory 31-in. telescope.



Space Flight Advanced Programs

Significant Tasks

Remote Manipulator System Control Technology

TM: Henry J. G. Kaupp, Jr./EH2
Reference OSF 1

Large space systems control technology will require advancements in methods of accurately modeling flexible structures, practical application of systems identification techniques, and development of closed-loop active control laws. The Orbiter/remote manipulator system (RMS)/payload is a flexible structure that can be configured to represent significant aspects of large space structure operations. It is, therefore, a suitable test article for investigation of on-orbit vibration damping.

Three phases of on-orbit experiments using the RMS and instrumented payloads are being developed to investigate potential control problems associated with large space structure development, construction, and operation. The requisite sensors, control and identification algorithms, and actuators for these experiments may be provided by any or all of the RMS, payload, and general-purpose computers. The first phase of the experiments requires minimal integration with existing Shuttle hardware and software and will support an evaluation of current modeling techniques in addition to an assessment of the practical applicability of system identification algorithms. Since it is not

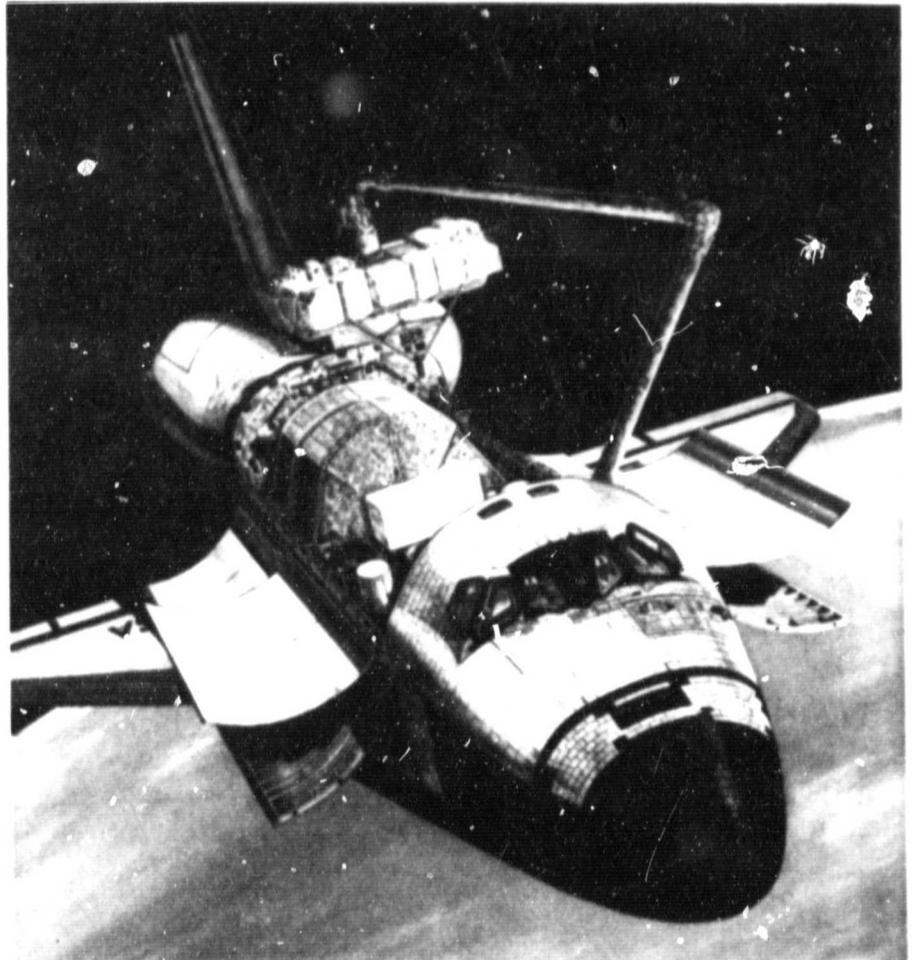
possible to implement closed-loop active control without hardware and software modifications to the Orbiter/RMS/payload system, the near-term experiments will serve primarily to augment the development of system identification algorithms and control laws for simulation of closed-loop experiments.

Experiments in the second phase will incorporate the modeling and system identification experience of the first phase with flight data to simulate closed-loop active control of the RMS and payloads such as the Shuttle Pallet Satellite (SPAS-01). Planning for the third phase of experiments will consider active control of the RMS and flexible payloads such as solar panels, appendages, containers, and elements of large space systems. These experiments may necessitate some additions or changes to the current Shuttle software and/or hardware to facilitate implementation of closed-loop active control.

The system identification procedure used to validate the RMS model using flight data from Space Shuttle flights 2, 3, and 4 required substantial engineering judgment to accommodate problems of resolution, of system non-linearity, and of the interdependence of sampling rate and numerical error. Progress had been made in implementing a more autonomous identification procedure that can be incorporated in an active vibration damping algorithm.

A series of maneuvers using the RMS and the SPAS-01 payload was performed on STS-7. Postflight analysis of data from RMS actuators and SPAS-01 sensors will support a simulation of active vibration damping. On STS-8, several maneuvers using the RMS and the Payload Flight Test Article payload were completed. Data from RMS actuators and strain gages will be used to evaluate revised system identification algorithms and an active control law.

Typical configuration for STS-7/RMS/SPAS-01 experiment investigations



Automated Rendezvous, Proximity, and Docking

TM: Bob Brown/FM
Reference OSF 2

Future on-orbit operations will require routine automated rendezvous, proximity, and docking operations with the space station and to satellites for servicing, retrieval, maintenance, repair, or inspection.

Work to develop automated on-orbit operations has resulted in definition of the Automated Rendezvous, Proximity, and Docking System, which enables autonomous, unmanned orbital operations. The system consists of seven basic components: a passively cooperative target vehicle such as the Space Telescope; an active orbital maneuvering vehicle; an accurate relative navigation sensor such as the Advanced Rendezvous and Docking Sensor; a Tracking and Data

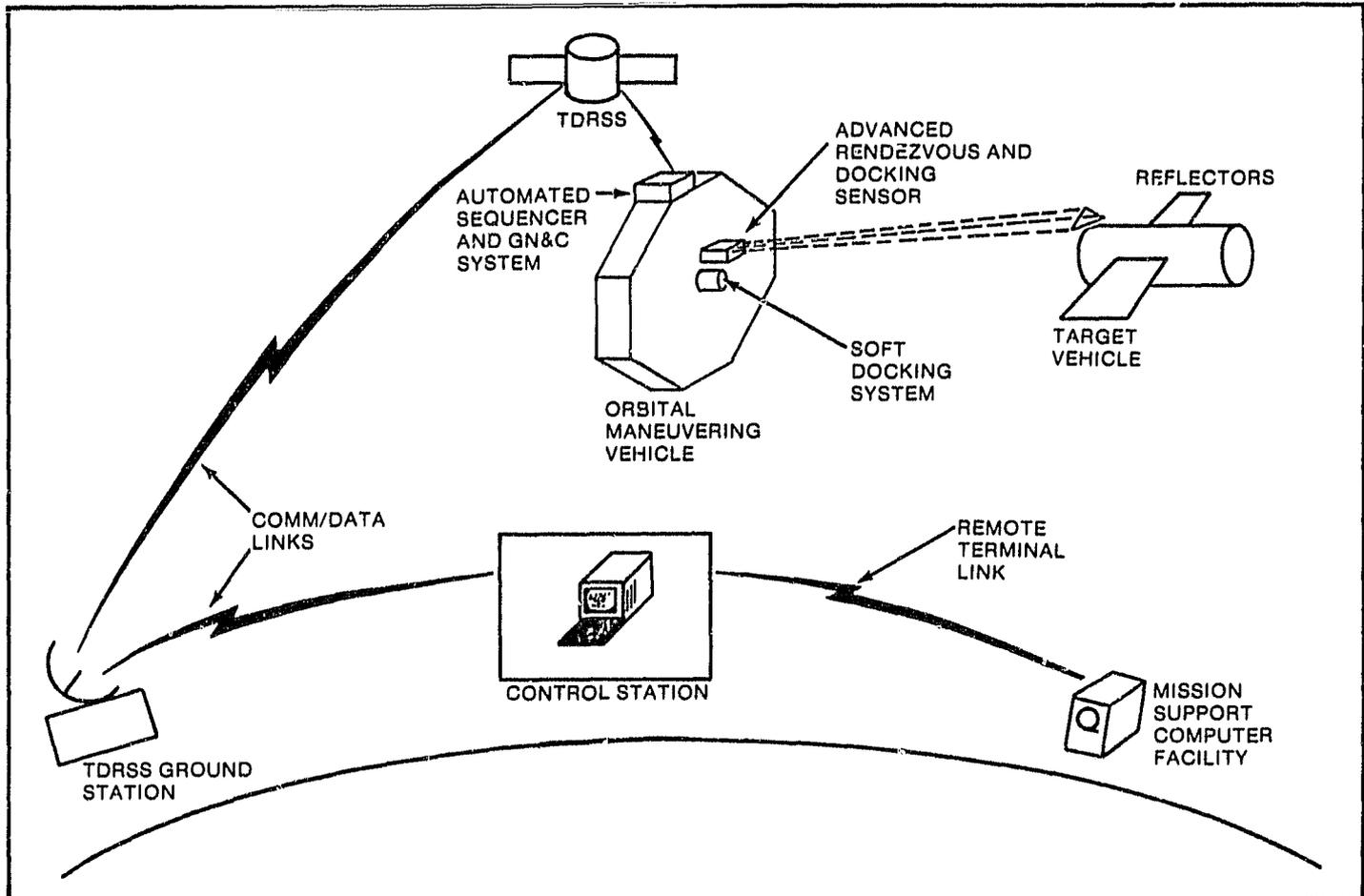
Relay Satellite System (TDRSS) communication and data link; the automated sequencer and guidance, navigation, and control (GN&C) system; the control station; and the Mission Support Computer Facility.

The automated sequencer provides an interface between the control station and the vehicle. On-orbit operations are accomplished by the sequencer by way of commands to the onboard GN&C system. Normal operations do not require a communication/data link to the control station; however, overall control of the vehicle is maintained at the control station by periodic communication/data links through the TDRSS.

The control station is generic and can be located on the ground, onboard the space station, or onboard a manned active vehicle. Computer support to the control station is provided by way of a remote terminal link, investigated in a previous study, to a ground-based computer facility.

To validate this automated concept, the Orbital Operations Simulator, a high-fidelity digital simulation of on-orbit vehicles in the orbital environment, was developed. The simulator is being used as a tool for automated operational technique development, trajectory design, performance analysis, and hardware/software requirements definition. Simulation effects currently include automated vehicle control by way of onboard computer software, manual backup control by way of hand-controller inputs, a closed-circuit-television downlink, a ground control station, and a high-fidelity on-orbit environment. Additional Orbital Operations Simulator capabilities include space station operations analysis, traffic control studies, integrated simulation of multivehicle operations, man-in-the-loop control, geosynchronous orbit mission operations, and automated satellite servicing requirements definition.

The Automated Rendezvous, Proximity, and Docking System.



**Satellite Services
Standard Interfaces**

TM: Gordon Rysavy/EB
Reference OSF 3

The fully operational Space Transportation System will have requirements for satellite service capability for payload deployment and retrieval, payload support on sortie missions, and satellite support servicing within or adjacent to the cargo bay. Potential satellite support services include (1) resupply of expendable items such as propellants or raw materials for processing, (2) checkout, maintenance, and repair, (3) reconfiguration of sensors, and (4) component exchange. Previous studies produced the requirements and concept definition of various items of satellite services equipment. Some of this equipment is available or under development, with the remainder being newly identified items for future development consideration.

Routine satellite servicing will require the standardization of both man and machine servicing interfaces. Standardization will allow satellite designers to incorporate servicing interfaces compatible with available and planned Space Transportation System servicing equipment and procedures.

The approach to this requirement is to develop satellite servicing guidelines leading to the implementation of standardized service interfaces between the Orbiter and satellites. The initial effort is to identify and define satellite interface design considerations with emphasis on servicing requirements for near-future satellites.

For the purpose of this task, it is assumed that the on-orbit servicing of satellites will be conducted with the Shuttle Orbiter. However, secondary consideration shall be given to servicing satellites from a permanently orbiting service station such as a space station using the same or similar service equipment as that used by the Orbiter.

An initial step in the baselining of available and projected servicing tools and equipment was accomplished with the September 1983 publication of the "Satellite Services Catalog—Tools and Equipment." This catalog delineates tools and equipment for EVA support, tool storage, payload carriers, and projected satellite servicing equipment. Also included in the catalog are Orbiter systems used during a servicing mission.

Spacecraft interface design considerations for satellite servicing.

DESIGN CONSIDERATION S/C INTERFACE	REMOVE/ REPLACE SWEPT VOL.	ARTICULATION ENVELOPES	CONNECTORS	JETTISON
Batteries	X	X	X	
Latches	X	X		
Umbilical	X	X	X	
Mech. Drives	X	X		
Instruments	X	X		
Berthing Fixtures	X	X		
Crew Loads		X		

**Integrated Atmospheric
Revitalization System Test**

TM: Nick Lance/EC3
Reference OSF 4

As future manned space missions such as a space station increase in duration and in number of crewmembers, the quantity of expendables required at launch, such as water (H₂O) and oxygen (O₂), increases proportionately in weight. For instance, the use of nonregenerable processes merely to replenish O₂ and remove carbon dioxide (CO₂) for a 90-day mission would require more than 700 lb of expendables per crewmember. Other requirements to maintain a habitable environment, such as the replenishment of nitrogen (N₂), would increase the stores requirement of expendables even more. Shuttle missions use expendables in the form of cryogenic O₂ for breathing and lithium hydroxide (LiOH) cartridges for atmospheric CO₂ removal. A space station will almost certainly use a regenerative life support system to efficiently provide a habitable atmosphere and to recover water for reuse.

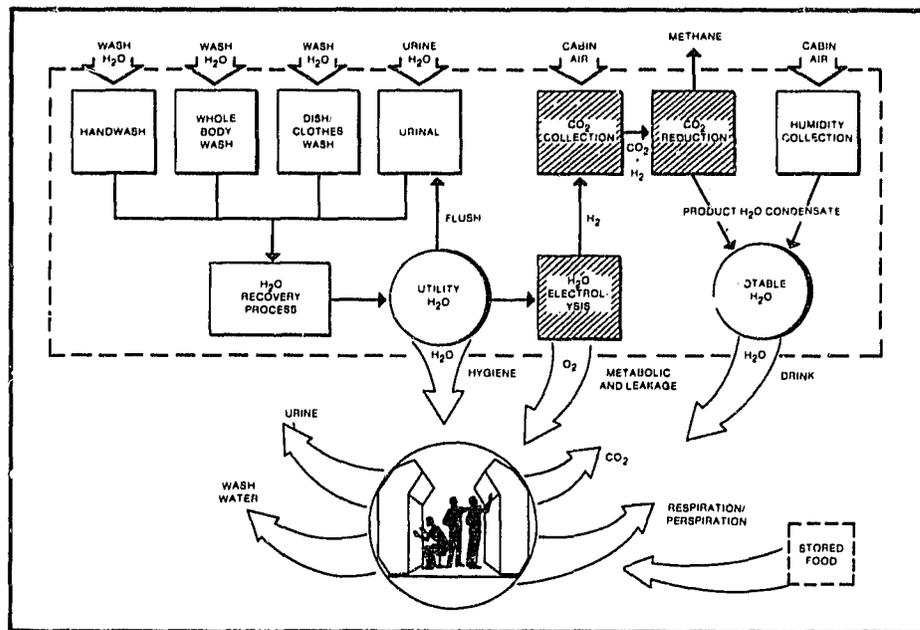
The single requirement for a regenerative atmospheric revitalization system (ARS) is to reclaim the O₂ from the respiratory CO₂ molecule. Presently, the most reliable and well-developed scheme to accomplish this O₂ reclamation involves the use of three separate subsystems. The CO₂ is removed from the cabin airstream flowing through a module consisting of a series of electrochemical cells. Each cell consists of two electrodes separated by a matrix containing an aqueous carbonate electrolyte solution. Plates adjacent to the electrodes provide passageways for the distribution of gases and electrical current. The basic concept is to react the basic hydroxyl ion (OH⁻) with CO₂ to form the carbonate ion (CO₃⁼). The CO₃⁼ is transferred across each cell in the presence of a reaction which combines O₂ with hydrogen (H₂) to form H₂O and electrical energy.

Upon reaching the opposite electrode, the CO₃⁼ reacts with H₂O to form OH⁻ and CO₂. The CO₂ along with the excess H₂ are then processed by a second subsystem. The Sabatier CO₂ reduction subsystem employs an exothermic chemical reaction across a noble metal ruthenium catalyst contained within an air-cooled reactor. The process produces H₂O, methane (CH₄), and heat. The CH₄ is dumped overboard, and the H₂O is

condensed and transferred to the third subsystem, an O₂ generation concept which employs the principle of water electrolysis. Passage of electrical energy across the cells of this electrochemical subsystem produces O₂ for breathing on one side of the cells and H₂ at the opposite electrodes. The O₂ goes to the cabin and the H₂ is recycled back to the electrochemical CO₂ collection subsystem.

Several development efforts during the past 20 years have resulted in the evolution of highly reliable, well-developed preprototype subsystems to accomplish the ARS requirement of O₂ reclamation. After delivery of three-man subsystems beginning in 1978, the hardware has been tested separately and in an integrated ARS configuration. Several hundred hours of successful testing have been accomplished on the individual subsystems. Each of the three subsystems incorporates electronics to provide automatic operational control, data interfaces for local parameter display and remote data recording, and parameter monitoring to provide an orderly subsystem startup and an orderly subsystem shutdown in the event of a process malfunction. Integrated unmanned testing as an ARS was also conducted in 1983 for 173 hours. The primary objectives accomplished during the test were demonstration of integrated system startup and normal operation, evaluation of facility interface hardware and support instrumentation and control, identification of instrumentation weaknesses (needed for evaluating subsystem performance), and correction of problems that concern the evaluation of subsystem performance.

Regenerative life support system.



Distributed Data Management System

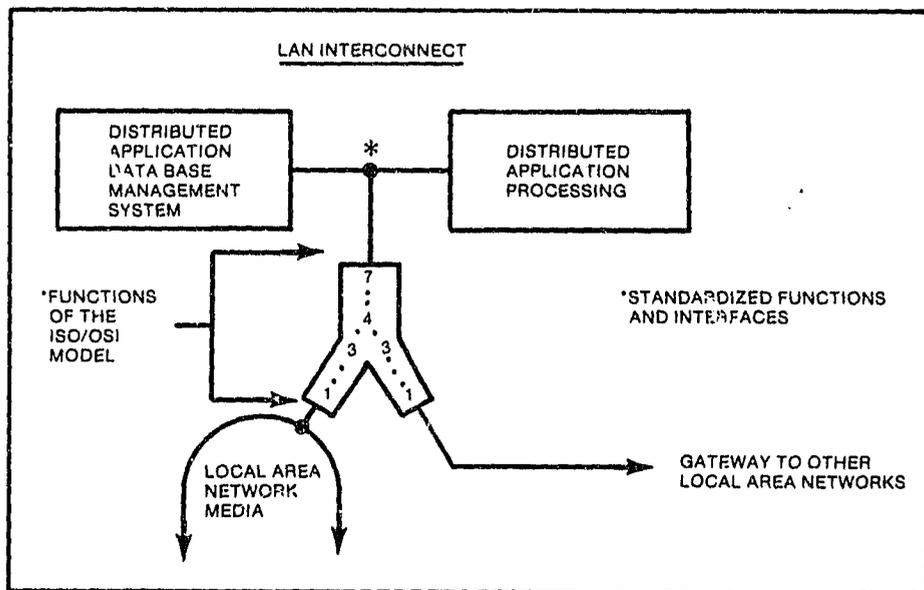
TM: W. L. Swingle/EH
Reference OSF 5

Future manned space programs, such as a space station, reflect an increasing emphasis on automation, remote operations, and system architectures amenable to modular implementation and capable of functional or technological evolution. The data and information management system concepts employed constitute a major factor in realizing these objectives. From the data and information management system viewpoint, design requirements and concepts must acknowledge the total end-to-end environment. This scope reflects a physical and geographical distribution of user entities who may be functionally autonomous but who must be integrated into a cooperative ground and orbital operations scenario involving core subsystem operations, control and monitoring of experiments or payloads, and space operations typified by the servicing of an interorbital transfer vehicle.

The data and information management system concept being pursued employs modularly structured operational entities, such as space station core subsystems or payload operations environments, combined into sets of semiautonomous Local Area Networks. Data exchange and information communications among or within Local Area Networks are accomplished by means of controlled and standardized interface units, which present a user-friendly interface to application processors. Network routing and data source addressing are transparent to the data or information user entities. The concept provides a high degree of automation to accomplish accessing and distribution, and reflects a structured and security-minded organization of distributed data base management entities. The overall approach for design requirements is the International Standard Organization (ISO) reference model for Open Systems Interconnect (OSI). Proof of principle will be demonstrated with a data management system test bed that reflects the Large Area Network concepts illustrated.

A preliminary system concept of a Large Area Network operation has been defined and is being implemented in the data management system test bed. It employs a distributed processing architecture with fiber optic ring network topology, and uses token access methodology. The distributed processing nodes address the function of display/control for user interfacing, environmental control and life support operations, ground network interfacing, and electrical power distribution and control. Connection of processing nodes to the fiber optic network is being implemented with a commercially available Proteon terminal, which supports level 1 of the ISO/OSI model. A systems analysis of level 7 (applications) interface requirements for a standard bus interface unit stipulates four generic services consisting of file access/store management, virtual terminal operations, remote job entry, and distributed data base management. A bubble memory hardware system is available to support the storage media requirement for data base input.

Local Area Network design concept.



Tethered Vehicle Dynamics and Analysis

TM: Milton C. Contella/EH2
Reference OSF 6

The tethered satellite system scheduled to be flown first in 1987 will demonstrate deployment of a tethered subsatellite as far as 100 km from the Space Shuttle to obtain a variety of engineering and science data relative to the Earth's upper atmosphere, magnetic field, and space plasma. As currently planned, demonstration of the tethered subsatellite system will consist of two scientific missions. The first mission will deploy an electrically conductive tether upward from the Earth a distance of approximately 10 to 20 km from the Space Shuttle. For the second flight, the satellite will be refurbished to an atmospheric probe configuration. It will be deployed earthward a distance of 100 km, or at an altitude above the Earth's surface of approximately 130 km. Both missions will involve a deployed satellite operational time of approximately 36 hours.

The potential for safety concerns is apparent when one considers the variety of possible configurations, the complexity of multibody tethered dynamics, the complexity of both the Space Shuttle and the boom/satellite control systems, and the numerous operational constraints associated with deployment, stationkeeping, and retrieval. No analysis tool exists which integrates engineering models of the Space Shuttle and the boom/satellite in one package.

An engineering simulation under construction will be used to address the following implications of tethered satellites to the Space Shuttle.

1. General safety of flight consideration for the Shuttle in the proximity of, or interacting with, a tethered object

2. Interactions between tethered objects and the Shuttle control system during stationkeeping with tethered objects

3. Active use of the Shuttle control system to initiate tethered object deployment and operation

4. Requirements on current Shuttle control system capabilities for conducting the operations

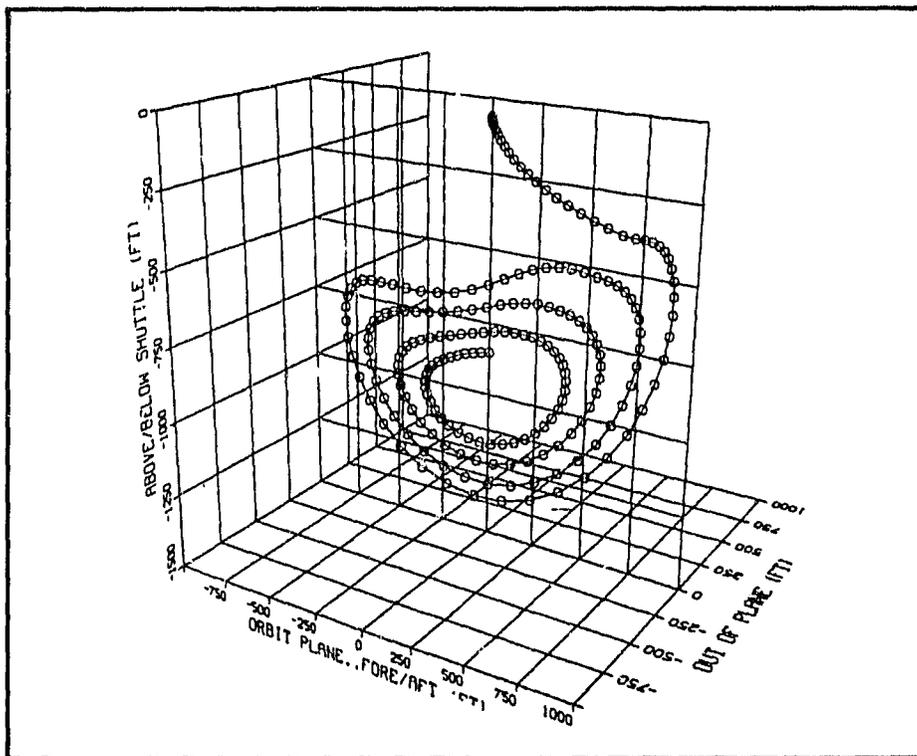
5. Active use of the Shuttle control system to retrieve tethered objects

Since the simulation was a new start, several techniques that had been successfully applied in the past were used. The first is a phased buildup approach using the leader/follower concept in which a simplified (leader) simulation is first created and kept independent of the full capability (follower) simulation. The leader simulation is then used to provide verification/comparison data for the follower simulation as development progresses.

The leader/follower concept is in successful operation. A linearized in-plane (leader) simulation including massless tether, deployment control laws, and drag was created and used to begin initial investigation, and an existing simulation with three degrees of freedom was also modified to the same configuration. The two independent leader simulations were then successfully compared to provide a verification data base for the full six-degree-of-freedom (follower) simulation under construction.

Currently, the overall simulation is organized in 10 libraries with more than 500 individual subroutines, and construction is continuing. The illustration provides a three-dimensional representation of a typical deployment to 1000 ft below the Orbiter. Note the complexity of possible motions. This trajectory was generated by the three-degree-of-freedom "leader" simulation.

Tether deployment to 1000 ft. The model parameters are orbit altitude of 134 n. mi., spherical Earth, Shuttle mass of 200 000 lb, and subsatellite mass of 1100 lb.



Tethered Orbital Refueling

TM: Ken Kroll/EP4
Reference OSF 7

Future orbiting vehicles, such as a space station, satellites, and space-based propulsion stages, will rely on fluid resupply. To provide this function, a fluid facility that can acquire and transfer liquid will be required.

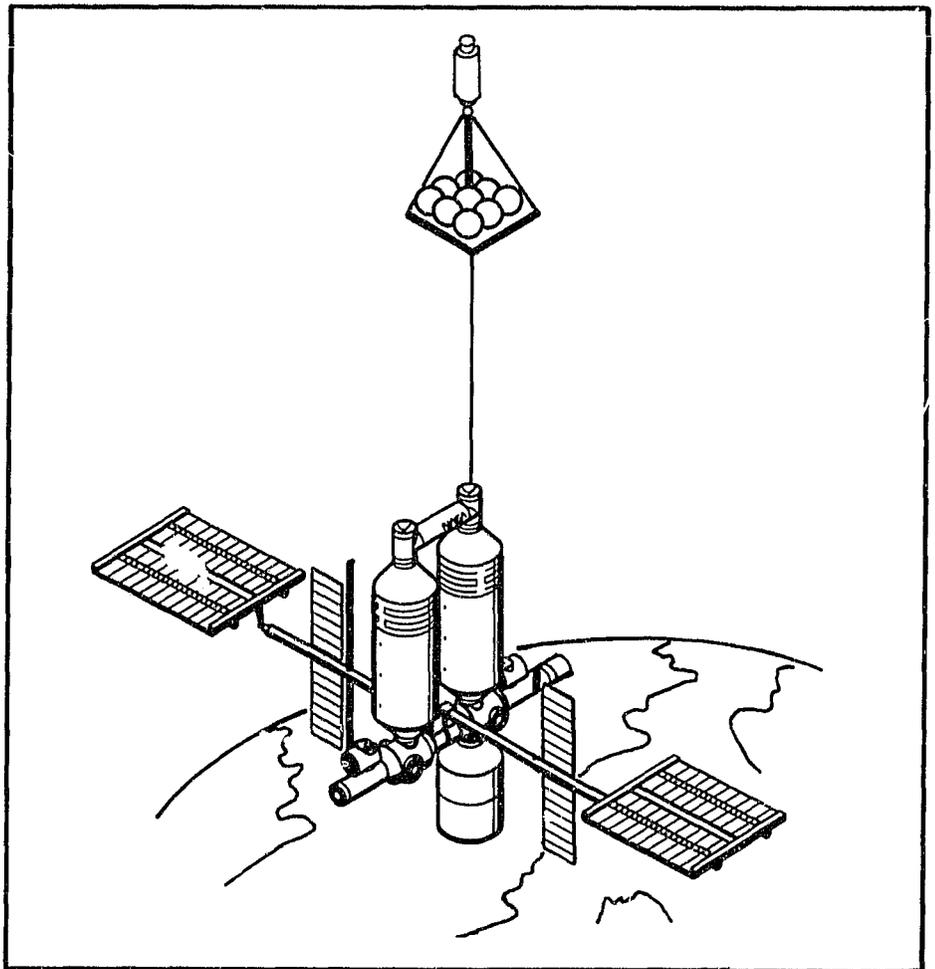
Currently, acquisition techniques such as bladders, surface tension devices, and propulsive settling are used to acquire liquid for transfer. Each of these techniques has limitations for long-term, space-based applications, especially with cryogenic fluids. Bladders, which are made of an elastic material, are frequently incompatible with oxidizers and cryogenics and have leakage problems. Surface tension devices, such as screens and vanes, are ineffective in containing cryogenics because of the low surface tensions, and screens are also sensitive to the vapor that may form within them from the heating of cryogenics. Propellant settling would increase supply requirements and would also create operational control complexity because of orbit changes while settling.

In addition, any nonsettling method of liquid acquisition would prevent the venting of gas. The compression of gas in the receiver tank during transfer could result in a pressure that would stop the fluid transfer.

The orbital environment itself can be used to settle liquid for acquisition by means of gravity-gradient force. This force results because the gravitational and centrifugal forces of an orbiting object only cancel perfectly at the center of gravity (c.g.). The gravity-gradient force is proportional to the distance above or below the c.g. and is directed outward from the c.g. along an Earth radial. At a sufficient distance from the c.g., liquid would settle and position itself toward the ends, where an outlet could be located. This configuration would simplify liquid acquisition and enable the use of conventional transfer techniques, possibly including gravity feed. The gravity-gradient force will stabilize a high length-to-width ratio pointing at the Earth, which also maximizes the force.

A tether is a structurally efficient means of providing long length for greater force and stability. A tethered orbital refueling facility would be one mass attached by tether to another mass, either the space station or an orbiter, with refueling to the desired space system taking place entirely at the refueling facility, not through the tether. A primary candidate would be an orbital transfer vehicle (OTV) refueling facility attached to the space station, as shown.

OTV refueling facility tethered to space station.



Catalytic Recombination on Thermal Protection Material During Reentry

TM: Carl D. Scott/ES3
Reference OSF 8

At reentry speeds, a strong shock wave develops in front of reentry vehicles such as the Shuttle Orbiter or an aerobraking orbit transfer vehicle (AOTV). The shock-layer air between the shock wave and the vehicle is compressed and heated to temperatures high enough to dissociate the oxygen and many of the nitrogen molecules. As this dissociated gas flows along the vehicle surface, it may recombine on the surface of thermal protection materials. This recombination process is exothermic and contributes to the reentry heat flux.

If thermal protection materials inhibit recombination and energy absorption (i.e., they are noncatalytic), a significant reduction in temperature will be achieved, thus saving weight or increasing mission capability. At Orbiter reentry velocity, the dissociation energy is as much as 65% to 70% of the total enthalpy. A noncatalytic material could reject as much as 65% of the incident fully catalytic heat flux, reducing temperatures by as much as 200 K. The dissociation energy for an AOTV could be as much as 75% of the total enthalpy. Actual thermal pro-

tection materials fall somewhere in between noncatalytic and fully catalytic, making it necessary to measure the coefficients to be able to predict the actual Orbiter or AOTV heat flux during reentry and thus to design the optimum thermal protection system or to determine its operational capability.

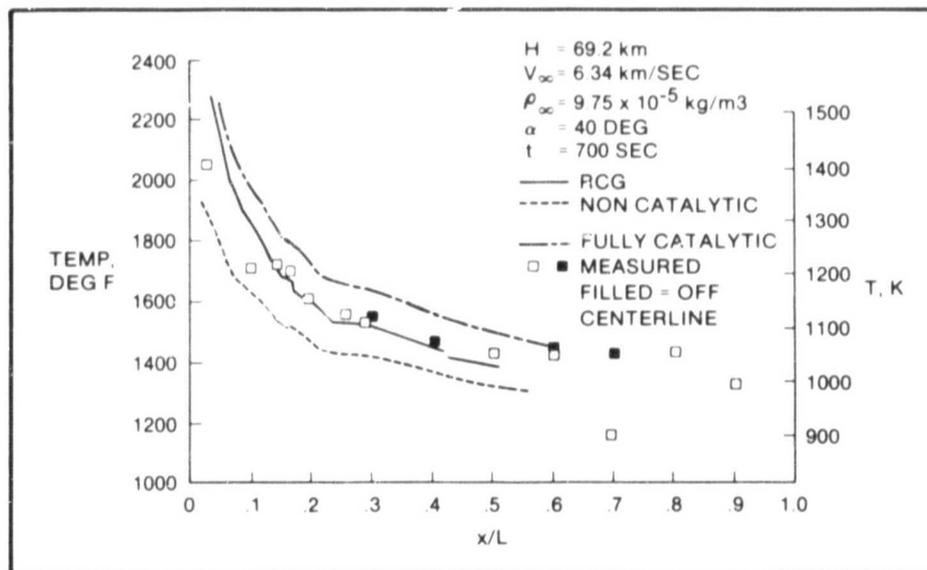
To determine the effects of the atom recombination on the heat flux, it was necessary to measure the oxygen and nitrogen recombination coefficients as functions of surface temperature. These recombination coefficients were then included as boundary conditions for flow-field or boundary-layer calculations to determine the predicted heat flux and resulting material temperature. The recombination coefficients were determined from heat flux measurements on material samples heated in a dissociated arc jet flow. The recombination coefficients were calculated from the measurements using a theoretical model that accounts for catalytic atom recombination in stagnation-point boundary-layer flows.

The prediction of flight heat fluxes and temperatures utilized these experimentally determined coefficients in nonequilibrium chemistry flow-field and boundary-layer computer codes. These codes are simula-

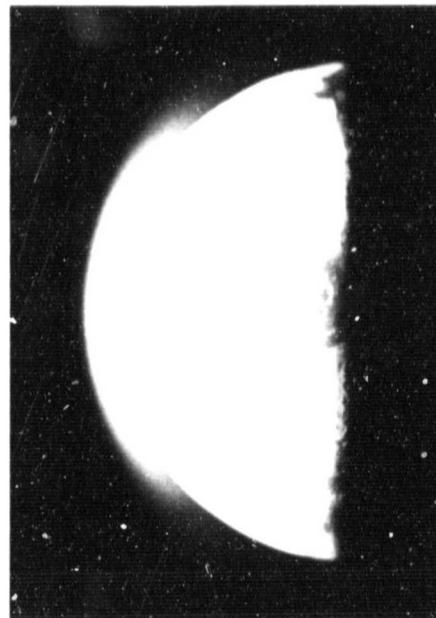
tions of the flow around the Orbiter or the AOTV during reentry and predict the convective and chemical energy flux at various times during the trajectory.

The results of these calculations showed that the Orbiter thermal protection system is not fully catalytic (as was previously assumed) nor is it completely noncatalytic. The agreement of the measured flight temperatures with the predictions is reasonably good but not precise, indicating the possibility of additional phenomena not accounted for in the flow or surface interaction model. However, the agreement is a substantial improvement over previous (fully catalytic) predictions for much of the windward surface of the vehicle. Lower temperatures predicted for the actual thermal protection system permitted greater confidence in the flights and increased the operational capability of the Orbiter. Similar measurements and calculations for an AOTV are necessary, including a refinement of the catalytic model and the nonequilibrium flow simulation codes. The AOTV environment will certainly deviate more significantly from equilibrium than that of the Orbiter since an AOTV has a higher altitude and velocity trajectory.

Measured temperatures compared with calculations for different catalytic recombination coefficients. Reaction-cured glass (RCG) recombination coefficient determined from arc jet measurements.



Arc jet measurement of catalytic recombination coefficient of oxygen on thermal protection material. Flow is from the left.



Aeronautics and Space Technology

Summary

Office of Aeronautics and Space Technology

Summary

The Lyndon B. Johnson Space Center (JSC) plays a significant role in support of the Office of Aeronautics and Space Technology (OAST). This role includes both the conduct of OAST-funded research and technology (R&T) programs and the provision of representatives to the various committees and working groups concerned with technical and programmatic planning. The principal thrusts of the JSC R&T program are in those areas in which its personnel have particular experience and expertise gained through the development and operation of NASA's manned spacecraft program from Project Mercury to the Space Shuttle.

A large portion of the activities in space R&T during fiscal year 1983 was centered on projects focused on developing technological readiness for the anticipated space station program. These activities include work in the areas of communications, crew and life support, energy generation and storage, space mechanisms, thermal management, human factors and man/machine systems, and system automation technology.

Another area of significant JSC support is that of advanced Space Transportation System (STS) R&T. Included are controls and guidance technology, propulsion technology, advanced thermal protection systems technology, and data base automation, plus continuing support to the Orbiter Experiments (OEX) Program, for which JSC provides the overall integration management and program planning.

Complementing the focused projects are activities of a more generic nature that include, in the space technology program, optical processing technology, advanced radar sensor systems, and studies examining the use of extraterrestrial materials. The JSC also has a modest role in the

OAST aeronautics program, which includes work in aircraft fire safety and software system development.

Finally, apart from the formal OAST-sponsored program, JSC responded to a solicitation from the Space Station Task Force to submit proposals for the development of space station system ground test beds. The fundamental intent of the initial test bed program is to provide the "transfer function" for the incorporation of ready and near-ready technologies into the space station development program. Many of these technologies which are to be evaluated in a ground test bed environment are currently under development throughout NASA under the sponsorship of the OAST space R&T program. The JSC offered proposals in the areas of (1) data management, (2) guidance, navigation, and control, (3) environmental control and life support systems, (4) thermal management systems, (5) electrical power systems, (6) communications and tracking, (7) onboard propulsion, (8) space mechanisms, and (9) fluids management. Several of the proposals reflect intercenter agreements in which JSC would cooperate with one or more other NASA centers in the development and operation of the test beds.

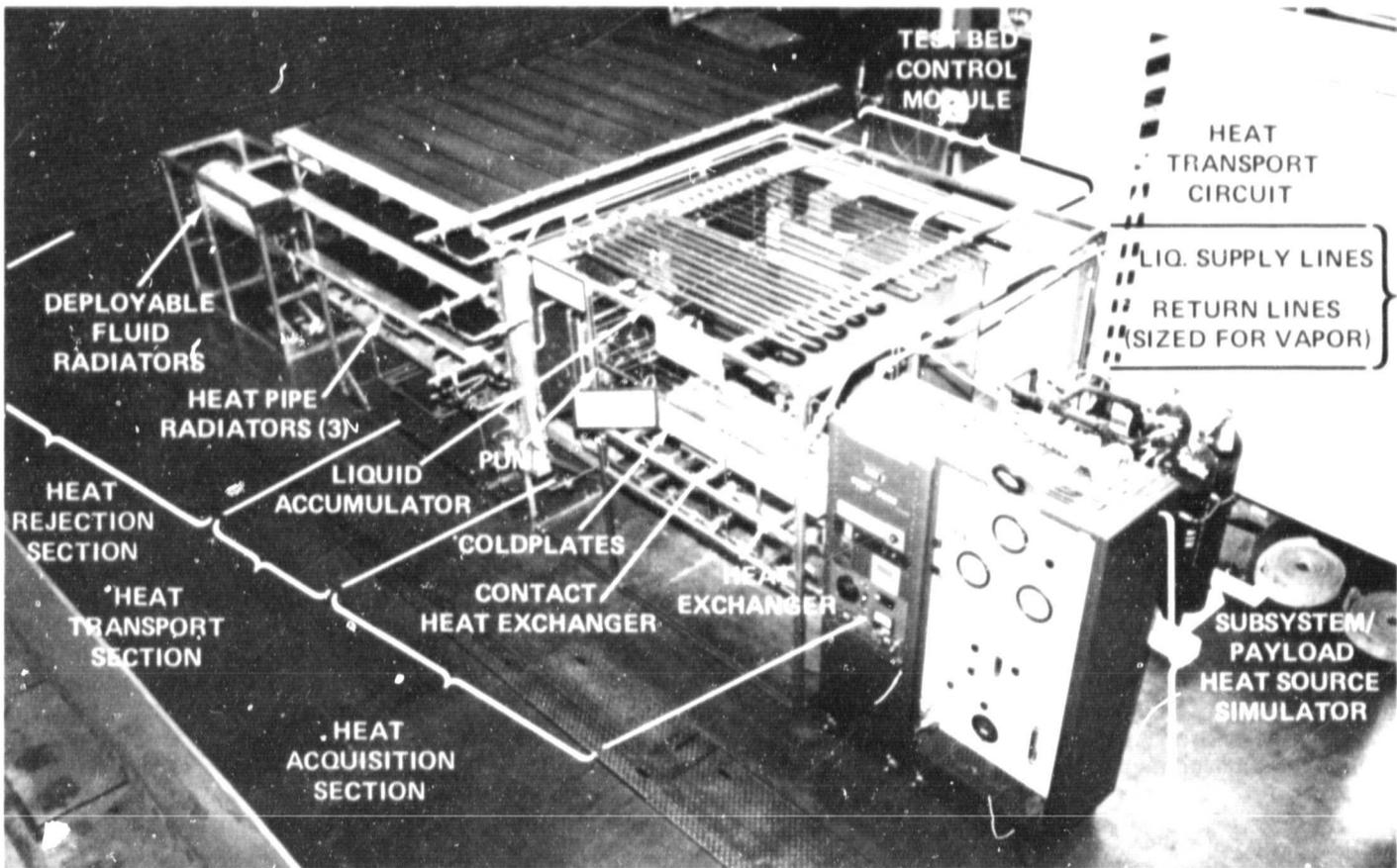
Space Energy Conversion R&T

For the past several years, JSC has been participating in a joint program with the NASA Lewis Research Center in the development of electrochemical energy storage technology. The overall objective of the program is to advance fuel cell and electrolysis cell technologies, to mature and integrate them into a regenerative fuel cell system, and to demonstrate the system for extended low-Earth-orbit mission applications. Maximized efficiency, high energy density, and long

life are the primary technical objectives of the program. The regenerative process, in which the electrolysis cell produces hydrogen and oxygen reactants from the fuel cell product water, offers the potential of a hydrogen/oxygen propellant supply for reaction control/propulsion systems and oxygen for life support needs. The second major area of investigation is thermal management. The objective of this research is to develop the technology for a system with multihundred kilowatt capacity that can operate much like a public utility, i.e., a system which is easily expandable as heat load demands grow and one in which a customer (heat source) can be integrated into any point in the system without the necessity of redesign or reconfiguration. This system requires advanced concepts in heat collection, transport, and rejection. Key technologies are the development of a two-phase, constant-temperature heat transport bus with contact heat exchangers and modular space-constructable heat pipe radiators. A photograph of developmental hardware under test at JSC is shown. The laboratory system, when fully configured, will allow comparative evaluation testing of advanced heat pipe concepts with conventional fluid-pumped systems. The JSC is developing both the regenerative fuel cell and thermal management technologies as part of its space-station-focused program. The interrelationship between these system technologies is illustrated.

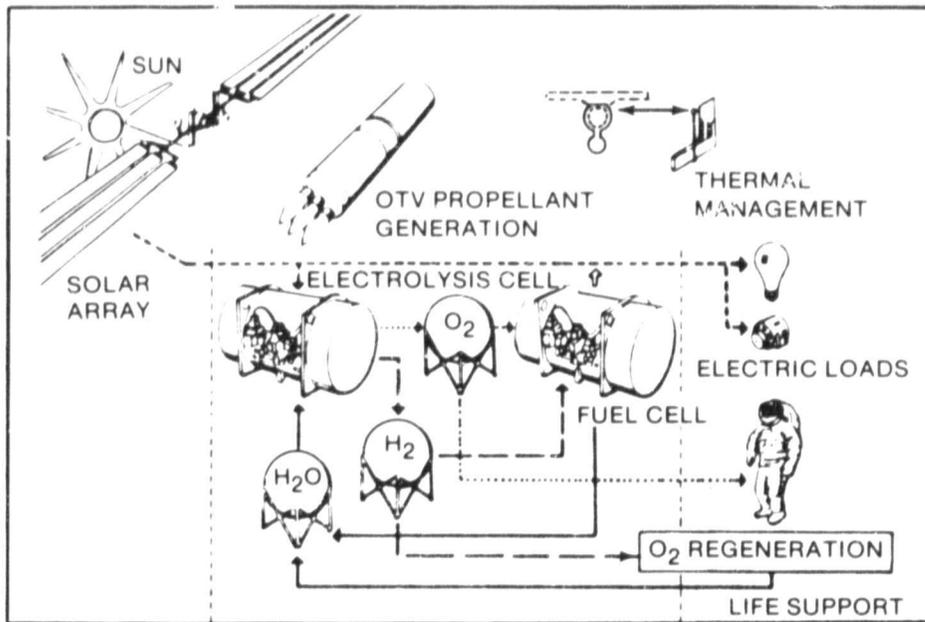
Transportation Systems R&T

The OEX Program is JSC's major activity in STS R&T. The program was initiated jointly by OAST and JSC to use the Space Shuttle as a flight research vehicle for the acquisition of information in the various technology disciplines that will augment the R&T



Two-phase thermal management system test bed.

Integrated orbital energy system.

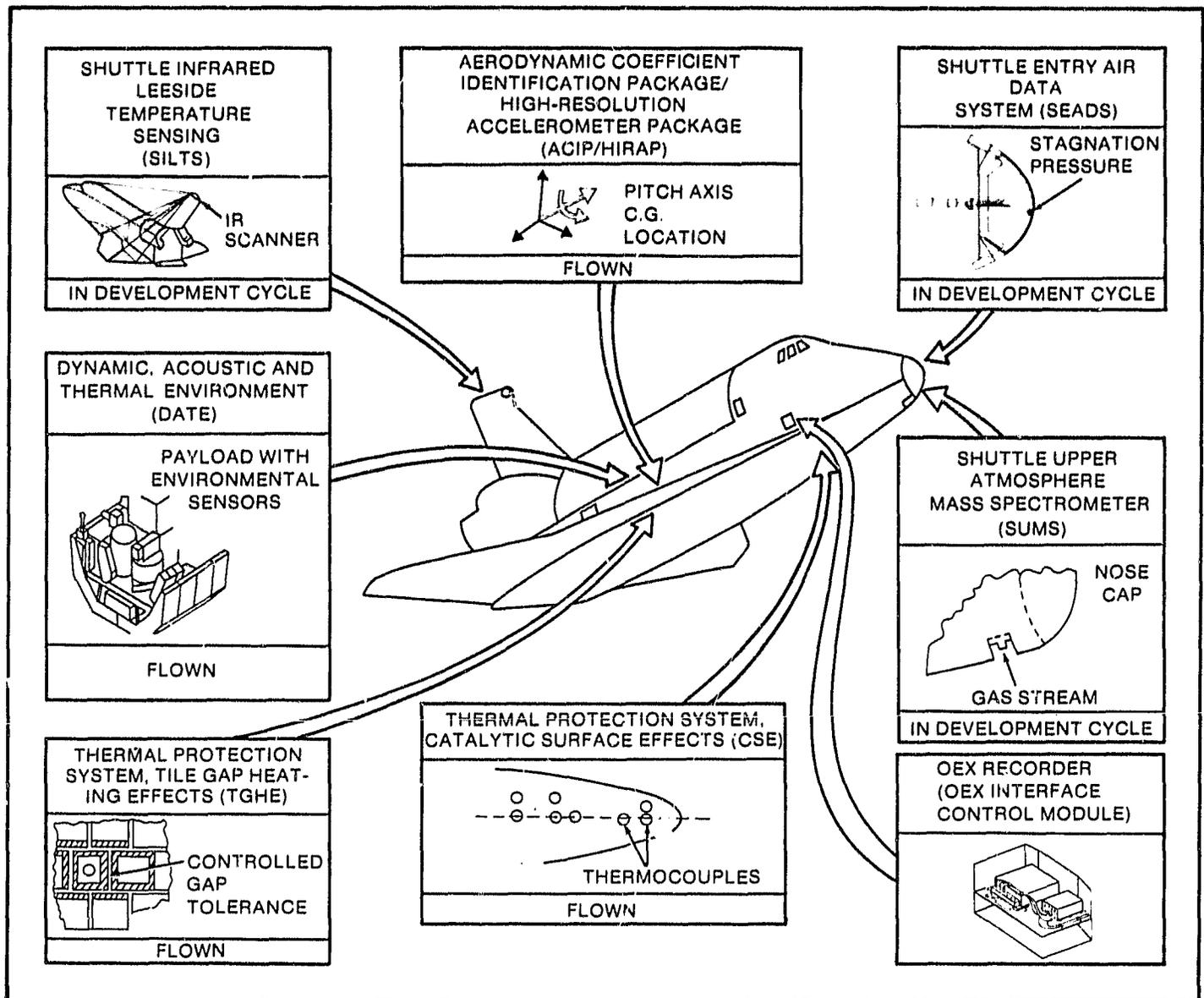


base for future space vehicle design. The OEX Program, which is NASA-wide, is structured to support tech-

nologists at the various NASA centers in developing flight experiments relevant to their research. In all, there are

some 13 approved OEX experiments. Five have been flown to date. Seven of the approved experiments that are designed to collect data on environments, aerodynamic/aerothermodynamic phenomena, and thermal protection systems are shown. Of these, ACIP/HIRAP, CSE, TGHE, and DATE have been flown. The fifth experiment flown (not shown on the figure) is Infrared Imagery of Shuttle (IRIS).

Johnson Space Center personnel also act as experimenters in the OEX Program. The ACIP is a JSC-sponsored experiment as is the Advanced OEX Autopilot, which is described later in this report. The JSC's principal function, however, is to provide overall management and planning support to OAST and to accomplish experiment/Orbiter compatibility assessments and management of the experiments into the vehicle. Considerable effort is also expended in the design and development of unique experiment components such



Orbiter Experiments Program.

as the SILTS tail pod and in the development of the data handling and recording system that is common to many of the OEX experiments.

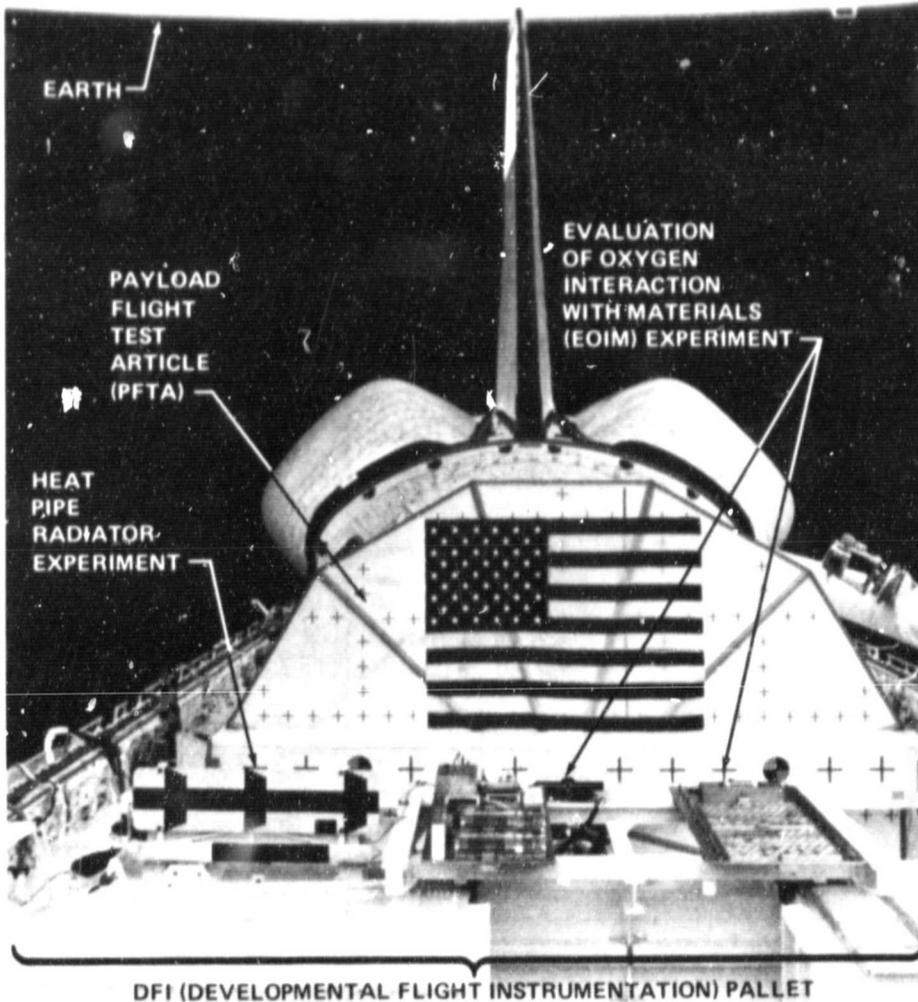
The STS R&T program has also sponsored an activity investigating the technology of automated flight operations data base management. Using the actual Space Shuttle mission planning and operations at JSC, the project will develop and demonstrate an automation architecture that integrates the various functions required for total mission planning and control.

JSC Flight Experiments

The OEX-sponsored ACIP has been flown on STS-1 and all subsequent flights. On STS-5, the additional HIRAP instruments (sponsored by the Langley Research Center) were added to ACIP to provide the sensitivity necessary to measure deceleration in the free-molecular-flow regimes. The ACIP/HIRAP will be flown on all flights through STS-20.

Two additional JSC-sponsored experiments from other OAST programs

were flown this year. An experiment titled Evaluation of Oxygen Interaction with Materials was flown on STS-5 and is discussed in a later section. In cooperation with other NASA centers, an updated package with more sophisticated sensors was flown on STS-8. A Heat Pipe Radiator Experiment was flown on STS-8 to validate zero-g operation of an advanced heat transport concept. These experiments are shown mounted in the vehicle.



STS-8 payload bay scene.

Platform Systems R&T

The two major activities in the platform systems R&T are concerned with the development of space station technology in two diverse areas: construction/docking systems and crew and life support systems. In the former area, the investigation is concerned with the technology development of mechanisms and apparatus for spacecraft berthing and docking, assembly of large structures, and handling of large payloads. This area includes microprocessor-controlled "smart mechanisms," which will be required to perform a variety of functions in a space station system. Current emphasis has been on the development of soft docking (nonimpact) system con-

cepts which would have potential application as the mechanical interconnect between space station modules and/or vehicles such as the space station and the Orbiter or the space station and the upper stage. The crew and life support work is concerned with the technology for regenerative life support systems. Regeneration refers to the collection, processing, and recovery of the constituents in the air and water systems such that they operate in a "closed-loop" fashion and thereby minimize consumable resupply weight and costs. The OAST-sponsored research has been concentrated on the subsystem technology needed for carbon dioxide removal and instrumentation subsystems re-

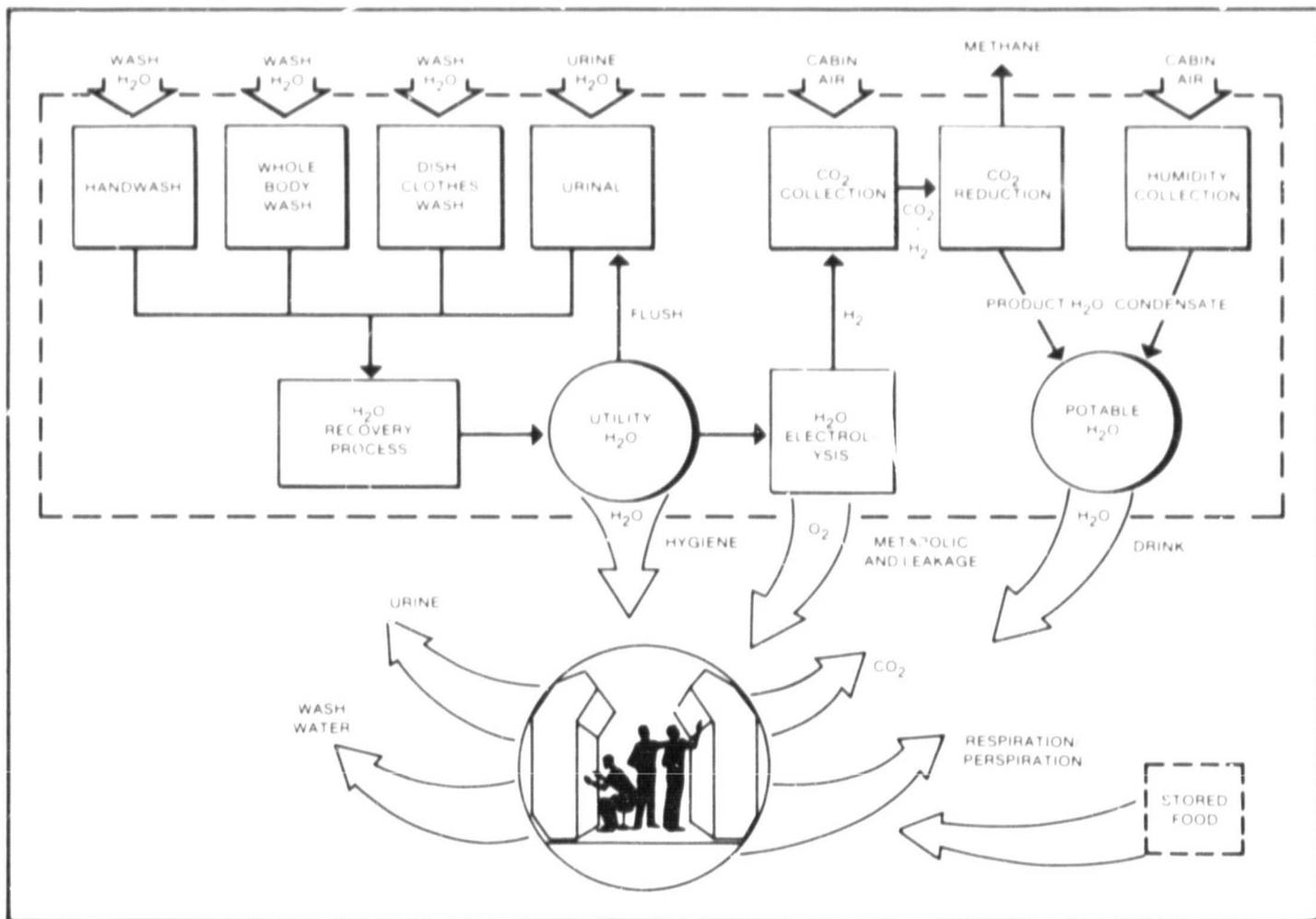
quired to monitor oxygen and water to ensure that safe atmospheric and water quantity standards are maintained in the habitable volumes. This area has also been supported by the Office of Space Flight Advanced Programs Office for several years. Portions have also been funded by the Office of Space Sciences and Applications in prior years. An environmental control and life support system as envisioned for a fully operational space station is shown schematically.

Controls and Human Factors R&T

Various tasks are being pursued in both controls and human factors research. The primary objective of the controls work is to develop and assess guidance and control concepts and techniques to provide needed capabilities for the full use of current and future space transportation systems. Activities include the development of a methodology for Orbiter on-orbit control envelope expansion to permit the accommodation of large payloads and structures appended to the vehicle. Software development methodologies are being examined, with emphasis on flight-critical guidance and control system functions, which offer promise of significant cost savings by interactively coupling the software development with the system hardware development.

Human factors research is concerned with the development of technologies that will lead to an increase in the effectiveness of man-machine interactions in space. A substantial part of this effort is in developing methods and techniques to provide the data necessary to ensure design integration of the human with the machine systems. Techniques for modeling human movement and strength capability being developed for eventual inclusion in automated crew station design programs are described in a later section of this report. Another key design parameter is the size and shape of astronauts. In conjunction with the U.S. Air Force, a noncontact measurement method based on laser mapping is being researched. A model of a suited astronaut illuminated with the laser system is shown. Three-dimensional position information for each element of the surface, which appears gridded, is digitized and stored for later retrieval and combination into

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OF POOR QUALITY



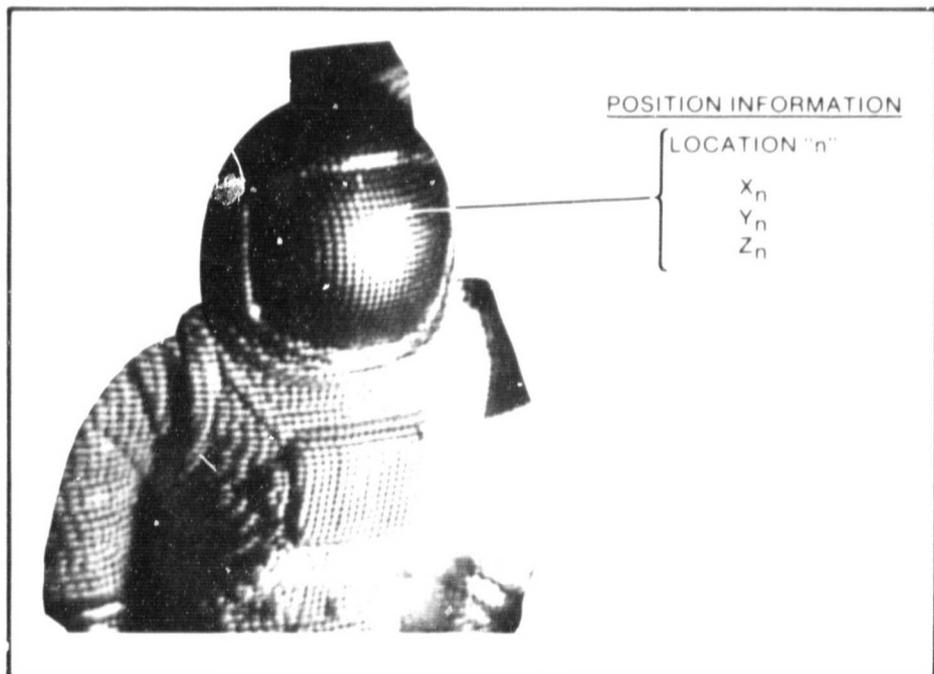
Regenerative life support system.

Laser anthropometric mapping.

a complete three-dimensional profile. Crew-related hardware technology is also a part of this program and includes the development of a generic work station and a helmet-mounted "heads-up display" to assist astronauts in the performance of extravehicular activity tasks.

Computer Science and Electronics R&T

In fiscal year 1983, two new programs were initiated in computer science and electronics R&T. Optical processing, or programmable mask technology, is being explored for a number of NASA applications such as pattern recognition, communication and radar signal processing, robotic vision, and voice recognition. Also in this year, a program investigating the technology of spacecraft system automation was started. It is described in a later section.



Research in multifunction synthetic aperture technology, a cooperative program with the Jet Propulsion Laboratory and the Department of Defense, has been underway at JSC for several years. The goal is to develop a low-cost active sensor with at least a two-fold increase in capability over current single-frequency systems that is capable of frequency variation, multipolarization, and extremely high resolution for a wide range of radar mapping missions.

Space Data and Communications R&T

The single active JSC program in space data and communications R&T is a space-station-focused activity in communications system technology. Initiated in fiscal year 1983, it is aimed at ensuring, from a total systems standpoint, that the communication and tracking system will be in the proper state of technological readiness for the space station program. Technical target areas include advanced radiofrequency equipment, ranging/tracking systems, and intervehicular communications systems. In the program, extensive breadboard system testing will be performed in the JSC Electronic Systems Test Laboratory to provide total end-to-end system performance evaluation including interfaces with relay satellites, ground stations, and other space vehicles.

Materials and Structures R&T

Future space activities may benefit from the exploitation of nonterrestrial resources. Lunar resources are of particular current interest. Two special sessions entitled *Return to the Moon* and *The Future Lunar Program* highlighted the XIV Lunar and Planetary Science Conference in 1983. Dr. Hans Mark, NASA Deputy Administrator, keynoted the first of these sessions symbolizing the importance of lunar resources to future NASA programs in solar system exploration and development. Specifically, lunar materials can be processed as a source of oxygen for fuel and of structural materials for lunar base applications, for interorbital space industrial operations, and for solar system exploration and development.

The JSC is pursuing research in chemical and physical processes for

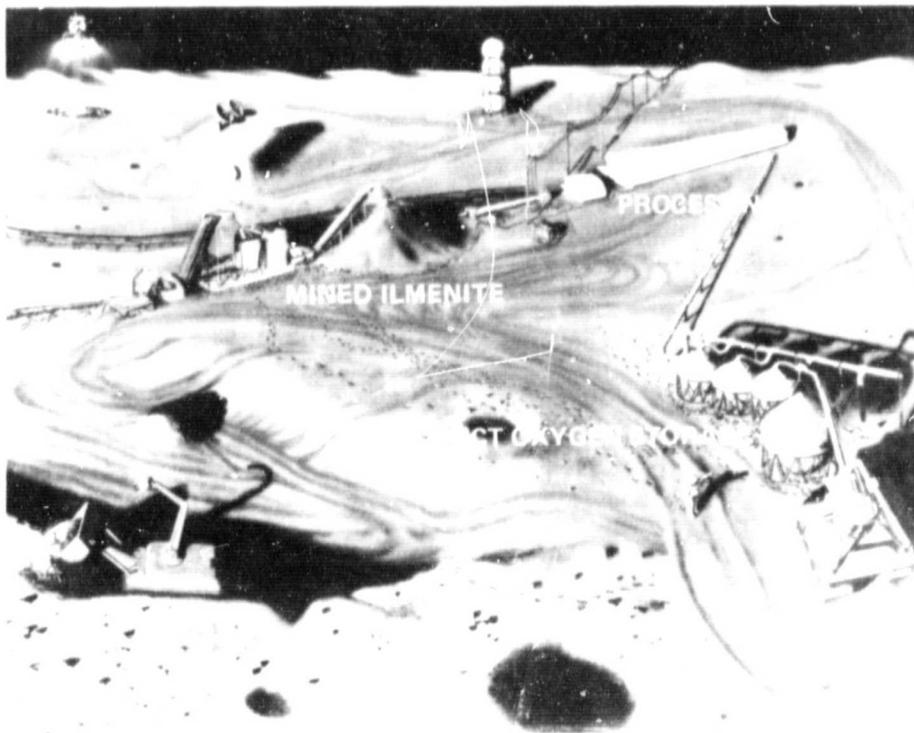
the extraction of usable quantities of materials from lunar rocks and soils. An artist's concept of a Moon-based oxygen production facility is shown. The oxygen, processed from ilmenite, is returned to low Earth orbit for use as a fuel in chemically propelled orbit transfer vehicles. Analyses indicate that, because of the Moon's low gravity, this technique could potentially be less costly than transporting the fuel from the Earth's surface.

Other JSC programs in materials and structures R&T have more immediate applications, i.e., investigating the effects of hypervelocity impacts on composite materials and developing an advanced carbon-carbon thermal protection system for the Space Shuttle and future reentry vehicles. The motivation for the first program is the real problem of micrometeorite and space debris impacts on space vehicles such as a space station. Very little is known about impact resistance of composites which are being used increasingly in space systems. Development of the thermal protection system, which is being investigated for a specific Space Shuttle application, is described in a later section.

Chemical Propulsion R&T

The Space Shuttle uses a propellant combination of nitrogen tetroxide and monomethyl hydrazine (NTO/MMH). However, health hazards, corrosive effects, and increasing costs associated with NTO/MMH make long-term use of this propellant combination undesirable. Studies have indicated that oxygen-hydrocarbon propellants offer a potentially attractive alternative to NTO/MMH for future Space Shuttles or other new orbital systems requiring propellants for attitude control and translational maneuvering. The objective of the JSC activity is to establish the technology base for such new propellant systems to minimize the development risks to future space system development programs that choose not to use NTO/MMH. In fiscal year 1983, a liquid oxygen/hydrocarbon auxiliary propulsion system study was completed as was combustion characterization of these types of propellants. Future activities are required in critical component technology development and test evaluation to firmly establish the technology base.

Lunar surface oxygen production facility.



Aeronautical Programs

The JSC has a modest continuing activity in support of aircraft fire safety research. The principal effort is in the development and evaluation of light-weight, fire-retardant, low smoke emitting, thermally stable nonmetallic materials for the interior of aircraft and spacecraft. This program has resulted in fabrication of a variety of secondary structures such as aircraft floor and wall panels using newly developed materials. These materials have been subjected to flammability testing both at JSC and at Federal Aviation Administration test facilities. Prototypes of these secondary structures also have been installed in commercial aircraft and are undergoing flight evaluation.

Also in fiscal year 1983, a software activity was initiated to support the HAL/S Language Definition and User Coordination Group (also referred to as the NASA HAL/S Board). This board was established in 1977 to provide language control for the standard HAL/S (high order assembly language for Shuttle flight computer) compiler, tools, and documentation. The JSC involvement stems from the fact that the Space Shuttle is the largest HAL/S user in terms of both programmers and lines of code. The JSC program is developing interactive debugger software and a common compiler design intended to provide software standardization for all users and to significantly increase programming efficiency.

Aeronautics and Space Technology

Significant Tasks

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Low-Earth-Orbit Energy Storage Using Regenerative Fuel Cells

TM: J. Dale Denals/EP5
Reference OAST 1

The placement of a manned space station in low Earth orbit is being pursued by NASA as "the next logical step in manned space flight." This concept will require multikilowatts of electrical power to perform routine orbital operations and such specialized functions as satellite servicing, space construction, and materials manufacturing.

In the past, all U.S. manned space programs except Mercury and Skylab have used fuel cells because of their superior flexibility, weight, and cost factors. Fuel cells are the most viable power system candidates for short-term missions. However, the space station will require multiyear continuous power in an alternating "daylight/nighttime" environment. Solar panels are an obvious solution to the daytime power requirements, and batteries have been the power source for nighttime conditions.

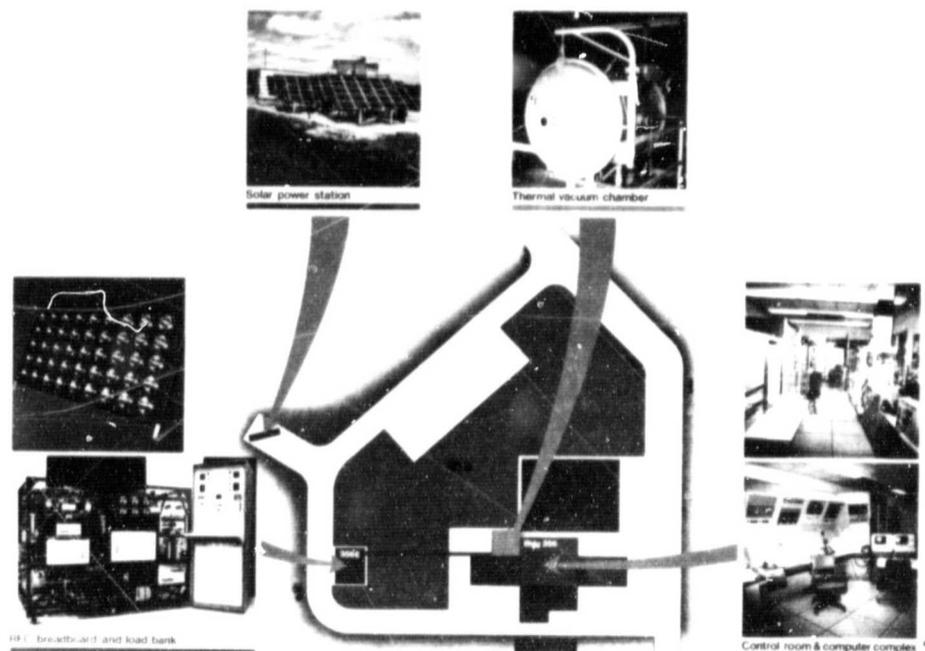
An alternate means of storing energy for nighttime low-Earth-orbit operation is being pursued. This approach consists of using a fuel cell that produces power and water during the dark side of the orbit combined with an electrolysis system that produces hydrogen and oxygen from the product water using solar-array-produced power on the light side of the orbit. These stored reactants are then reused by the fuel cell. This concept is called a regenerative fuel cell system. The approach of using regenerative fuel cells as an energy storage system is not only feasible but also practical and advantageous in many areas. The advantages it offers include high efficiency, low weight, potential for long life, good emergency capability, potential for weight-saving by integration with other subsystems, and the inherent capability to take advantage of reactant residuals from the Space Shuttle on its visits to the space station.

A joint effort between the NASA Lewis Research Center and Johnson Space Center (JSC) is presently underway to develop the technology of both the solid polymer electrolyte (acidic) and the capillary matrix (alkaline) regenerative fuel cells. These two technologies continue to be evaluated and compared by performing breadboard tests at JSC.

The solid polymer electrolyte breadboard system was delivered to JSC in February 1983 and was placed in simulated testing on May 6, 1983. The integration of this breadboard system with a 1.5-kW solar power station, a load bank, and a control and computer room is illustrated. More than 1000 simulated orbital cycles have been accumulated on this regenerative fuel cell breadboard as of September 21, 1983. This value represents more than 60 days of Earth-orbit operation without failure or shutdown caused by the electrolysis of fuel cell modules. The shutdowns and failures that have occurred are attributable to the use of "breadboard" components and the initiation of a new test facility.

Experience has shown that the solar power station can be connected to the electrolysis system directly with no power conditioning, a demonstration of the flexibility of the electrolysis system in handling a varying power input. Preliminary data show no measurable water loss, an indication that little or no makeup water will be required for multiyear operation in space. Test data have also verified that a 55% efficient energy in/energy out cycle is achievable with existing technology and proper operating parameters. A continuation of this testing will reveal additional information beyond the "demonstration of concept" phase.

Regenerative Fuel Cell Test Facility.



Thermal Management for On-Orbit Energy Systems

TM: J. Gary Rankin/EC2
Reference OAST 2

Manned or unmanned space platforms projected for the 1990's and beyond may produce electrical power levels of several hundred kilowatts. Efficient thermal management is mandatory because generation, transfer, and storage of the electrical energy needed for these applications will require the dissipation of huge quantities of waste heat. No low-cost, reliable orbital thermal management system capable of providing this level of heat rejection exists. Such a system would need to overcome limitations inherent in current system designs. Ways to increase energy capacity, reject waste heat, and provide power for a broad range of space applications are requiring an entirely new technical effort in thermal management.

The key to the thermal management concept lies in the creation of a thermal "utility" system, analogous to municipal public utilities, where basic "trunk" lines are provided and into which individual customers can be integrated. The system must be designed so changes in location or load of individual customers have minimal effect on the utility's capability to serve loads of the remaining customers. Such a centralized system would allow reduced operational and payload integration costs, as well as reduced cost for all payload users, by having common instrument thermal designs. Keys to reduction in thermal management system costs are system modularity; subsystems integration; stepwise growth capability to very large satellites; volume and weight reduction; extended life by maintenance/replacement; and expansion of the thermal management technology base to provide simpler, more reliable systems.

To accomplish these goals, development has begun on several concepts involving two-phase (gas/liquid) heat transport devices. A centralized, pump-assisted two-phase heat transport loop (or "thermal bus") would transfer heat by evaporation and condensation of the working fluid rather than by sensible heat changes of a single-phase cooling fluid. This loop

would operate at an almost constant temperature over its entire length, making users insensitive to their order of placement around the loop. Such a thermal bus would also be capable of transporting large thermal loads over long distances with pumping requirements that are very small compared to single-phase systems.

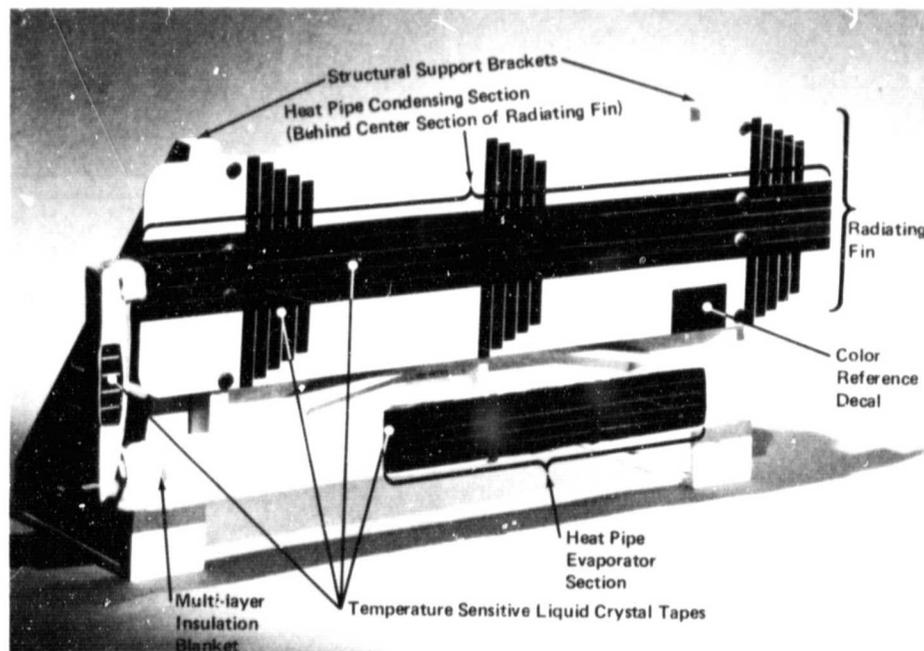
A space-constructable radiator system, the keystone of which is an innovative high-capacity heat pipe, will enable building heat-rejection systems to virtually any desired size (heat load capability) using a relatively small number of components. Large heat pipes with radiator fins attached would be "plugged in" to contact heat exchangers that provide heat from the centralized thermal bus. Such a system would be relatively insensitive to micrometeoroids or debris as the puncture of any pipe would cause only the loss of its 2-kW capability. This system could be maintained by simple replacement of elements.

During fiscal year 1983, the thermal bus subsystem concept study was completed. A baseline system that contains capillary wicked coldplates/heat exchangers plumbed in parallel was selected. A liquid pump provides the small pressure head necessary for circulation, and passive, self-contained valves modulate the liquid

supply to each heat exchanger. Detailed design, component testing, and prototype subsystem hardware fabrication are planned for fiscal year 1984.

Fabrication of full-size (50 ft long) space-constructable radiator prototype hardware elements was begun in late fiscal year 1983, with thermal vacuum testing of two units scheduled for early fiscal year 1984. The cancellation of the TDRSS-B satellite as the payload for the STS-2 mission provided a unique opportunity to demonstrate on-orbit operation of the high-capacity monogroove heat pipe used in the space-constructable radiator subsystem. A flight experiment was conceived, designed, fabricated, tested, integrated with a payload carrier, and installed in the Orbiter *Challenger's* payload bay in less than 4 months and successfully operated in flight on STS-8. Still color photographs and direct crew visual observation of color changes in a pattern of temperature-sensitive liquid crystal tapes provided the temperature data necessary to verify successful on-orbit startup and orbital transient response of the heat pipe when subjected to a heat load from its attached electrical heaters. This on-orbit demonstration verified analytical design tools and provided confidence in the use of high-capacity heat pipes for future space applications.

STS-8 Heat Pipe Radiator Experiment.



Atomic Oxygen Interaction Studies

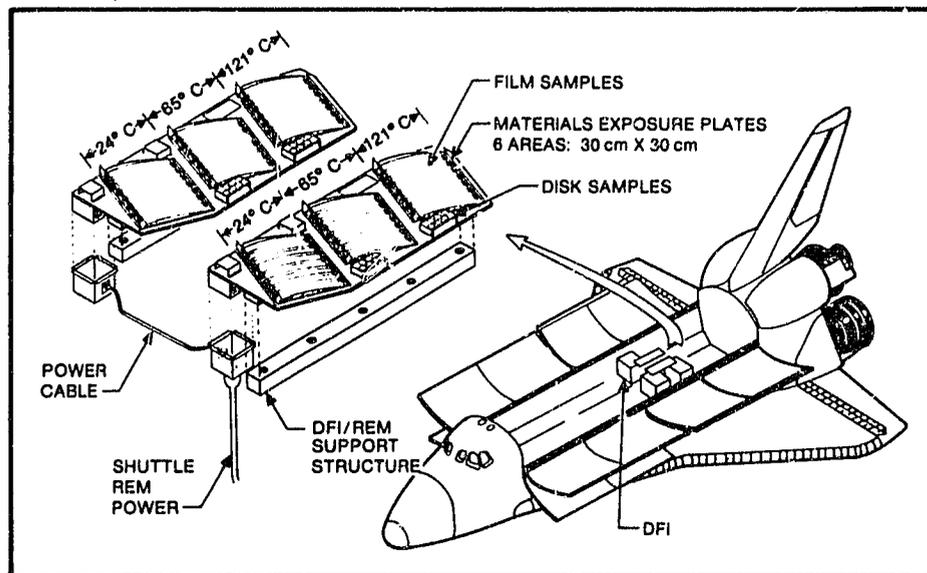
TM: Lubert J. Leger/ES5
TM: James T. Visentino/ES5
Reference OAST 3

Flight tests were conducted during the STS-5 mission to evaluate the interaction of atomic oxygen with advanced space-flight materials proposed for the Orbiter, the Space Telescope, and the NASA tethered satellite program. Laboratory studies have shown that atomic oxygen within the low-Earth-orbital ambient environment is extremely reactive when impinging on solid surfaces. At orbital altitudes, chemical changes can occur for spacecraft materials which alter optical and electrical properties and remove layers of material. If the atoms impinge with kinetic energy of orbital velocity (approximately 5 eV for atomic oxygen), chemical reactions are accelerated and the mass loss for many materials becomes more pronounced.

Material specimens were provided by several NASA centers and aerospace contractors for evaluation within an atomic oxygen environment at a nominal Orbiter altitude of 160 n. mi. for approximately 44 hours. These specimens were integrated into a flight package and mounted on experiment trays attached to a payload carrier within the Orbiter bay. Each experiment tray included two disk sampleholders and three heater plates onto which horizontal and inclined thin-film specimens were mounted. The heater plates were thermostatically controlled to three temperatures (24°, 65°, and 121° C) and were activated by the crew at the beginning of side-Sun exposure and turned off at the end of this exposure. The heaters were rotated 20° relative to the Orbiter axis to enable the velocity vector, and therefore the oxygen impingement angle, to sweep across the width of the heaters and expose the samples uniformly.

Laboratory tests conducted on these specimens after completion of atomic oxygen exposure revealed significant mass erosion for Mylar, Tedlar, and Kapton films; conversion of conductive silver (used in electrical connections) to its nonconductive oxide; and complete loss of osmium (a material used to coat far-ultraviolet optics for advanced astronomical spacecraft) from its nonreactive substrates. Scanning electron microscope examinations showed significant surface morphology changes after exposure to the atomic oxygen environment. Materials such as Teflon were not as susceptible to atomic oxygen reaction as nonfluorinated materials, such as Kapton and Mylar. The reaction rates for these materials appear to be non-temperature-dependent over a temperature range of 24° to 121° C, probably because of the high kinetic energy (5 eV) of the oxygen atoms. The average reaction efficiencies for Kapton, Mylar, and Tedlar were determined from this flight experiment to be 2.1×10^{-24} , 1.8×10^{-24} , and 1.3×10^{-24} cm³/atom, respectively. The results of these studies are being assessed, and methods (or techniques) to retard the oxidation processes are being proposed. An updated package was flown on STS-8. The results are being analyzed and will be described in a future report. Follow-on experiments are planned with objectives of obtaining quantitative rates for a larger number of materials, evaluating the reactivity of additional metal surfaces, and evaluating protective techniques.

STS-5 experiment tray configuration.



Construction/Docking Technology

TM: William K. Creasy/ET5
Reference OAST 4

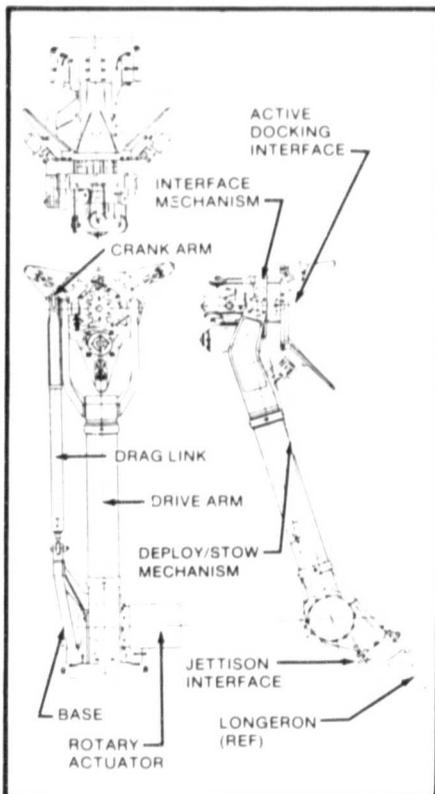
Future space activities will require a broad capability for docking and berthing many types and sizes of spacecraft, space structures, and payloads. Planned adjuncts to the STS system include a range of massive spacecraft, large, relatively fragile structures, and sensitive scientific platforms that will require very low energy docking and berthing. These linkups will be required for functions such as assembly of large structures, crew and equipment transfer, inspection, and servicing. To accomplish these objectives, the need exists to identify component technology needs and design drivers, and to validate component and system design through development tests.

The general approach to this task includes requirements definition, concept design, analysis, and prototype testing. Future program requirements are used to define design requirements as an ongoing activity. Based on these requirements, concept designs are performed with detailed design of selected prototypes. Parametric trade studies are performed to refine designs and to identify design drivers. Component technology efforts in the area of microcomputer-controlled actuator/attenuator devices include component prototyping and testing. As required, full-scale developmental systems are fabricated and "proof-of-concept" ground tests performed. The handling and positioning aid illustrated is an example of the type of hardware system developed using this approach. The device was designed to hold a satellite or structure in a safe and stable position near the Orbiter for construction or servicing. The concept was developed by analyzing a variety of potential construction and servicing missions to determine the size, degrees of articulation, etc., required. The development test article shown was then constructed to functionally represent a flight unit. The development test article is to be delivered to Johnson Space Center for proof of concept in the Manipulator Development Facility.

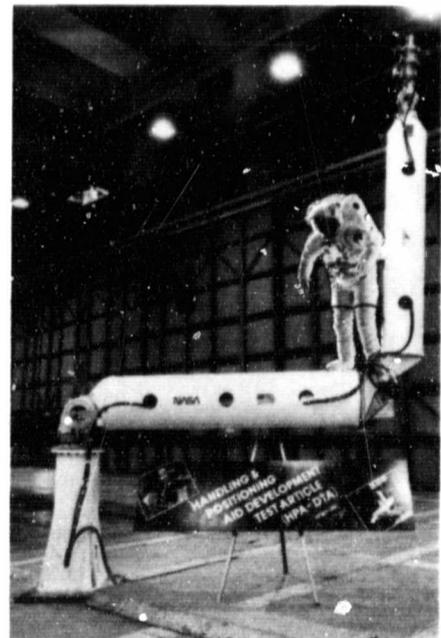
The payload installation and deployment aid concept design illustrated was developed as part of the construction/docking technology program. Its function is to move payloads through a described path between the confined volume of the Orbiter payload bay and a position outside the bay. The docking interface mechanism on the payload installation and deployment aid will serve as a small port docking system—one of a class of docking/berthing devices under development. The docking system development hardware is being fabricated and will be available for testing in fiscal year 1984.

Also this fiscal year, significant progress has been made in the design, analysis, and component development areas. The design of a large port docking system with crew transfer capability as would be required for a space station has been started. The analysis capability to parametrically study the docking dynamics of this particular configuration is available. For the next fiscal year, extensive parametric studies are planned. In the area of component development, a prototype electromechanical actuator/attenuator is being acquired for incorporation in the ground test article.

Payload installation and deployment aid.



Handling and positioning aid development test article.



Atmospheric Carbon Dioxide Removal

TM: Robert J. Cusick/EC3
Reference OAST 5

In the environmental atmosphere of any closed spacecraft, the respiratory carbon dioxide (CO₂) exhaled by the crew must be removed from the air to avoid a buildup to toxic levels. Prolonged exposure to CO₂ concentrations in air of less than about 4 mm Hg will not cause any biochemical or other effects on the crew. A typical Space Shuttle flight with five crewmembers maintains a nominal CO₂ level of 3 to 4 mm Hg. Concentration moderately above this level may cause adaptive biochemical changes perceived as a mild physiological strain. If the concentration is allowed to increase to between 11 and 23 mm Hg, the reactions are progressively distracting discomfort, dizziness, and possibly eventual stupor and unconsciousness. A CO₂ removal device to maintain the spacecraft atmosphere in a safe condition is mandatory for all manned space applications.

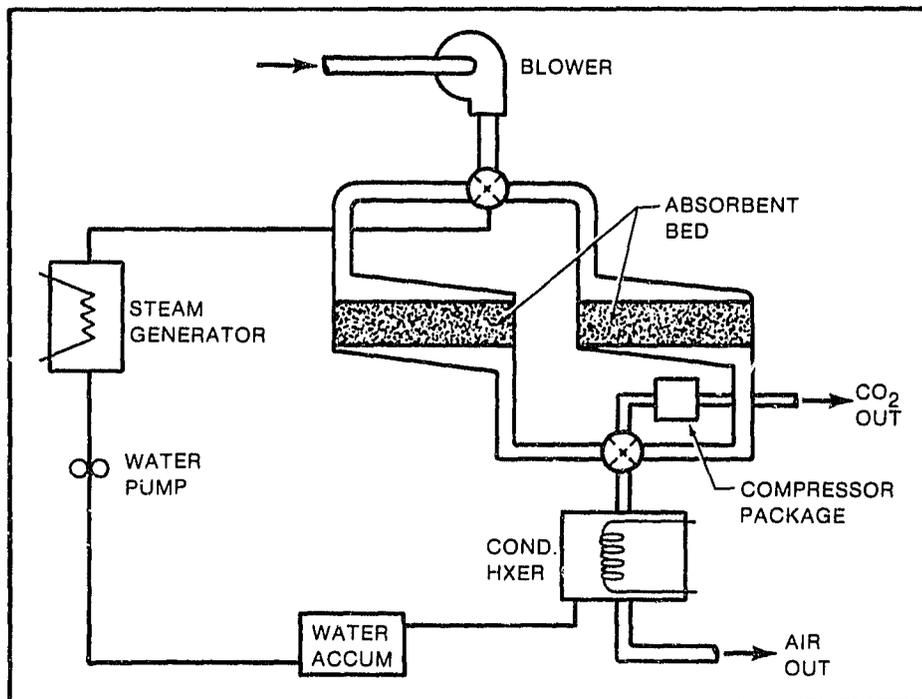
Two fundamentally different approaches to CO₂ removal have been used in previous U.S. manned space flights. The primary approach, and that used on the Space Shuttle, employs an expendable, solid, lithium hydroxide (LiOH) chemical packed into a cartridge. The longer term Skylab missions employed a regenerable molecular sieve system to remove the CO₂ and desorb to the vacuum of space. The Skylab molecular sieve system has a weight advantage over the LiOH canister system for mission durations of 20 days and longer.

Regenerable systems have been directed primarily at CO₂ control but have also controlled humidity as a prerequisite to CO₂ removal or as a byproduct of CO₂ removal. In general, a bed packed with small chemical granules is used to physically or chemically remove CO₂. The bed is usually regenerated (desorbed) by exposure to low pressure (space vacuum or equivalent) or to elevated temperatures (as high as 232° C) or by a combination of both. Considerable effort has been made in developing an alternate approach employing a solid, porous, inert amine to remove CO₂ from the cabin air. A vacuum desorbed, solid amine system also has substantial weight advantages compared to LiOH systems for extended missions such as envisioned in the space station program.

The laboratory system illustrated employs a solid amine CO₂ absorbing material, IRA-45, a weak base ion-exchange resin. The granular substrate exposes a very large surface area of amine to the cabin atmosphere, which is circulated through the canister to remove CO₂ from the air. The amine resin chemically absorbs CO₂ by first combining with water to form a hydrated amine. The CO₂ then reacts with the hydrated amine to form a bicarbonate. The amine is regenerated by applying steam heat to break the bicarbonate bond and release the CO₂. The major component of the subsystem is a canister containing the packed amine with an electrically heated steam generator built into the inlet header. During desorption, valves isolate the canister, and as steam approaches the outlet end of the bed, a high-purity (99%) CO₂ wave evolves off the bed. A sensor detects the flow increase and switches the CO₂ to a reduction system. The steam used for desorption is recovered by first evaporating it into the process airflow during CO₂ absorption and then condensing it in the cabin humidity control heat exchanger. A controller/sequencer is used to time and sequence the various valving, pump, and fan flow activities. The controller also assists in fault detection and automatic shut-down sequencing.

The system has undergone parametric testing in the Johnson Space Center development laboratory. A modified version of this system will undergo additional evaluation in future unmanned and manned environmental chamber testing.

Simplified solid amine schematic.



**Automated Subsystems
Control Technology**

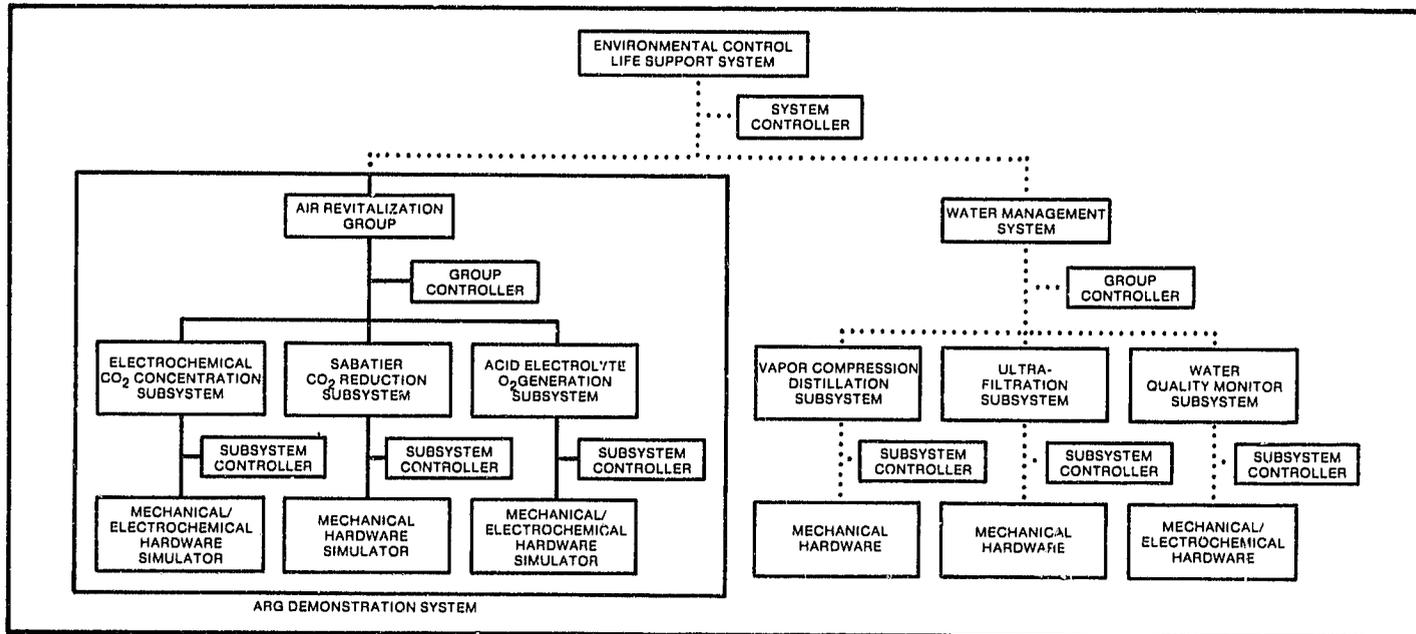
TM: Nick Lance/EC3
Reference OAST 6

The current approach for the control of subsystems in manned space vehicles is very labor intensive for both flightcrew and ground support personnel. A permanently manned space station will require near-autonomous automated control of its systems and subsystems to significantly reduce the demand on space and ground personnel. Efficiently organized local and archival storage, and rapid retrieval and display of subsystem operation, status, and maintenance information will be required across the various space station subsystems. A program is underway to develop and demonstrate the technology of generic automation techniques for the control of spacecraft subsystems.

To ensure the generic nature of the automated subsystem control techniques developed, an application study is being conducted to determine the control and monitor requirements of three representative space station subsystems: environmental control and life support, electrical power, and guidance, navigation, and control. Using the results of this study, a conceptual design of a generic automated control system will be generated and applied specifically to the environmental control and life support subsystem. The generic control techniques will then be demonstrated in hardware and software using only the air revitalization group of the environmental control and life support subsystem. Four controllers will be fabricated: one for the control and monitoring of each of the three air revitalization group subsystems—electrochemical CO₂ concentration, Sabatier CO₂ reduction, and acid electrolyte O₂ generation—and one to perform the air revitalization group supervisory functions. In parallel with the fabrication of these controllers, simulators for each subsystem will be designed and built. These simulators will be of sufficient fidelity to verify the automation concepts implemented.

In the application study, eight different system-level architectures have been evaluated. Results of this evaluation indicate that a distributed system architecture is preferred over a centralized architecture. Within the highest rated of the distributed architectures, the linear bus topology illustrated was determined to be a common building block at the subsystem level and therefore was selected for implementing the air revitalization group control system. Definition of the functions required of a generic controller is expected to be completed by the end of calendar year 1983.

Automated environmental control and life support subsystem conceptual design.



Advanced Autopilot for Manned Spacecraft

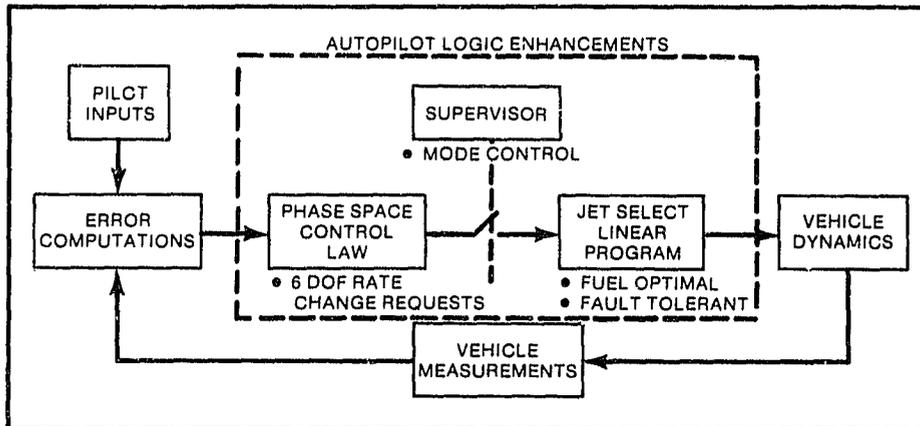
TM: Terry D. Humphrey/EH4
Reference OAST 7

Spacecraft control systems have generally required several simplifying assumptions about the spacecraft's behavior to make the design problem tractable. Rigorous control algorithms for only a limited class of spacecraft maneuvers exist, and they are of little general use. Accordingly, spacecraft autopilots have typically been designed by assuming that the dynamics are decoupled by axis; this assumption allows independent control of each axis, as in the Space Shuttle. Such control laws use attitude and attitude-rate feedback to generate rotational acceleration requests and, in many cases, open-loop computation of translational acceleration requests. Table lookup or dot product schemes are used to perform jet selection on a pass/bypass basis. When jets fail, or when unexpectedly large changes in vehicle mass and inertia properties occur during a mission, table lookup jet-select algorithms may become inadequate or fail to accomplish their function. Such systems, although suitable for vehicles with simple symmetry and jet configurations and unchanging inertia, may be inadequate as control systems for more complex spacecraft.

A new advanced on-orbit autopilot has been designed for rotation and translation control of a rigid spacecraft of arbitrary design, using reaction control jets as control effectors. The advanced autopilot incorporates a six-dimensional phase space control law and a linear programming algorithm for jet selection and provides an integrated solution to the previously described autopilot design limitations. The new control law uses pilot inputs and state feedback to generate rate change requests and performs certain transformations to achieve a spherical deadzone in state space. Closed-loop control of all six spacecraft degrees of freedom is achieved by this one control law, whereas current systems use multiple iterations of their control laws, one iteration per axis. The phase space control law requests rate changes to be produced by the control effectors, and a linear jet-selection algorithm is used to translate these requests into a fuel-optimal sequence of jet firings. If achievement of the rate change requested by the phase space control law is possible, the linear jet select will successfully do so and thus will provide the maximum possible fault tolerance to jet failures.

A set of functional design requirements has been developed for the Space Shuttle incorporating the new advanced on-orbit autopilot concepts. An engineering model has been developed and used in high-fidelity simulations to verify the performance of the new autopilot, and comparisons have been made with an existing spacecraft autopilot. Simulations have shown that the new autopilot requires substantially fewer words of core memory, less average central processing unit time, and fewer firings, and consumes as much as 25.7% less propellant for the cases tested. These functional design requirements are also being used to develop an implementation for use as an experiment on the Space Shuttle. Operation of this autopilot on the Space Shuttle will provide in-flight experience, validating performance, and will provide a useful comparison between this autopilot and the existing Shuttle on-orbit autopilot for future vehicle autopilot design.

Advanced autopilot system.



**Flight Operations
Data Management System**

TM: William V. Bates, Jr./DF7
Reference OAST 8

A large and varied quantity of data are required to support the monitoring and control of manned space flights. Much of these data is in some computerized form. Unfortunately, the data cannot usually be obtained by computer systems other than the originating system. A means of sharing data from various sources in automated fashion so that reentry of data on different computer systems can be avoided is needed. The ability to retrieve required data regardless of original source can permit a more automated monitoring of flights and vastly reduce the manpower required. Once that objective has been accomplished in a limited system, the technology developed can be transferred to the Space Shuttle and space station areas that could most benefit from it.

The basic approach was to identify and examine the needed and available data bases of all the various elements concerned with the planning

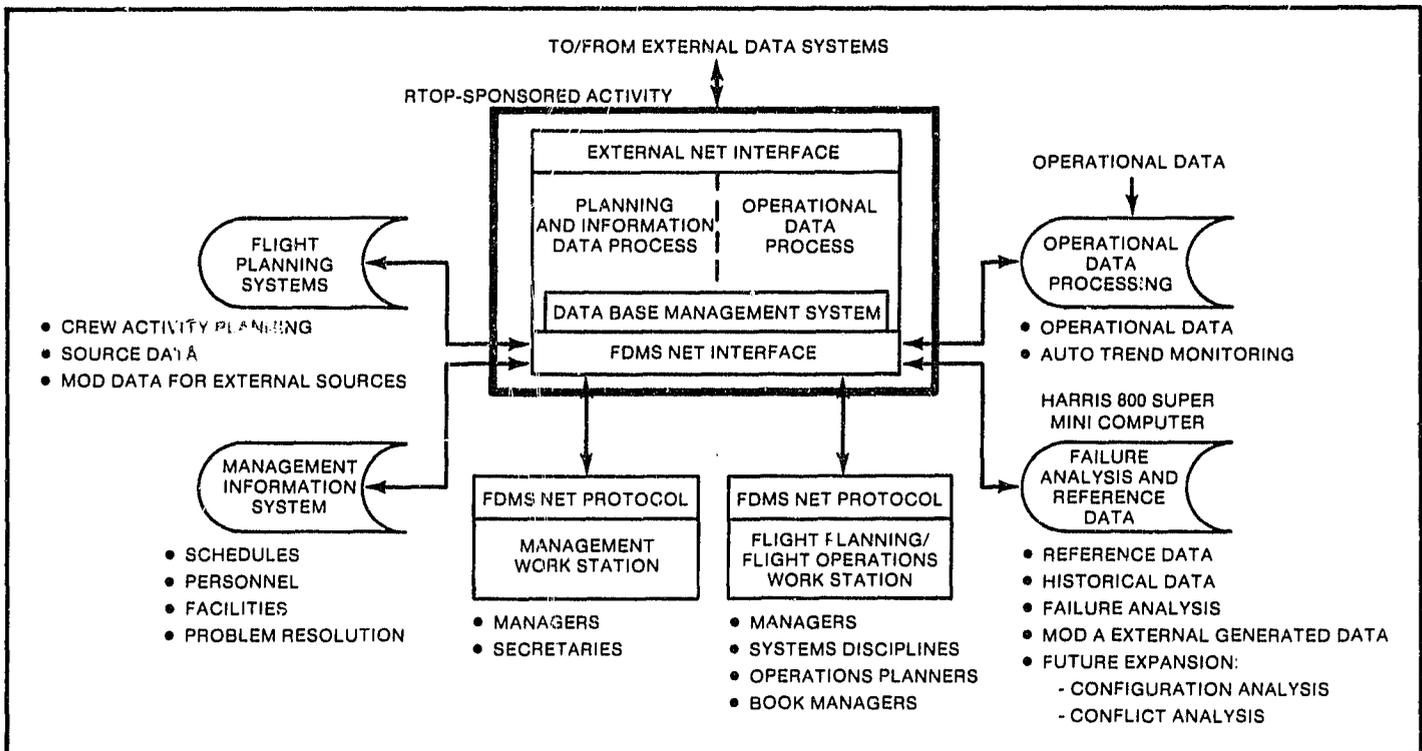
and operation of the Space Shuttle missions within the Johnson Space Center Mission Operations complex. From this effort, a system concept was developed to permit the eventual sharing of data among the identified elements. A simplified version of such a data management system is illustrated with the many and varied functions which contribute to the total mission planning and control process. The nucleus of the system, and that to which the research and technology activity was addressed, is the Data Base Management System as illustrated. This system also provides the communications interface with the complete Flight Data Management System net and other external nets as required. Having established the basic system concept and architecture, artificial intelligence and expert systems techniques now need to be investigated to provide controllers with a type of automated fault detection and trend monitoring capability.

The existing applicable data bases and computer systems that must be used in the ultimate automated system were analyzed and documented

in a detailed set of computer system and software package worksheets. Additional data bases were created such as that for consumables. A standard nomenclature system was developed. The overall systems approach was completed. Some initial automation of failure analysis was completed using the actual Shuttle system as the development model. Results were documented and transmitted as completed.

A Data Base Management System was selected and procured to form the nucleus for the planned network. Interface software design and data design were completed and documented for the limited system demonstration. Data used for tracking the operational instrumentation/flight-critical multiplexer-demultiplexer channelization have been loaded and will be used in real time by the flight control team on Space Shuttle flight STS-9. The network required to provide communication capability between all this diverse equipment is in development under this task. Other groups, using other funding sources, are acquiring the equipment and software that comprise the management information system, operational data processing, and intelligent user work stations.

Flight Operations Data Management System.



Strength and Motion Modeling

TM: B. J. Woolford/EN44
Reference OAST 9

The most versatile element in future space programs will continue to be man in space. However, the limits of human capabilities in the space environment have yet to be quantified. This lack impacts the planning done on Earth for tasks in zero g both inside and outside the spacecraft.

Many factors determine the performance of humans in space. These include both the environment and the individual's capabilities. For example, a work station with a restraint system can make a task easier or more difficult, depending on its size and shape, on the arrangement of controls and displays at the work station, and on its accessibility. Similarly, an individual's size, speed, and strength may cause one task to be more difficult or another to be easier than average. Key human factors include reach envelopes and patterns of motion.

Current techniques for assessing human factors center around building mockups and evaluating the concepts based on the feedback from a few individuals who attempt to carry out the planned tasks in the mockup. This procedure is usable only after a great deal of design has been completed and requires building mockups at a high cost in money and time. Very few iterations can be afforded. Also, no test on Earth can totally capture the kinetics and dynamics under zero-g conditions.

The requirement for accuracy in predicting such factors as size and motion in zero g has led to development of mathematical models which can be used in conjunction with computer-aided design to allow a preliminary design team to examine proposed configurations on the computer much sooner than could be done in a mockup. Three major problems are addressed: size and shape of astronauts, reach motions, and dynamic activities. To model the size and shape of human bodies, some method of collecting actual data is required. In conjunction with the U.S. Air Force, a project is underway to develop a noncontact method for mapping the surfaces of three-dimensional bodies. Reach motions similarly require three-dimensional data to describe the envelope about a person that can be reached by motions of arms, trunk, etc. Data giving potential force at a position is also necessary to develop fully dynamic models.

The modeling of human motion is a very active research field. In particular, models that display realistic bodies in realistic settings have been developed. The engineer can construct figures from these models that have the exact dimensions of a given person or that typify a small person, an average person, etc. The body model developed under this study task, "Bubbleman," is composed of hundreds of spheres which give a somewhat bumpy look but provide significant advantages in computer processing time. Bodies can be made with more or less fidelity as required.

Besides modeling the human body, techniques for generating the goal-directed motion of humans have been developed. This capability allows the design engineer to specify a beginning position and an ending position, with the intermediate steps to be filled in by the models. By this means, checking for access, clearances, and fit becomes a drawing-board-level activity rather than one conducted in expensive mockups.

"Bubbleman" — computer body model.



Programmable Mask Technology

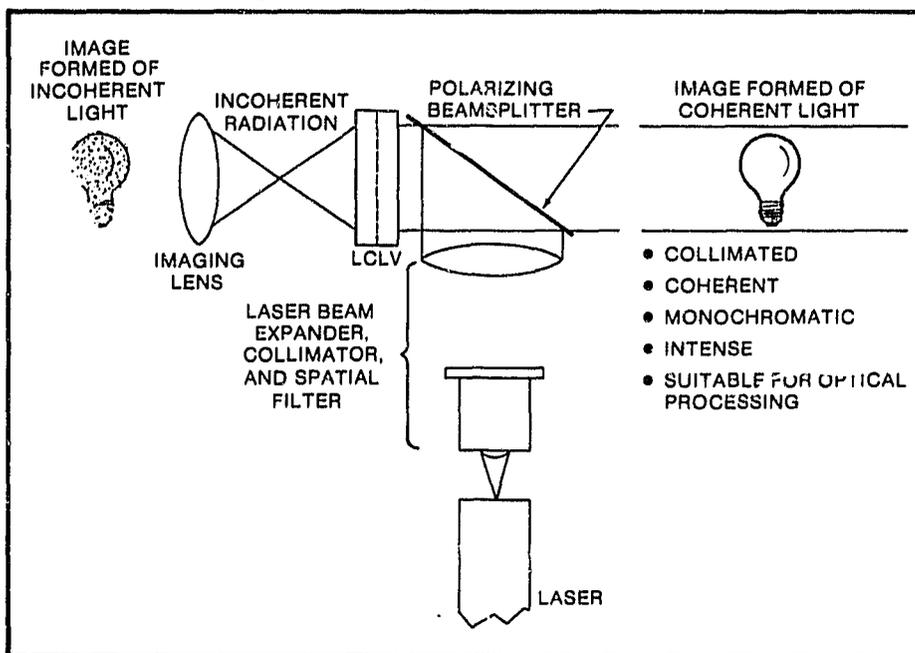
TM: Harry Erwin/EE6
Reference OAST 10

Optical data processing systems are dependent on the accurate and reliable interpretation of data contained in some form of radiant energy. Typical categories that require some type of information processing in the optical wavelengths are pattern recognition, robotic vision, dynamic displays, and Fourier transform analysis. Until recently, available information processing techniques were based primarily on the use of computers. The parallel processing characteristics of programmable mask optical processors obviate a considerable portion of the software complexity and, because of the intrinsic traits of optical phenomena, enhance system reliability. A programmable mask is a device that can be used to process or modify an optical signal containing data as a variation of intensity, polarization, frequency, or phase to produce a desired information output. Devices available for the implementation of programmable masks are in a state of rudimentary development. To provide performance that will more nearly approach theoretical limits and make the techniques useful for space applications, more research is required.

At Johnson Space Center, various devices employing a diversity of physical phenomena are being examined. Such techniques as liquid crystal light valves, deformable mirror devices, magneto-optic modulators, acoustic-optic processors, microchannel spatial light modulators, and optical bistable crystal units are all capable of parallel processing of two- and, in some cases, three-dimensional data. Laboratory investigations are being made to uncover the most effective means of using the various techniques. Although the devices procured for this investigation have limited performance capabilities, concepts of the methods to be used in actual operations can be formulated.

A liquid crystal light valve with a cadmium sulfide photosensitive surface has been acquired, and investigation of various processing tasks is underway. Applications include Fourier transform analysis and pattern recognition. Refinement of liquid crystal light valve technology through the enhancement of resolution, frequency response, and sensitivity is also being investigated. These improvements will result from the application of a silicon photosensitive surface and improved fabrication techniques. A magneto-optic array and a deformable mirror device are being procured to provide different approaches to the use of a programmable mask in the processing of optical information.

Image enhancement using liquid crystal light valve technology.



Refining of Nonterrestrial Materials

TM: David S. McKay/SN4
Reference OAST 11

Future manned and unmanneJ space activities could benefit from the use of extraterrestrial resources. Of particular interest is the extraction of metals, minerals, and glasses from lunar rocks and soils for ultimate use in constructing and supporting projects both on the lunar surface and elsewhere in free space. Recently, interest has been renewed in the possibility of extracting large quantities of oxygen from lunar ilmenite for use as a fuel for upper stage propulsion systems.

Although techniques for mineral separation are well developed for terrestrial applications, their extraterrestrial application is highly empirical. Both the operations and the detailed system configuration would have to be modified for the special properties of the lunar samples and for the space environment. Electrostatic mineral separation techniques are the most interesting because they can work well without a fluid. Unfortunately, these techniques are the most empirical of all those available. Magnetic techniques may also prove useful, especially for separating metals. Only laboratory testing followed by space experiments can quantify these techniques.

Ilmenite, the most abundant lunar soil oxide, is approximately 58 wt% FeO and is a prime candidate as a lunar oxygen source. In addition to oxygen,

lunar ilmenite may also prove a substantial source of hydrogen adsorbed from the solar wind. Solar wind hydrogen tends to concentrate in the finer lunar soil fractions and it is expected that the enhancement may yield as much as 0.2 wt% hydrogen from the <0.02-mm soil ilmenite fraction. Thus, lunar oxygen may be extractable from ilmenite using in situ adsorbed hydrogen as the reducing agent. For that reason, sizing as well as concentration of the oxide are likely to be important lunar mining operations. Terrestrial ilmenite is readily concentrated from beach sands using low-power industrial electrostatic techniques. Electrostatic mineral concentration and sizing are likely to be particularly advantageous in the lunar vacuum because the inhibiting effect of atmospheric drag on the separation of fines will be eliminated.

In fiscal year 1983, electrostatic separation of lunar ilmenite was demonstrated for the first time in a mineral separator designed and built at Johnson Space Center. The ilmenite concentration in a 0.09- to 0.15-mm size fraction of Apollo 11 soil sample 10084 was increased sevenfold from approximately 7 vol% to approximately 50 vol% after one pass through the separator in nitrogen at a feed temperature of approximately 180° C. At the end of

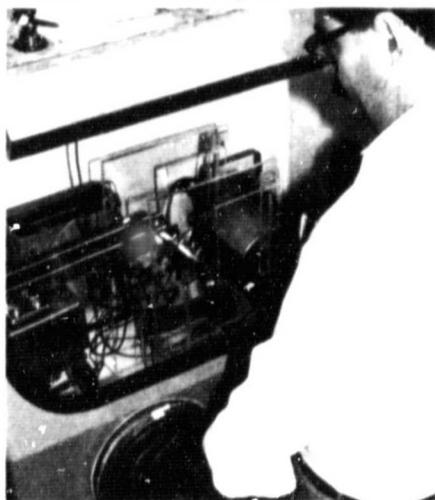
the fiscal year, a vacuum version of the apparatus was ready for testing and it is expected to elevate lunar soil ilmenite concentration from the 50% level obtained in nitrogen to more than 75%.

Earlier in the year, electrostatic separation performance was evaluated on a series of four component lunar soil simulants composed of terrestrial varieties of the most common lunar soil minerals—anorthite, ilmenite, olivine, and pyroxene in the weight ratio 4/1/1/4. Ilmenite in the 0.09- to 0.15-mm fraction of the mixtures was concentrated in one pass from 10 to 94 wt% in nitrogen at an approximate feed temperature of 180° C, demonstrating the effectiveness of the technique on compound mineral mixtures.

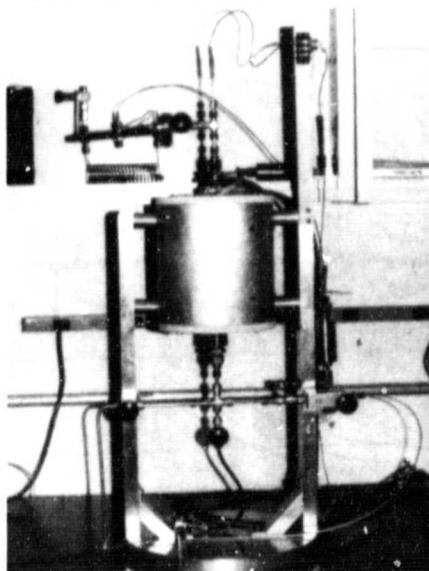
A study of contact charging of anorthite, ilmenite, olivine, and pyroxene on aluminum was also undertaken in an attempt to predict mineral species behavior in the separator. It was found that charge polarity of the nonconductor mineral species, anorthite, olivine, and pyroxene, was the same as that deduced from their behavior in the separator and that charge magnitudes correlated with percent bridging oxygens in the crystal structures of the silicates. The quantity of contact charge was also found to depend on grain size in each species. To a first approximation, total contact charge increased slightly faster than the surface area of the comminuted samples, an indication that each of the species could be sized electrostatically because the electrostatic force-to-mass ratio increases with decreasing grain size. That is not the case with magnetic separation techniques, for example, because the magnetic force is volume dependent. Subsequently, electrostatic sizing of terrestrial ilmenite was demonstrated in air at both room temperature and approximately 150° C using mixtures of the three size ranges: 0.09 to 0.15, 0.15 to 0.25, and 0.25 to 0.50 mm.

Experimental hydrogen reduction of comminuted terrestrial ilmenite was also studied this year in the pressure-controlled reactor shown. In preliminary trials, approximately 50% of introduced hydrogen was oxidized to water by the ilmenite at 720° C and 20 psi overpressure, indicating successful reduction of the FeO component of the oxide with acceptable efficiency.

Electrostatic mineral separator.



Pressure-controlled reactor.



**Advanced Carbon-Carbon
Standoff Panel**

TM: Donald M. Curry/ES3
Reference OAST 12

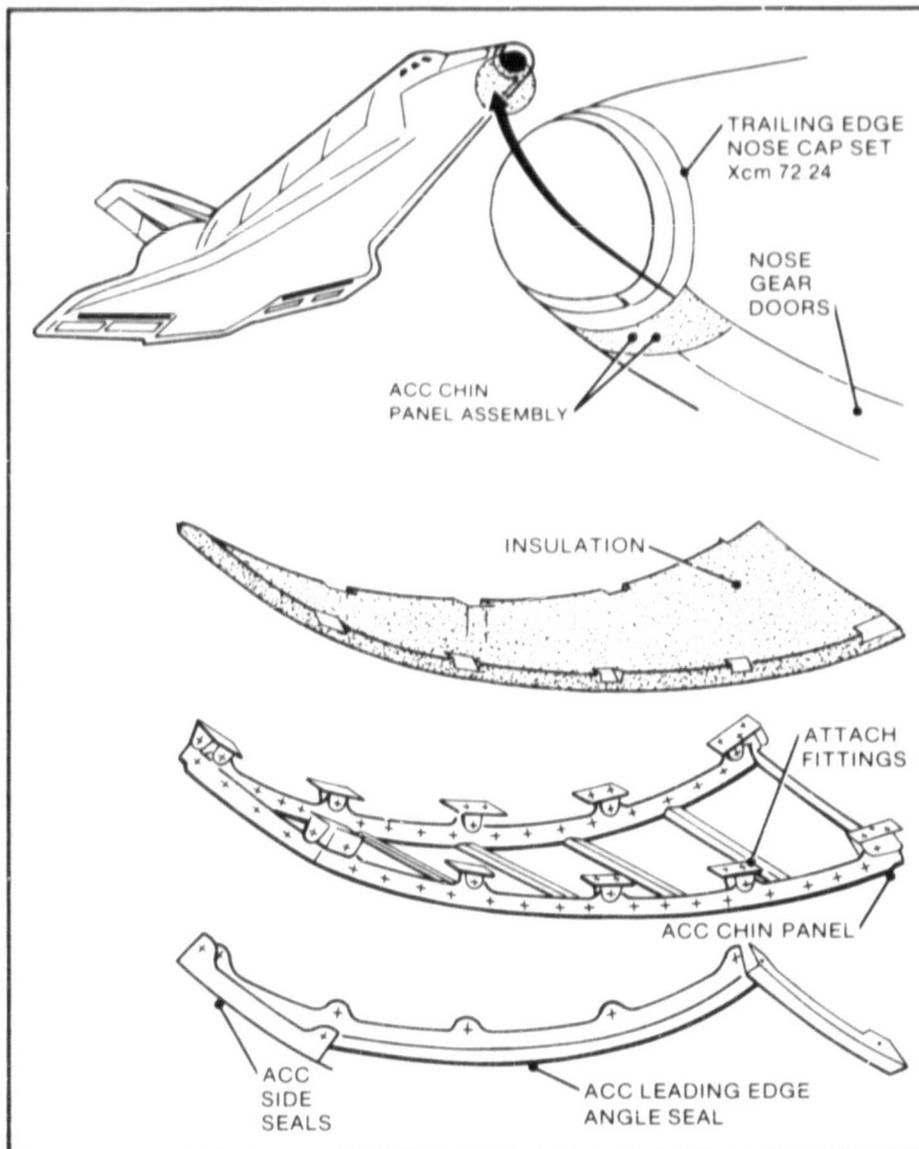
High-temperature reusable surface insulation tiles, employed as the exterior covering for the Shuttle Orbiter lower surfaces, exhibit low strength and lack desirable impact, handling, and other damage tolerance characteristics. The development of the advanced carbon-carbon material, with increased strength and resistance to oxidation, may prove competitive with the current high-temperature reusable surface insulation for specific operational applications.

The area selected to establish the feasibility of fabricating an advanced carbon-carbon panel that is weight and cost competitive with the high-temperature reusable surface insulation system is located on the underside of the Orbiter vehicle between the reinforced carbon-carbon nose cap and nose landing gear door, extending transversely to approximately the nose gear door outboard trim line. This region of the Orbiter has required tile rework after each of the STS flights, including a redesign of the tile/reinforced carbon-carbon nose cap interface.

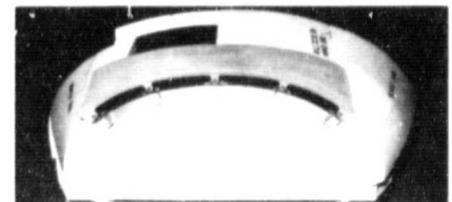
The JSC has performed analytical studies of, designed, and fabricated a carbon standoff panel using the advanced carbon-carbon material to replace the high-temperature reusable surface insulation tiles. The panel assembly was designed for retrofit on the Shuttle but was fabricated for installation on the JSC Nose Cap and Interfacing Components test article.

The advanced carbon-carbon panel has been delivered to Johnson Space Center for full-scale testing using the Nose Cap test article as a test bed and for assessment as a flight article on a future Orbiter flight. The chin panel is doubly contoured with approximate dimensions of 10 in. in width by 54 in. circumferential length having a 7-ply skin thickness (approx. 0.081 in.) with 16-ply (approx. 0.186 in.) lugs. The completed advanced carbon-carbon panel/seal weight was 6 lb, resulting in an estimated installed system weight of approximately 18 to 20 lb. The chin panel is the first large full-scale part fabricated using the advanced carbon-carbon material; therefore, dimensional data were obtained at ACC-4 and coated conditions. Data consisted of overall length, offset dimensions at various butt line locations to establish growth and contour changes at the leading and trailing edges, lug thicknesses, and lug hole dimensions. The results of these measurements indicated that the chin panel grew slightly in the coating process and the contour opened modestly, but the changes were judged to be so small that they are readily manageable on installation. An internal insulation blanket system consisting of 8-lb/ft³ cerachrome encapsulated with AB312 cloth has been fabricated to prevent exceeding Orbiter structural limit temperatures.

Detail of advanced carbon-carbon chin panel



Johnson Space Center test article.



**Space Sciences and
Applications
Solar System Explorations**

Summary

Office of Space Sciences and Applications

Solar System Explorations

Summary

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Solar system explorations are performed through a combination of flight missions, ground-based (or Earth orbital) observations of planets, laboratory research on samples of terrestrial and extraterrestrial origins, experimental duplication or simulation of planetary processes, and synthesis of data from all these sources. The scientific data and samples returned from the Moon during the Apollo missions are still under examination and study by scientists at the Johnson Space Center (JSC), proof that scientific progress can continue long after the operational phase of a mission has ended. However, new sources of samples and data are also important in providing new or otherwise unobtainable insights.

Research on the small bodies and inner planets of the solar system the surfaces of which are accessible to remote observations from Earth or by spacecraft and the collection of samples for analysis in terrestrial laboratories continues to be the major JSC solar system exploration thrust. The study of these bodies of the solar system is being tied to an understanding of the geology of the Earth in an interactive manner to improve our understanding both of Earth and of the other planets. Work continues on the recent initiative of defining the future scientific exploration and use of the Moon, which is anticipated to be a major NASA program within the next two decades.

Some highlights of JSC research are described in this summary, and a selection of research reports is included in the Significant Tasks section.

Origin of the Solar System

Meteorites and cosmic dust represent samples of solar system material that has not been extensively altered since the solar system formed 4.5

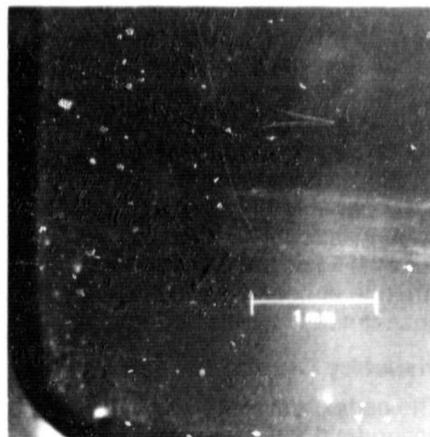
billion years ago. Scientists at JSC have collected stratospheric dust samples using WB-57, U-2, and ER-2 aircraft equipped with inertial wing-mounted collectors. The cosmic dust collection is being used by numerous investigators throughout the world to study primitive solar system material. With the eruption of the El Chichón volcano in Mexico, large amounts of volcanic dust were injected into the stratosphere and have remained there for almost a year. This dust has been sampled on four different occasions. Our sampling has produced information regarding the settling rates of the stratospheric particles. Although numerous research groups have worked on the study of the El Chichón volcanic ash and its atmospheric effects, it appears that the JSC group produced the only extensive, quantitative data on the nature, abundance, and settling rate of the volcanic ash component of the stratospheric cloud. Our studies have shown that the unexpectedly slow gravitational settling rates can be attributed to irregular particle shapes and to the formation

of low-density clusters of particles in the stratosphere.

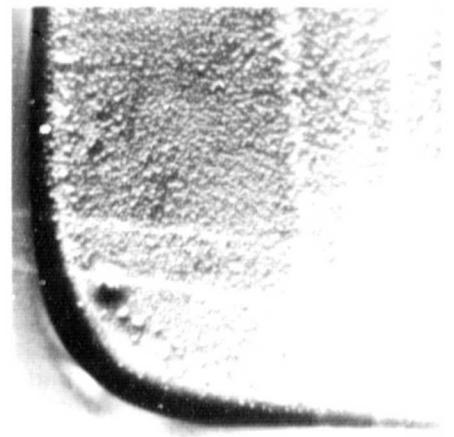
Preparations have been completed for the Chemistry of Micrometeoroid Experiment (CME), which will be deployed on the Long Duration Exposure Facility (LDEF) during a forthcoming Shuttle mission. Three different types of collector surfaces will be exposed to the micrometeoroid environment. The natural micrometeoroid collisions will be recorded on the collector surfaces in the form of microscopic impact craters which contain molten impactor material on the bottoms and walls. From chemical analysis of the residual material, the compositions of the micrometeoroids can be determined. The CME instrument enables the collection of both micrometeoroids and cometary dust in low Earth orbit and thus complements other investigations of cosmic dust.

Two meteorites recovered on polar icecaps in Antarctica have been shown to be samples of the planetary surfaces of Mars and the Moon. Within the past 2 years, a meteorite recov-

Stratospheric dust collection flag prior to El Chichón eruption.



Atmospheric collection flag 6 months after El Chichón eruption (principally sulfuric acid droplets).

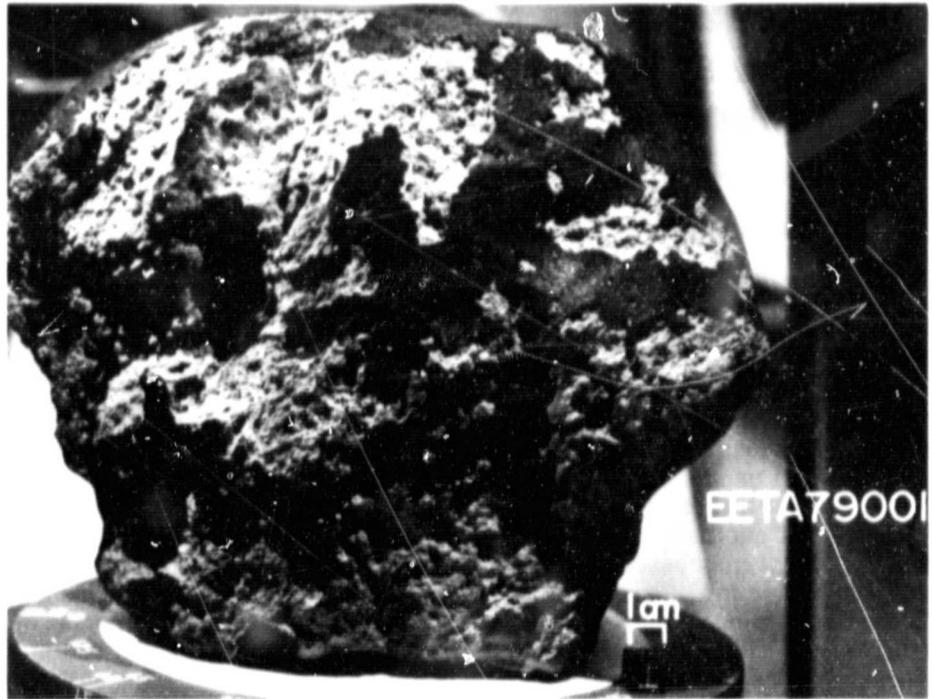


ered from Antarctica has been shown to be a piece of the surface of Mars. This discovery has been enhanced by the recovery of another meteorite in Antarctica which is similar to breccia from the lunar highlands. The chemical and petrographic compositions of the sample are identical to those of lunar breccia within the lunar sample collection at JSC. In addition, the presence of large concentrations of solar gases clearly indicates that the matrix of the sample had been exposed to the solar wind for a period of time before breccia formation. The large concentrations of solar gases and the suggestion of long-term cosmic-ray exposure are consistent with an origin from the lunar regolith. Such characteristics are dissimilar to known meteorites and may be difficult to reconcile with an origin from the regolith of an asteroid. The actual mechanism by which a sample is removed from a planetary surface by impact, escapes the gravitational field of that body, and is later captured by the Earth is undergoing considerable discussion in the scientific community.

Lunar Science

Within the past year, major emphasis has been placed on obtaining new types of lunar materials within the JSC lunar sample collection by slabbing several of the large breccia samples. New faces have been exposed, and several newly recognized sample types have been revealed. Detailed study of the samples is underway by the scientific community. The breccia samples were created more than 4 b.y. ago by the intense meteoroid bombardment and mixing of materials on the lunar surface. Some of the material mixed within the breccia samples may be remnants of the early lunar crust before the period of extensive igneous activity.

Igneous processes involving the production, migration, and crystallization of silicate melts are known to have been important in the formation of planetary crusts on the Earth, the Moon, Mars, and some meteorite parent bodies, and probably were important on Mercury and Venus as well. Such processes leave distinctive signatures on the chemical and isotopic compositions of the rocks they produce. One of the goals of



Meteorite recovered in Antarctica which is believed to have originated on the martian surface. The meteorite contains samples of gases which are nearly identical to those measured in the martian atmosphere by the Viking landers.

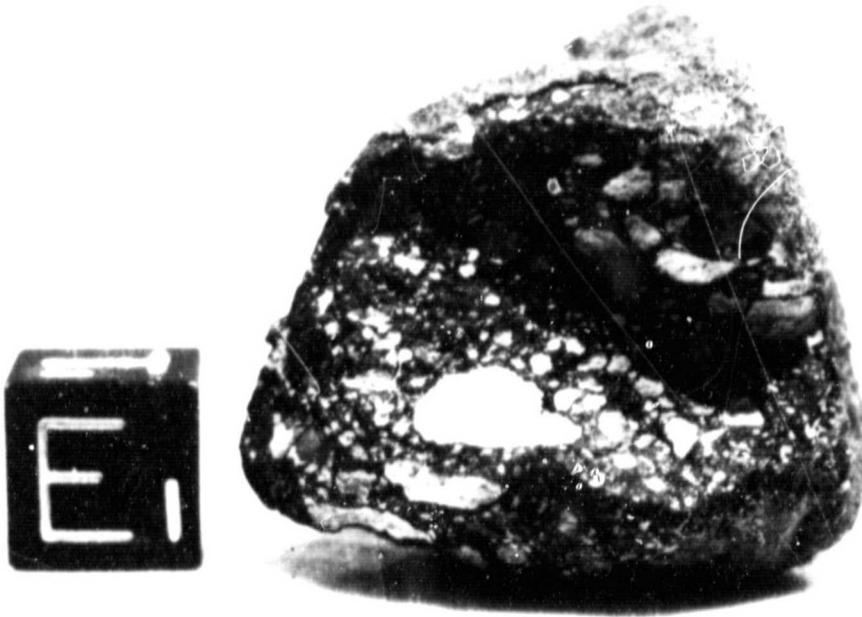
planetary geochemists is to decode the history of these early processes by deciphering the chemical signatures found within the rocks from planetary crusts. The trace elements (having concentrations of only a few hundred parts per million or less) are strongly influenced by their "partitioning" between silicate melts and rock-forming minerals in contact with these melts. Laboratory simulations duplicating conditions in the deep lunar crust provide means of evaluating the relationship between rocks, the environment of formation, and the chronology necessary to make a coherent picture of lunar development. Results from laboratory experiments have been incorporated in model calculations to investigate the petrogenesis of early lunar crustal materials (namely lunar anorthosites). The results suggest that formation of the anorthosite crustal material by way of a process approximating simple crystal accumulation from relatively unfractured liquids does not violate constraints imposed by trace-element abundances and distributions.

Planetary Crusts

The early crust of the Moon although not understood completely, is at least

amenable to sampling. The Earth's early crust has largely been destroyed by geologic recycling processes, erosion, and mountain building such as plate tectonics. Scientists at JSC are attempting to understand the Earth's early crust by examining the occurrence of anorthosites, rock types that are rare on Earth but abundant on the Moon. Anorthosites of the Canadian shield are under field and laboratory investigation, and a preliminary model of terrestrial crustal growth has been developed. Geochemical studies of 1.1- to 1.7-b.y. rocks from eastern Canada and northern New York indicate that by their time in history, the Earth's mantle had developed extensive heterogeneities because of previous fractionation events. It appears that an earlier fractionation of the Earth's crust from the mantle had depleted certain components in the extensive volume of mantle that now resides under certain portions of the region studied. Studies of lunar samples had revealed that similar depleted reservoirs in the lunar mantle resulted from a crust-mantle fractionation around 4.4 b.y. ago. Then, a later fractionation produced the younger 3.0- to 3.7-b.y. mare volcanic rocks. Because of the differences in

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Meteorite recovered in Antarctica that has been shown to be of lunar origin. Mineralogical and chemical composition is identical to that found for some samples returned from the Moon during the Apollo Program.

gravity, size, and volatile contents, the specific composition of the depleted components is different on the Moon from that of the Earth. Thus, some of the large-scale planetary processes that were learned about in some detail from lunar samples appear to have similar terrestrial counterparts that are modified by the more complex geologic history of the Earth. However, without the benefit of the simpler case provided by the Moon, it would have been more difficult to recognize the validity of the approach for terrestrial processes.

Remote Sensing

Remote sensing is a tool that can be used to study the nature of planetary surfaces. However, the interpretation of the mineralogical and chemical composition of planetary surfaces raises complicated issues in spectroscopic and data interpretation. One means of better understanding the nature of data returned by remote-sensing techniques is to make laboratory spectral measurements of mineral oxides and oxyhydroxides. The iron oxides and oxyhydroxides have been examined to understand how a variety of physicochemical properties

such as mean particle diameter, particle shape, chemical composition, crystallographic phase, magnetic parameters, and Mossbauer parameters affect the spectral signatures. Information obtained from these investigations has provided insights into the interpretation of spectra for Mars and the Moon. Experimental synthesis of possible martian surface minerals and materials continues in conjunction with laboratory investigations.

Technology

To stay at the forefront of expansion of knowledge, new technology must be developed and evaluated. The scientific staff within the Solar System Exploration Division continues to develop instruments and techniques that support its research programs and open future opportunities. Technical development within the past few years includes operation of the clean laboratory and sample handling procedures for cosmic dust, collection of volcanic ash samples in the stratosphere from the El Chichón volcanic eruption, development of techniques for analysis of trace quantities of hydrogen in lunar samples, continuation of the development of an isotope-

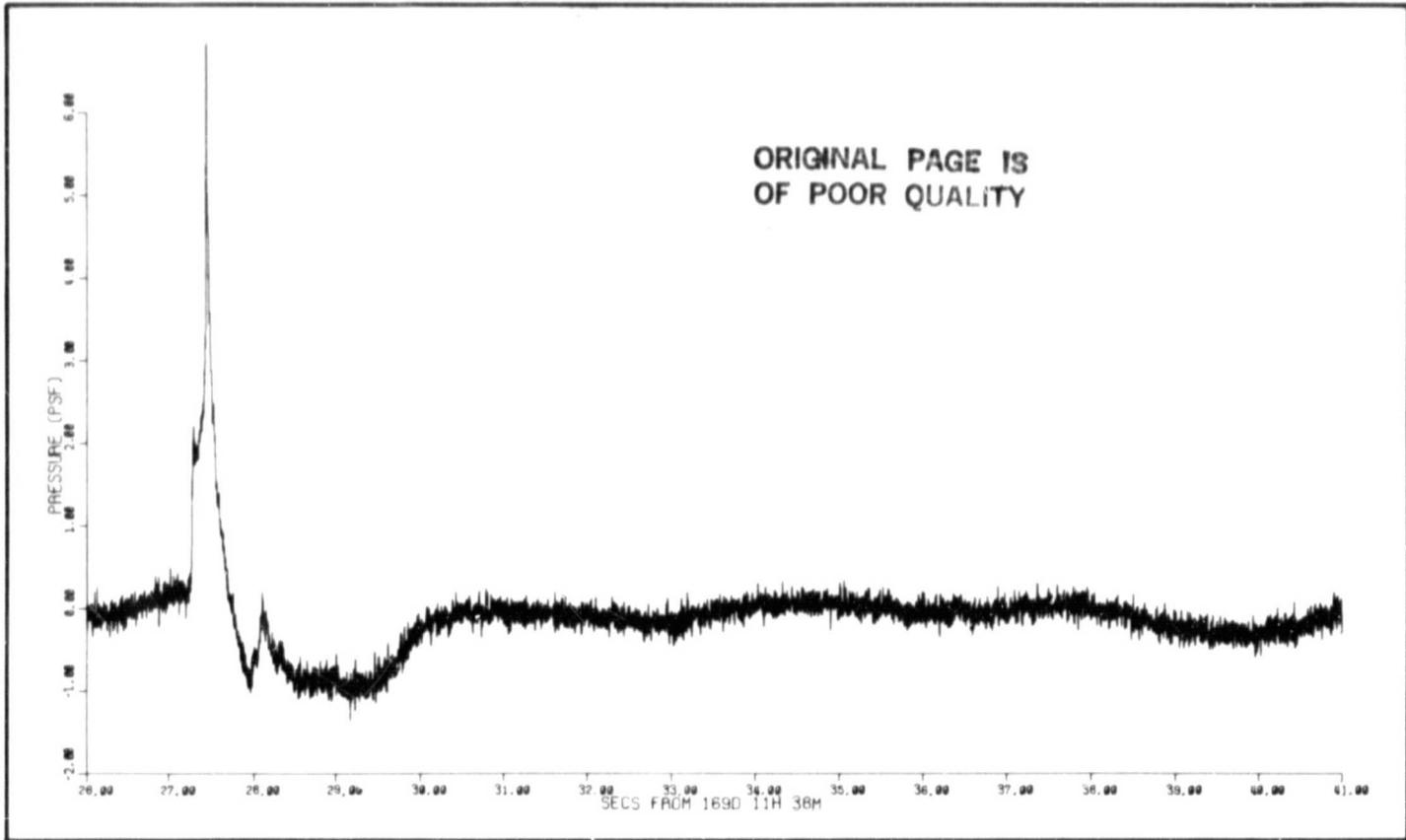
dilution mass spectrometer for use on flight programs, installation and operation of a state-of-the-art electron microprobe, installation of Mossbauer analysis capabilities, and development of a light gas gun for hypervelocity impact studies of composite materials. Also, instruments for detecting and recording Space Shuttle sonic boom signatures have been developed and improved, an example signature from STS-7 launch is shown. Other technology developments that may be useful for planetary exploration are described in the Office of Aeronautics and Space Technology section of this report.

Lunar Exploration

With the Space Shuttle now in the operational phase, the space agency is looking at future space activities. The Shuttle is but the first step in a process that can be viewed as an expansion of human activity into space—first near Earth, later farther out into the solar system. One of the possible expansions which could take place is to establish a permanent presence on the Moon. A permanently inhabited research base on the Moon could be in operation by the end of the first decade of the 21st century. Such a facility would enable intensive study of the Moon to address unanswered questions from the research of the Apollo era. It would also hasten the beneficial use of lunar materials for activities throughout the Earth-Moon system. Finally, it would prepare the way for manned exploration of Mars and the establishment of a second human society in the solar system.

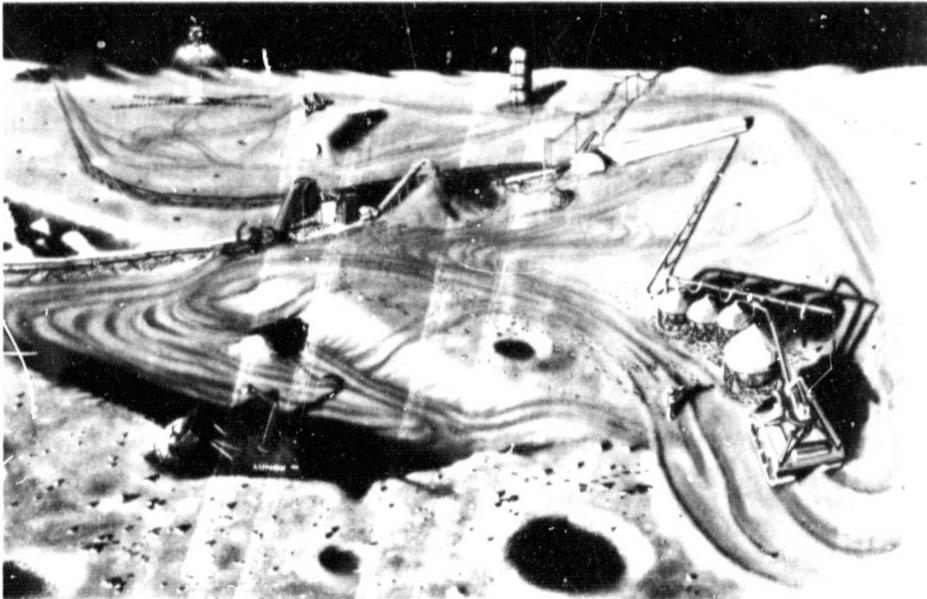
A base of operations on the Moon is qualitatively different from the space station activities envisioned because the Moon has substance, firm footings for extended structures, protection from high-energy radiation, and elements and compounds from which material objects can be fabricated. Thus, a lunar program will have scientific and applications components. A better understanding of the formation and history of the Moon, the Earth, and other planetary bodies will be a prime objective of the initial lunar base. The buildup of scientific capabilities will enable use of the Moon as a research base for astronomy, high-energy physics, life sciences, and

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STS-7 ascent sonic boom signature recorded at station 5.

Lunar Surface Oxygen Production Facility. (Painting by Pat Rawlings based on model by Hubert Davis, Eagle Engineering, Inc.) Bulk soil from a strip mine on the Moon is delivered by front-end loaders to an automated processing facility, where the mineral ilmenite (FeTiO_3) is separated and then chemically reduced by heating in the presence of hydrogen. The products of the reaction are metallic iron, titanium oxide, and water. The water is piped to an electrolysis facility, where the hydrogen is recovered and the oxygen is stored in spherical tanks after liquefaction. In the right foreground, a filled tank is about to be carried to the landing pad where a lunar module is landing (left background). In the upper center is a stack of imported hydrogen tanks. Powerlines stretch over the ridge to a power station, possibly a nuclear reactor.



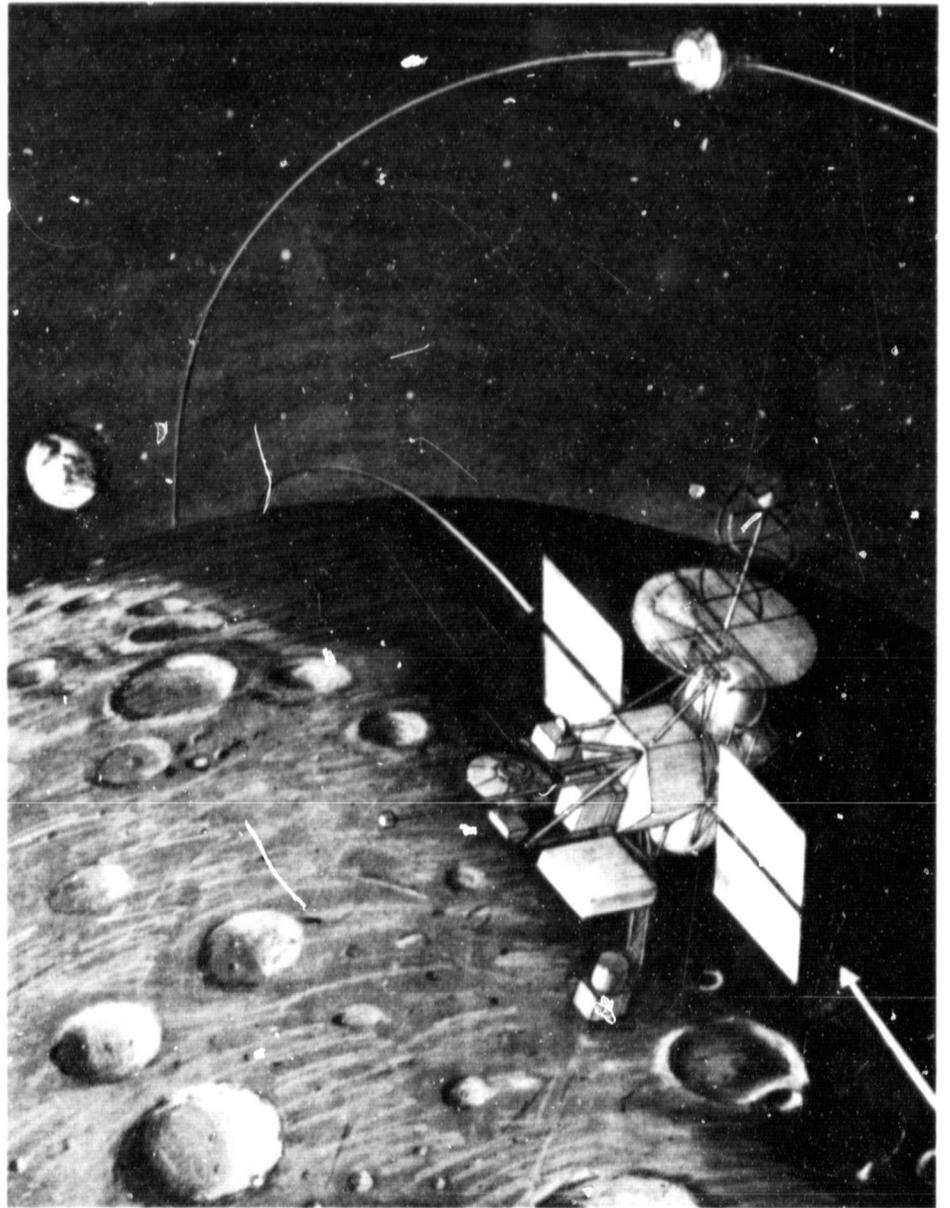
other disciplines. Also important will be research on methods for using the lunar environment and materials to benefit mankind.

To undertake the establishment of a lunar base, several key developments are required. First, it will be necessary to have a space transportation system capable of delivering the base hardware and resupplying the facility. Second, the uses of the lunar base must be made sufficiently clear to the leaders of society to ensure that investment in the enterprise can be supported. To establish the framework for the decision to return to the Moon, a project was initiated at JSC with the intent of identifying the principal objectives of a lunar base program, the current state of knowledge, and the developments necessary for accomplishment.

To properly plan for the potential lunar base, a satisfactory level of understanding about the nature of the lunar environment and the lunar surface is required. Currently, the martian surface is better understood and mapped at a greater resolution than is the surface of our nearest

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neighbor—the Moon. For lunar resource and lunar base exploration purposes, it is desirable to have as one of the early elements of this program a lunar geochemical and mapping orbiter. This mission, of modest cost, would verify the best locations for and optimum uses of a lunar base as well as establish base maps for future lunar operations performed in conjunction with the facility. Such a precursor mission could be launched around 1990.



Lunar polar mapping orbiter.

**Space Sciences and
Applications
Solar System Explorations**

Significant Tasks

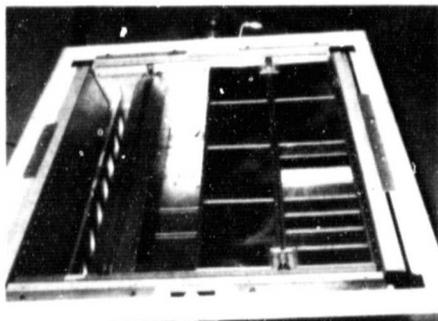
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The Chemistry of Micrometeoroid Experiment

PI: Friedrich Horz/SN4
Reference OSSA 1

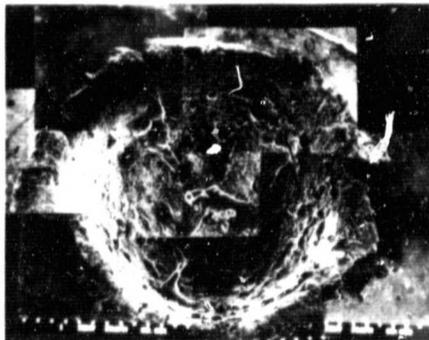
The Chemistry of Micrometeoroid Experiment (CME) will be deployed on the Long Duration Exposure Facility (LDEF) during STS-13 and will be returned to Earth after an exposure time of approximately 12 months at an altitude of 400 km. Natural micrometeoroids will impinge on high-purity substrates and either melt or vaporize from shock heating on impact at cosmic velocities (7 to >25 km/sec). These melts or vapor deposits may be analyzed on retrieval by means of state-of-the-art microanalytical instruments. The objective of CME is to chemically characterize these microscopic projectiles that typically may weigh only 10^{-9} to 10^{-15} g. Inasmuch as most of these particles are derived from comets—based on direct observation and theory—the chemical information obtained will be related to the nonvolatile solids (silicates) of comets. In brief, the instrument performs cometary sciences in low Earth orbit and thus complements other investigations of cosmic dust.

The active part of LDEF-CME. A 12-in-deep tray houses two clamshell devices, one of which (right hand) is opened, exposing the pure gold collectors of high-quality surface finish (reflections) and a number of experimental substrates (small rectangles in lower right corner). Total surface area exposed is about 1 m².



Three different types of collector surfaces will be exposed, totaling some 4 m². Pure gold sheets ($>99.99\%$ Au) of 0.5 mm thickness will be mounted on a clamshell device that "opens" after LDEF deployment and closes a few days before retrieval; ground handling and all other activities occur with the clamshells closed to minimize potential contamination. Natural micrometeoroid collisions will be recorded on the gold substrate in the form of microscopic impact craters, which, in turn, contain molten impactor material on bottoms or walls. The "active" part of CME with one of the clamshells (right side) partly opened is illustrated. Also shown is an experimental impact crater illustrating the impactor melt in its bottom and the type of crater morphology expected. Such experimental craters are being generated at velocities from 3 to 10 km/sec to "calibrate" the flight instrument. Calibration centers predominantly on the degree to which the impactor melt may chemically differ from that of the actual projectile as selective vapor loss of specific elements/oxides may occur. Modest loss of Na₂O and appreciable loss (up to 40%) of K₂O was observed in these simulation experiments.

Experimental impact crater produced in gold target by soda lime glass impactor at 6.2 km/sec. Note the copious amounts of impactor melt in the form of flow-fronts and lobes at the crater bottom and walls. An exceedingly thin glass liner actually drapes the entire crater cavity and the crater rim.



The other major collector surface (approximately 2 m²) is totally passive and consists of approximately 200 individual micrometeoroid "capture cells." Each cell is covered by a 1.5- μ m-thick plastic foil that stands about 0.2 mm above a germanium (Ge) substrate ($>99.99\%$ pure and 0.6 mm thick). The objective is to let the cosmic dust particle penetrate the foil with relative ease and to have it impinge on the Ge substrate with essentially unaltered velocity. The vaporized species generated during impact will condense on the underside of the plastic foil in the vicinity of the relatively small penetration hole; this underside is coated with high-purity tantalum ($>99.999\%$) for a number of analytical reasons, predominantly secondary electron yield during secondary ion mass spectrometry analysis (ion probe). Again, micrometeoroid impact experiments—performed by collaborators in Heidelberg, Germany, and Washington University, St. Louis, Missouri—demonstrate the feasibility of this approach.

Finally, approximately 1 m² exposes relatively pure aluminum ($>99.9\%$ Al); these surfaces serve the same purpose as the Au substrate and will be analyzed in identical fashion. We expect some 60 impact events on all 4 m² that are analyzable using present microanalytical techniques and which represent impacts by particles of mass $>10^{-11}$ g. Numerous other events of still smaller micrometeoroids will occur, but these are presently beyond analytical capability for quantitative analyses. A secondary objective may emerge as these collector surfaces may also yield information about man-made debris, predominantly in the form of Al₂O₃ particles generated during firing of solid-state rocket motors.

Volcanic Dust in the Stratosphere

PI: James L. Gooding and
Uel S. Clanton/SN2
Reference OSSA 2

Explosive eruptions of the El Chichón, Mexico, volcano from March 28 to April 4, 1982, injected large quantities of gas and fine dust (volcanic ash) into the stratosphere and provided a unique opportunity for multidisciplinary studies of the nature and effects of such clouds. First, stratospheric clouds of volcanic ejecta may perturb the delicate thermal balance of the atmosphere and lead to changes in weather and climate. Second, gaseous or particulate debris in the stratosphere, if sufficiently concentrated, can interfere with jet aircraft flying at those altitudes. Reliable prediction of possible consequences of volcanic clouds for meteorology or aviation depends heavily on acquisition of accurate information about the composition, volume, and longevity of the volcanic cloud material.

Samples of the El Chichón cloud material were collected using cosmic dust collection hardware and techniques described in the 1982 report. All collectors were processed in a Class 100 clean laboratory. Eight different collection flags were flown on each of four different aircraft missions spanning the period April 27, 1982, to March 28, 1983. All missions were flown over North and Central America (long. $\sim 70^\circ$ to 150° W, lat. $\sim 10^\circ$ S to 75° N) at collection altitudes of 16.8 to 19.2 km and at the normal aircraft cruise speed of 410 kn.

Each flag was examined by optical microscopy, and small samples were removed from selected flags for study by scanning electron microscopy (SEM) and energy-dispersive X-ray spectrometry. Number abundances and size distributions of particles were determined by means of two different techniques: using quantitative gravimetric recovery of ash loads from individual flags, combined with SEM sizing of particles, and using an automatic liquid particle counter

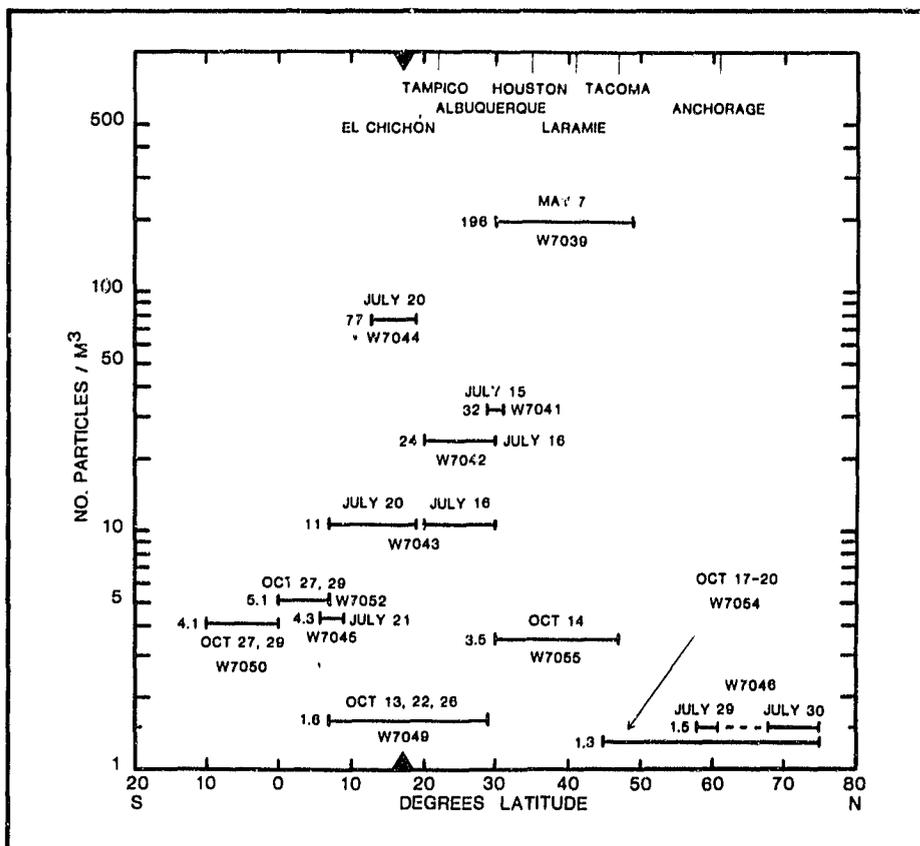
(based on photometry of light scattered from a helium-neon laser beam passed through each sample) to analyze liquid suspensions of ash particles obtained by quantitatively rinsing individual flags with ultrapure Freon-113.

Sampling and analytical work produced three important results. First, the stratospheric ash cloud spread rapidly in latitude to distant areas both north and south of the volcano. At the minimum, the ash cloud covered latitudes 10° to 60° N in July and 10° S to 75° N in October 1982. Second, ash particles $>2 \mu\text{m}$ size, predominantly vesicular shards of rhyolite-andesite glass, were significant parts of the cloud for at least 6 months after eruption, with their unexpectedly slow gravitational settling rates attributable to irregular particle shape and the formation of low-density clusters of particles in the stratosphere. Third, the abundance of ash in the original stratospheric cloud was probably at least 480 tons.

Results confirmed the observation by other investigators that the El Chichón volcanic cloud produced a heavy load of sulfuric acid droplets in the stratosphere. Although Mission 1 and Mission 2 samples consisted mostly of free ash particles and clusters of particles, Mission 3 samples were dominated by liquid droplets with entrained ash particles. Mission 4 samples contained relatively little particulate material but included very large numbers of liquid droplets, and clearly showed that, approximately 1 year after the eruption, the stratosphere was burdened with several times more sulfuric acid aerosol than is normal. During Mission 4, the large acid load in the stratosphere resulted in significant corrosion of both the stainless steel parts of the collectors and the exterior of the aircraft.

Although many different research groups participated in the scientific study of El Chichón volcano and its atmospheric effects, it appears that JSC produced the only extensive, quantitative data on the nature, abundance, and settling rate of the ash component of the stratospheric cloud. In addition to our own studies, documented samples have been provided to nine different research groups in response to their individual requests.

Stratospheric abundances of 2- to $40\text{-}\mu\text{m}$ ash.



The Earth's Early Crust and Mantle

PI: William C. Phinney/SN4
Reference OSSA 3

The planetary processes that were involved in the earliest separation of Earth's crust and mantle remain largely unknown. The very rare occurrences of rocks from the first 1.5 billion years (b.y.) of Earth history severely limit the evidence for such processes. However, some of the more common younger rocks can preserve evidence that bears on older processes. Many volcanic or other igneous crustal rocks form by partial melting within the mantle. As the melts then rise into or onto the crust and form additions to the crust, they leave anomalous residual compositions in the affected volumes of mantle at various times throughout Earth's history. When one of these volumes of mantle undergoes further melting or fractionation at an even later time, the resulting crustal rocks of the later event may inherit clues about the earlier fractionations of crust and mantle in the form of anomalous isotopic ratios, trace-element distributions, and/or mineral assemblages. The study of ancient rocks can provide evidence on the nature and location of even earlier events for which no crustal rocks are preserved. The resulting data can help us to understand the more basic questions of why and how these very early events took place.

Recent geochemical investigations of 1.1- to 1.7-b.y. rocks from eastern Canada and northern New York indicate that by their time in history, the Earth's mantle had developed extensive heterogeneities from previous fractionation events. For example, the isotopic ratios for $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ in the northern occurrences are anomalously high for neodymium (Nd) and low for strontium (Sr), whereas the more southerly occurrences are anomalously low for Nd and high for Sr. These results imply that an earlier fractionation of crust from mantle had depleted certain components in the extensive volume of mantle that now resides under the northern areas, whereas other portions of the mantle to the south had not undergone the same fractionation and depletion. By 1.7 b.y., there were at

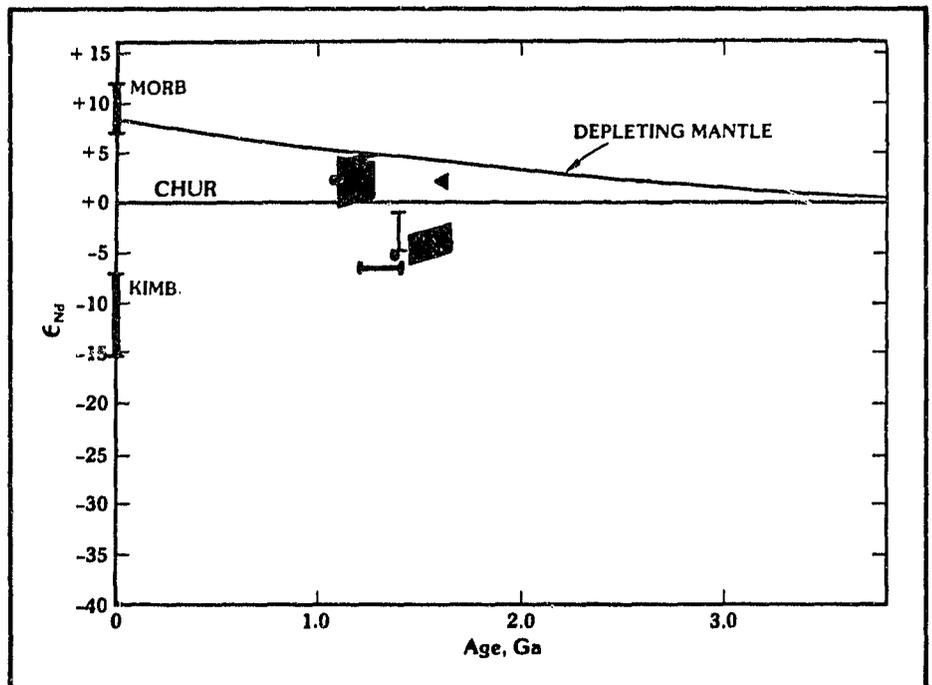
least two distinct types of mantle reservoirs supplying new igneous material to the crust in eastern Canada. These differences are illustrated. The plotted variable ϵ_{Nd} is a measure of the departure of the $^{143}\text{Nd}/^{144}\text{Nd}$ ratio from an ideally nonfractionated mantle reservoir; the more positive the ϵ value, the more depleted the mantle reservoir.

Current data suggest that the boundary between depleted and nondepleted reservoirs follows a northeasterly trend from the northern shore of Lake Huron to the Atlantic coast of Labrador; the depleted reservoir is located on the southeastern side of this trend line and the nondepleted reservoir on the northwestern. Although the precise areal extent of these reservoirs remains to be determined, evidence for the existence of an extensive depleted mantle to the northwest under much of Ontario as long as 2.8 b.y. ago limits the width of the nondepleted zone. The meaning of the boundary between the reservoirs is not yet certain, but such possibilities as an ancient continental margin, small mantle regions

that for unknown reasons have not participated in crustal formation during the first 3.0 b.y. of Earth history, or tapping of a deep, primitive mantle source must be considered.

Previous studies of lunar samples have revealed that similar depleted reservoirs in the lunar mantle resulted from a crust-mantle fractionation at about 4.4 b.y. Then, a later fractionation produced the younger 3.0- to 3.7-b.y.-old mare volcanic rocks in which anomalies are preserved from the 4.4-b.y. fractionation. Because of differences in gravity, size, and volatile contents, the specific composition of the depleted components is a bit different on the Moon from that on the Earth. Thus, some of the large-scale planetary processes that were determined from the study of lunar samples appear to have similar terrestrial counterparts that are somewhat modified by the more complex geologic history of Earth. However, without the benefit of the simpler case provided by the Moon, it would have been more difficult to recognize the validity of the approach for terrestrial processes.

Plot of age vs. ϵ_{Nd} for igneous intrusions from the eastern Canadian shield. Intrusions derived from sources with a depleted signature appear above the chondritic evolution line (CHUR); those from sources with an enriched signature appear below the line. The upper line shows the trend for a depleting mantle, which intersects the ϵ_{Nd} axis at the current value of midocean ridge volcanics (MORB). An example of an enriched source, Australian kimberlites (KIMB), is shown for comparison.



Development of an Analytical Method for Determination of Hydrogen in Lunar Materials

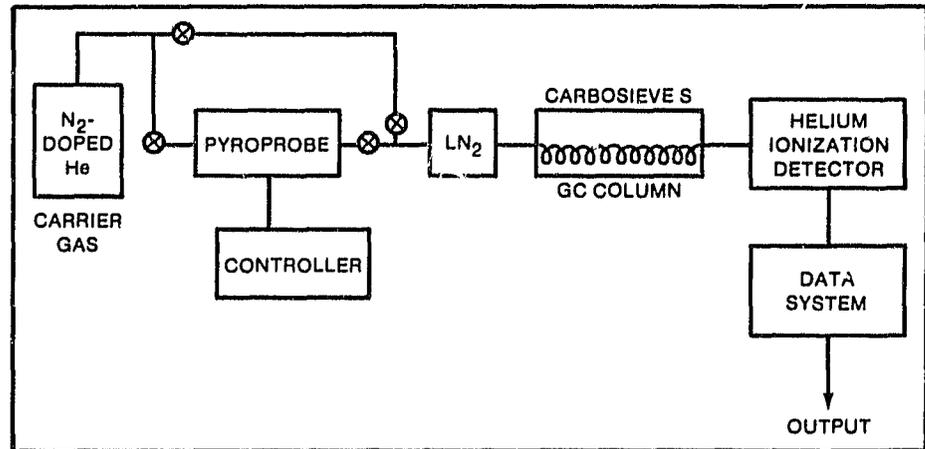
PI: Everett K. Gibson, Jr./SN4
Reference OSSA 4

Chemical analyses often must be performed on samples that are limited in size and availability or that cannot be destroyed. In most instances, a few tenths of a milligram can be spared for analysis. With the recent interest in the future establishment of a lunar base, there is renewed interest in the possibility of lunar materials providing a portion of the consumables required to support such a facility. Hydrogen is a solar-wind species the concentration of which in lunar soils varies with the particular soil type or particle size. To predict the potential usefulness of the available lunar hydrogen for propellants and consumables, a simple technique capable of determining the hydrogen concentrations in bulk soils is desired. In addition, the analytical technique must be capable of making measurements on various grain size fractions and for different particle types within the soils.

A method capable of determining the hydrogen concentrations in submilligram soil samples has been developed. It consists of heating the lunar samples in a helium atmosphere in a pyroprobe followed by gas-chromatographic determination of hydrogen using the ultrasensitive helium ionization detector. A schematic of the analytical system is given. The gas chromatograph (GC) and analysis system was operated under the conditions listed. The carrier gas was helium which contained 104 p/m nitrogen. Standards of hydrogen in helium were used for calibration of the system. They were injected by means of a gas sampling valve equipped with a 100- μ l sampling loop. Chromatographic signals were recorded on a strip chart recorder using 0.001 V full scale and were integrated on a central processor data system. Smallest sample concentration of hydrogen measurable was about 1 μ g.

The analytical method was used for the analysis of various lunar soils. Bulk hydrogen concentration of the lunar soils ranged from 19 to 106 μ gH/g. The immature soils contained the smallest quantities of hydrogen, and the most mature soils contained the greatest concentrations of hydrogen. Analytical values for bulk lunar soil hydrogen concentrations were found to be similar to those reported in the literature. Previous measurements of hydrogen concentrations in lunar soils were made using sample sizes ranging from 0.5 to 3.0 g. Using the newly developed analytical technique, the hydrogen analysis can be performed using sample sizes between 1 and 3 mg. The pyrolysis technique is simple, fairly rapid, and very sensitive. It can be adapted for the determination of volatile components in a wide variety of materials.

Schematic of equipment.



EXPERIMENTAL CONDITIONS

Column	7 ft Carbosieve S, 120/140 mesh
Column temperature, °C	80
Detector	Helium ionization
Carrier gas	Helium doped with 104 p/m nitrogen
Flow rate, ml/min	20
Pyrolysis temperature, °C	900
Pyrolysis time, min	1
Trap for condensables	Liquid nitrogen

Lunar Base Studies

TM: Wendell Mendell/SN3 and
M. B. Duke/SN
Reference OSSA 5

A permanently inhabited research base on the Moon could be in operation by 2010. Such a base would enable intensive study of the Moon to address questions unanswered from Apollo research. It would also hasten the beneficial use of lunar materials for activities throughout the Earth-Moon system. Finally, it would prepare the way for manned exploration of Mars and the establishment of an extraterrestrial human society.

To establish a lunar base, several key developments are necessary. A space transportation system capable of delivering the base hardware and resupplying the inhabitants is required. The uses of the lunar base must be made sufficiently clear to the leaders of society to ensure that investment in the enterprise can be supported. To establish the framework for the decision to return to the Moon, a project was initiated at Johnson Space Center to identify the principal objectives of a lunar base program, the current state of knowledge, and the developments necessary to perform the program.

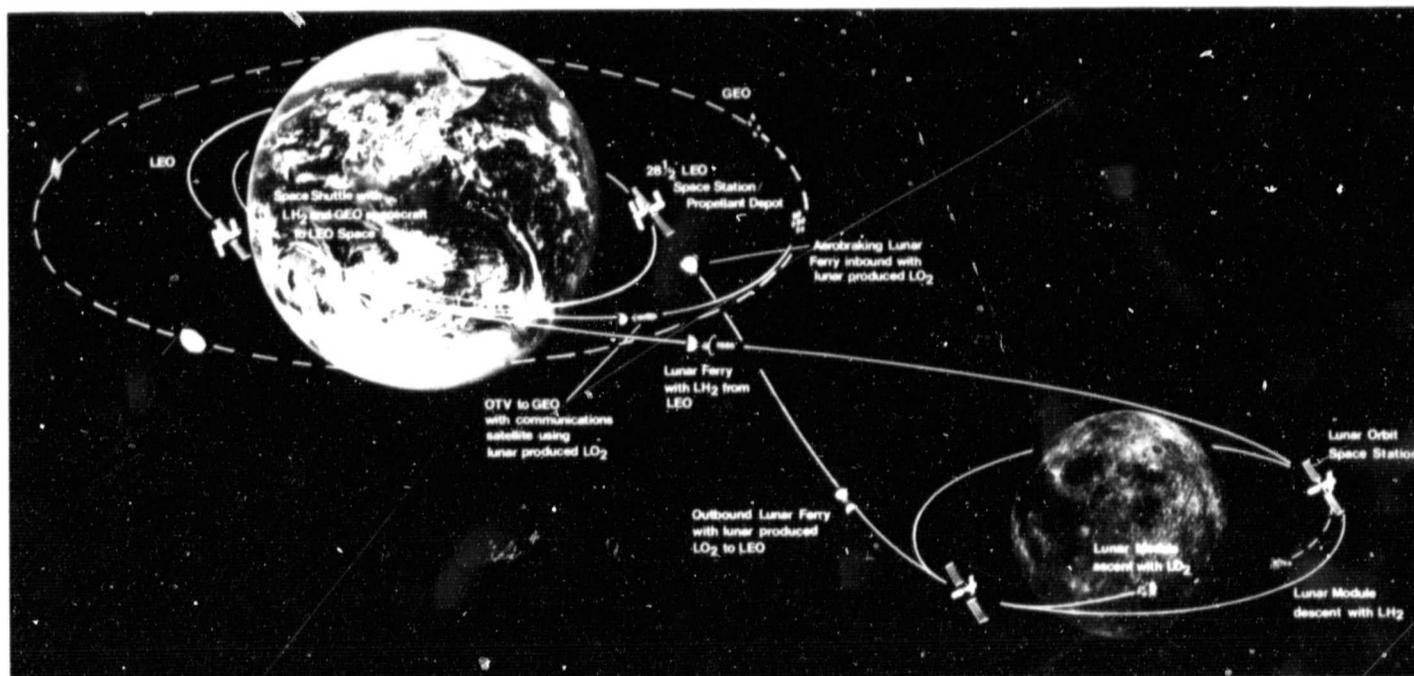
One topic addressed in a study sponsored by Johnson Space Center was the possibility that liquid oxygen (LO_2) produced on the Moon by reaction of hydrogen with the mineral ilmenite, an iron-titanium oxide, could provide a source of oxidizer for chemical rockets operating between low Earth orbit (LEO) and geostationary orbit (GEO). To achieve such a capability would require the establishment of a lunar mining and milling operation.

The system also requires the capability of bringing hydrogen from Earth, storing liquid hydrogen (LH_2) and LO_2 in Earth orbit and possibly in lunar orbit, and transferring tanks of oxygen from the lunar surface to lunar orbit and then to Earth orbit. Such a system is illustrated. Results of an analysis show that the ratio of oxygen returned to Earth orbit to hydrogen transported from Earth is 2.5:1. The proposed system uses primarily existing technology and therefore is considered conservative. Thus, the analysis emphasizes the need for further study of approaches that can increase the "mass payback ratio." Other studies for understanding potential uses of lunar materials and the lunar environment also should be undertaken.

One important element of a program to define a lunar base is the completion of a satisfactory level of lunar mapping. Existing lunar maps are incomplete at the resolution necessary to provide support for lunar base planning, particularly for polar and farside locations. A Lunar Geochemical Orbiter mission is planned by NASA's planetary exploration program, to be flown in the early 1990's. For lunar resource and lunar base exploration purposes, it is desirable to add imaging capability to the Lunar Geochemical Orbiter mission. Such a lunar mapping satellite would provide data necessary to verify the best location for and optimum uses of a lunar base, as well as establishing base maps for lunar logistics operations performed in conjunction with the base.

Work is proceeding to obtain a broad overview of lunar base requirements. The ability to establish a lunar base as an evolutionary step in the U.S. space program depends on near-term decisions with respect to the Space Transportation System. Therefore, in 1984, the interaction of the lunar initiative and space station concepts will be investigated.

The future space economy may well include importation of lunar resources for use in Earth orbit. A candidate resource under study is oxygen derived from rocks on the lunar surface. Nodes in the space transportation system will be the surface of the Earth, a low Earth orbit (LEO) space station, a station in lunar space, and the lunar surface. Transportation links will be the Space Shuttle, a translunar freighter, and a lunar module for shipment to the Moon's surface.



Spectral Properties of Submicron Powders of Iron Oxides and Oxyhydroxides

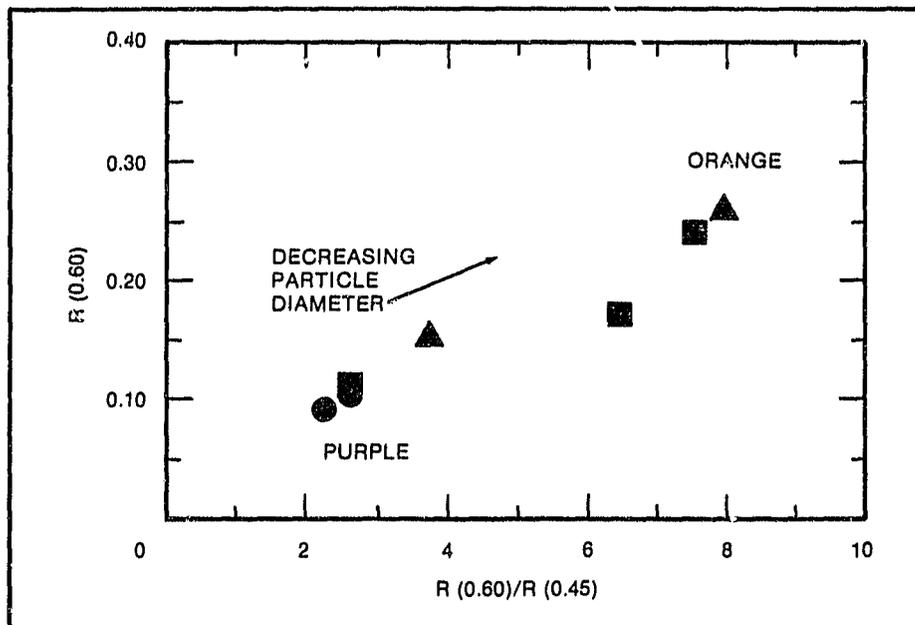
PI: Richard V. Morris/SN4
Reference OSSA 6

The spectral properties of iron oxides and oxyhydroxides are important not only for understanding the basic physics and chemistry of the compounds but also for applications such as remote sensing of the Earth and Mars, where the compounds are optically important constituents of the surficial material. Spectral reflectance measurements between 0.35 and 2.20 μm over the temperature interval between about -110° and 20° C were made for a suite of well-characterized submicron powders of iron oxides and oxyhydroxides having the nominal mineralogy hematite (α - Fe_2O_3), maghemite (γ - Fe_2O_3), magnetite (Fe_3O_4), goethite (α - FeOOH), and lepidocrocite (γ - FeOOH). Departures from the nominal mineralogies and the physical characteristics of the individual powders were determined by a variety of physicochemical data including mean particle diameter, particle shape, chemical composition, crystallographic phase, magnetic parameters, and Mossbauer parameters. Only the nominal magnetite powders had significant departures from the nominal mineralogy because of their fine particulate nature; they were actually cation-deficient magnetites having about 18.0 wt% FeO as compared with 30.0 wt% FeO for stoichiometric magnetite.

A structured absorption edge due to crystal-field transitions extending from weak absorption in the near-infrared to intense absorption in the near-ultraviolet is characteristic of the ferric oxides and oxyhydroxides and is responsible for their intense color. Particularly for hematite, the number and position of the spectral features were consistent with significant splitting of the degenerate cubic levels by noncubic components of the crystal field. The position of the crystal-field band at lowest energy, assigned to the envelope of the components of the split cubic 4T_1 level, was near 0.86, 0.91, 0.92, and 0.98 μm at room temperature for hematite, goethite, maghemite, and lepidocrocite, respectively. Comparison with Mossbauer data suggests that covalent character increases sequentially through the aforementioned series. The positions of the spectral features were relatively independent of temperature down to about -110° C. The maximum shifts observed were on the order of 0.02 μm shortward for the ferric oxyhydroxides. Variations in the magnitude of the spectral reflectance for hematite as a function of mean particle diameter were consistent with scattering theory. The absorption strength of the crystal-field bands increased with increasing mean particle diameter over the range 0.1 to

0.8 μm ; visually, this increase corresponds to a change in color from orange to deep purple. This effect is shown quantitatively. The position of the split cubic 4T_1 band shifted longward by about 0.02 μm with decreasing mean particle diameter; this effect is consistent with wavelength-dependent scattering. The cation-deficient magnetite powders were very strong absorbers throughout the near-ultraviolet, visible, and near-infrared wavelengths; their spectral properties were independent of temperature between about -110° and 20° C.

Plot of reflectivity R at 0.60 μm against the ratio of reflectivity at 0.60 μm to that at 0.45 μm for submicron hematite powders.



Experimental Trace-Element Geochemistry

PI: Gordon A. McKay/SN4
Reference OSSA 7

Igneous processes involving the production, migration, and crystallization of silicate melts are known to have been important in the formation of planetary crusts on Earth, the Moon, Mars, and some meteorite parent planets, and probably on Mercury and Venus as well. Such processes leave distinctive signatures on the chemical and isotopic compositions of the rocks they produce. One goal of planetary geochemists is to try to reconstruct the history of these processes by deciphering the chemical signatures found in rocks from planetary crusts. Some particularly useful signatures are carried in the abundances of elements that are present in most rocks in very small concentrations. The abundances of these "trace" elements are strongly influenced by their "partitioning" between silicate melts and rock-forming minerals in contact with these melts. Hence, a record of the history of melt-mineral interactions will be retained in the trace-element abundances of resulting rocks.

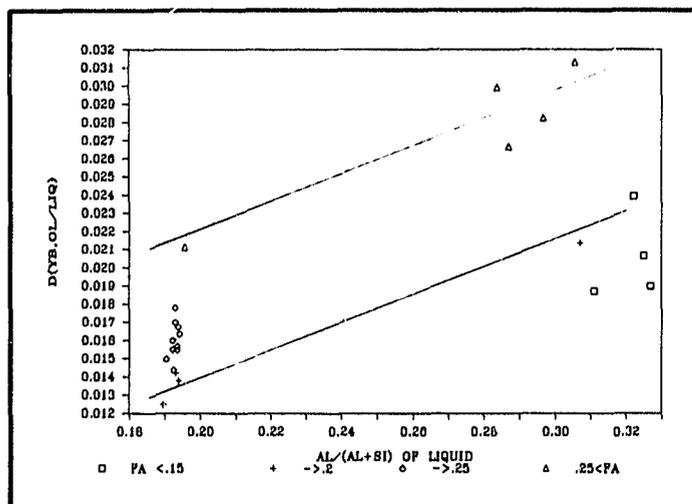
One approach to using trace-element abundances to unravel the history of melt-mineral interactions is through mathematical modeling. In this approach, a plausible history of melt-mineral interactions leading to a particular sample is postulated, the effects of this history on trace-element abundances are modeled, and the resulting calculated abundances are compared with observed abundances.

One major limitation to this approach is that not enough is known about melt-mineral partitioning for many trace elements and minerals. Partitioning is influenced in unknown ways by many variables in nature. To improve knowledge of trace-element partitioning, an ongoing program of partitioning studies is being conducted at Johnson Space Center. The experimental approach consists of equilibrating synthetic rock compositions at near-liquidus temperatures and pressures, quenching the equilibrated charges to room temperature, and measuring the concentrations of selected elements in the resulting crystals and surrounding glass by using special electron microprobe techniques with sensitivities of about 10 p/m. From the trace-element concentrations obtained in this manner, distribution coefficients are computed for use in the mathematical models.

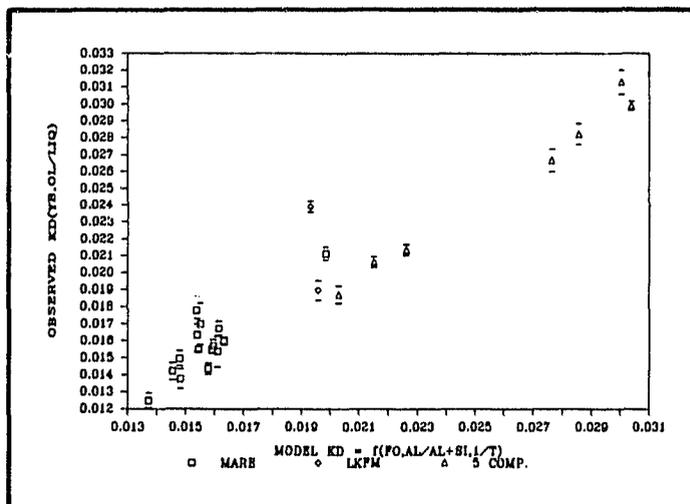
Recent work has focused on understanding the manner in which mineral and melt compositions affect distribution coefficient (D) values for the partitioning of rare earth elements (REE) between olivine and lunar basaltic melts. Results suggest that values are strongly correlated with the composition of olivine and with the ratio of aluminum (Al) to aluminum plus silicon (Al+Si) in the melt. These correlations are illustrated for one of the REE, ytterbium (Yb). For each range of olivine composition, there is a parallel correlation of $D(\text{Yb})$ with $\text{Al}/(\text{Al}+\text{Si})$. These results have been incorporated into an empirical model which predicts $D(\text{Yb})$ as a function of the compositional parameters and temperature.

Results from these and other experiments have been incorporated in model calculations to investigate the petrogenesis of lunar anorthosite, a major constituent of the original lunar crust. These calculations suggest that formation of anorthosites by simple crystal accumulation from relatively unfractonated liquids does not violate constraints imposed by REE systematics. Uncertainty remains in the absolute and relative values for europium and the trivalent REE for application to anorthosite petrogenesis. It is important to continue investigating distribution coefficients for application to this problem.

Olivine/melt distribution coefficient for Yb vs. Al/Al+Si of the melt. Symbols correspond to different ranges of olivine composition (FA). Parallel correlation trends are shown for two different FA ranges.



Observed values for olivine/melt Yb distribution coefficient vs. values predicted from empirical model based on olivine composition, melt $\text{Al}_i/\text{Al}+\text{Si}$, and temperature. Different symbols are used for the three melt compositions studied: lunar mare and highlands basalts and a simple five-component synthetic mix.



Trapped Solar Gases in a Lunar Meteorite

PI: D. D. Bogard/SN4
Reference OSSA 8

We have measured the isotopic abundances of the noble gas elements helium (He), neon (Ne), argon (Ar), krypton (Kr), and xenon (Xe) in a primarily matrix sample of Antarctic meteorite ALHA81005, which may have had a lunar origin. This sample contained very large concentrations of obviously implanted solar-wind gases. Absolute concentrations and relative abundances of these trapped gases are quite similar to typical solar-gas-rich soils and breccias returned from the Moon. Isotopic compositions of the trapped gas in ALHA81005 are also identical to solar gas trapped in lunar samples (e.g., trapped $^4\text{He}/^3\text{He} = 2600$, $^{20}\text{Ne}/^{22}\text{Ne} = 12.5$, $^{40}\text{Ar}/^{36}\text{Ar} = 1.8$). Isotopic ratios of Kr and Xe plot on the mass-fractionation trends for lunar soils, and there is no obvious evidence of excess radiogenic ^{129}Xe or fission-produced Xe.

Fayetteville and Pesyanoe are the two regolith-derived meteorites with the largest known concentrations of solar-wind gases. Although the ^4He concentration in Pesyanoe is as high as in ALHA81005, the other noble gas concentrations in Pesyanoe are much lower; consequently, Pesyanoe has a much less fractionated noble gas abundance pattern compared to ALHA81005 and to lunar fines and breccias. Meteorites rich in solar gases typically have considerably less mass fractionation of gases (e.g., much larger $^4\text{He}/^{132}\text{Xe}$) compared to lunar samples. This fact is probably due to the much higher levels of regolith gardening and ion reimplantation, with accompanying mass-fractionated gas loss, of lunar regolith compared to regoliths on meteorite parent bodies. A preliminary value for the potassium (K) concentration of the ALHA81005 matrix indicates that $\sim 1.4 \times 10^{-6}$ cm³/g of radiogenic ^{40}Ar should be produced in 4 b.y. The measured ^{40}Ar concentration in ALHA81005 of ~ 20 times this value strongly suggests the presence of an atmosphere-implanted

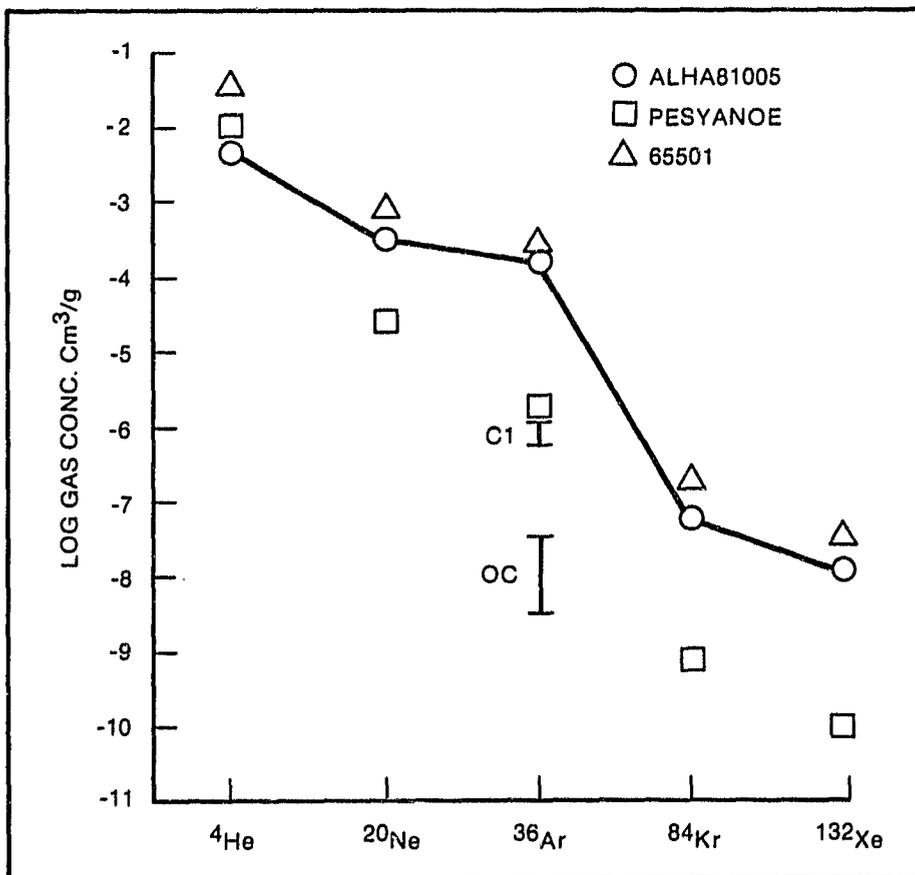
^{40}Ar component, which is a typical occurrence on the Moon throughout much of its history. Presumably for an asteroid parent body, the much shorter gravitational escape time for ^{40}Ar , the much smaller cross section of the parent body surface, and the likely weaker solar-wind fields would greatly reduce the effectiveness of the atmospheric-implantation process. In fact, the $^{40}\text{Ar}/^{36}\text{Ar}$ ratios in the Pesyanoe and Fayetteville meteorites are much larger than in ALHA81005 and lunar soils, and much of the ^{40}Ar in the first two meteorites is due to in situ decay of K.

Even noble gas isotopes with low relative abundances (e.g., ^3He and ^{38}Ar) are primarily of solar-wind origin in ALHA81005. However, if we adopt a trapped $^{21}\text{Ne}/^{22}\text{Ne}$ ratio of 0.030, we estimate that about 17% of the measured ^{21}Ne , or $\sim 26 \times 10^{-8}$ cm³/g, is

cosmic ray produced. For a lunar surface irradiation, this value would represent at least 100 m.y. of cosmic-ray exposure.

The presence of large concentrations of solar gases in ALHA81005 clearly indicates that the matrix was finely spread on a surface exposed to the solar wind for a period of time before breccia formation. The large concentrations of solar gases with a mass-fractionation pattern like lunar regolith samples, the excess concentrations of radiogenic ^{40}Ar , and the suggestion of long cosmic-ray exposure are all consistent with an origin of ALHA81005 from the lunar regolith. Such characteristics are dissimilar to known meteorites and may be difficult to reconcile with an origin from the regolith of an asteroid.

Measured noble gas concentrations in a matrix sample of ALHA81005, in the solar-gas-rich meteorite Pesyanoe, and in lunar fines sample 65501. Also shown are the typical range of ^{36}Ar concentrations in ordinary chondrites (OC) and in type 1 carbonaceous chondrites (C1).



In Situ Measurements of Stratospheric Ozone

PI: Donald E. Robbins/SN3
Reference OSSA 9

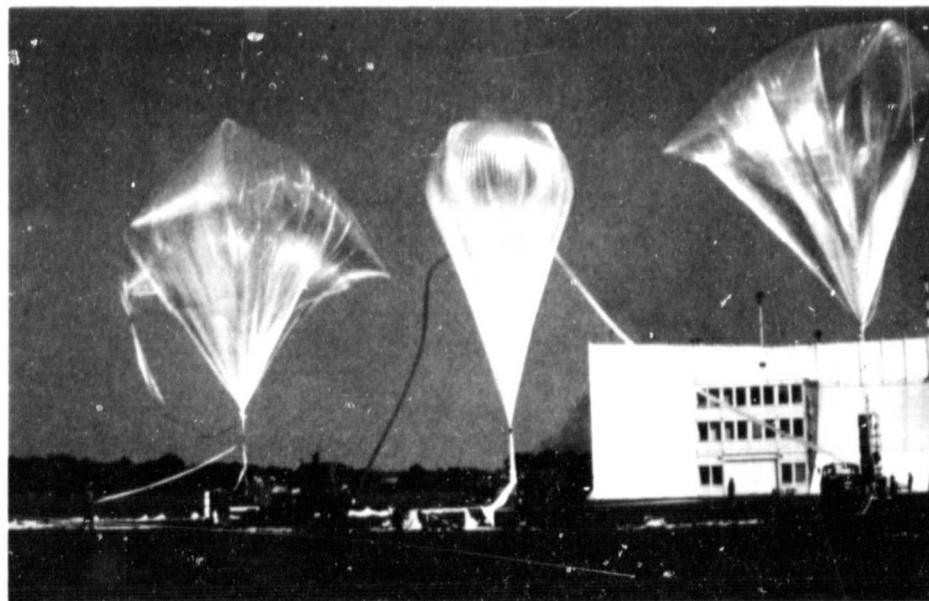
The objective of this study is to measure atmospheric ozone with the highest accuracy possible to aid in validating satellite measurements and testing models used to study the chemistry of stratospheric ozone.

Less than 5 years ago, the best accuracies quoted for in situ ozone measurements were in the range of 15%. Measurements of ozone vertical distributions are required within an accuracy of 3% to 5% to adequately assess the long-term stability of ozone. During 1982 and 1983, several improvements were made to the Johnson Space Center (JSC) ozone instrument that allow measurements of ozone with an accuracy within 3% at altitudes below 35 km. Although the instrument is capable of making measurements as high as 45 km, some questions about possible loss of ozone on the walls of the inlet line and absorption cell at higher altitudes have arisen. A task of assessing the magnitude of these losses has been initiated.

The JSC has participated in four international balloon campaigns to assess accuracies of techniques used to measure species involved in ozone chemistry. We were the only group to provide in situ measurements of ozone during the two flights of the Balloon Intercomparison Campaign (BIC). Those flights were made in September 1982 and June 1983. Data reduction has been completed. Analysis and comparison with results of the remote measurement techniques are in progress. Two flights were made during the Balloon Ozone Intercomparison Campaign (BOIC), one on a Goddard Space Flight Center gondola on which five other groups made in situ measurements. Data analysis and comparisons are in progress. The second flight of BOIC was on a University of Minnesota gondola that carried a mass spectrometer to measure the ozone profile. Analysis of data is in progress. Three of these balloon flights (the two of BOIC and BIC-II) were made within 1 month during the summer of 1983.

We have participated in the September 1983 campaign of the MAP/GLOBUS program in France. The JSC made two balloon flights as part of that campaign and serves as the "transfer standard" to allow inter-comparisons between the European campaign and the American BIC and BOIC campaigns.

Preparing balloons for flight.



Radar Studies of Active Experiments in the Ionosphere

PI: R. Jerry Jost/8N3
Reference OSSA 10

An integral component that links the Sun and the Earth is the ionosphere. The ionosphere is a zone of plasma created by the effect of solar radiation on gases in the upper atmosphere (60 to 1000 km altitude) and is typically defined as that part of the atmosphere in which free electrons exist in sufficient numbers to affect radio-wave propagation. Magnetic storms and auroras may disrupt the transmission of radio and telecommunication signals in the ionosphere. Plasma motions and electric currents in this region affect, and are affected by, processes in the magnetosphere above and the atmosphere below. Therefore, the ionosphere is an important region in terms both of the physical processes that link the Sun and the Earth and of navigation and telecommunication systems.

For almost a decade, research interest in the ionosphere has evolved from describing its general characteristics to detailed investigations of its many naturally disturbed states as well as intentional, artificially produced disturbances. These disturbances are characterized as plasma irregularities spanning wavelengths or scale lengths from hundreds of kilometers to fractions of a meter. An ideal, inexpensive technique for studying these irregularities is to use ground-based, remote-sensing radar. The Johnson Space Center (JSC) has directed activities toward developing a portable very high frequency (VHF) backscatter radar that is particularly suited for measuring several parameters of ionospheric disturbances, either natural or artificial, at wavelengths of a few meters. The primary study emphasis has been placed on active experiments, in which the ionosphere is used as an infinite laboratory and is intentionally perturbed to trace natural phenomena or to excite physical processes that induce these phenomena artificially. Because these experiments are complex, they are typically performed in collaboration with other domestic government agencies, universities, or foreign governments. The JSC research has concentrated on ionospheric modification through

high frequency (HF) radio-wave heating and chemical release from sounding rockets.

To be specific, during HF heating experiments conducted in conjunction with Arecibo Observatory in the Caribbean Sea, the JSC 50-MHz radar has been used to monitor the development of short-scale (3 m) geomagnetic-field-aligned plasma irregularities artificially produced in the ionosphere. The generation of short-scale ionospheric irregularities is observed when a high-power HF wave reflects at various "zones" or layers in the ionosphere. The theoretically important parameters of the irregularities measured by the radar are the growth and decay time constants, the long-term temporal behavior, and the absolute radar cross section. The experiment technique is illustrated.

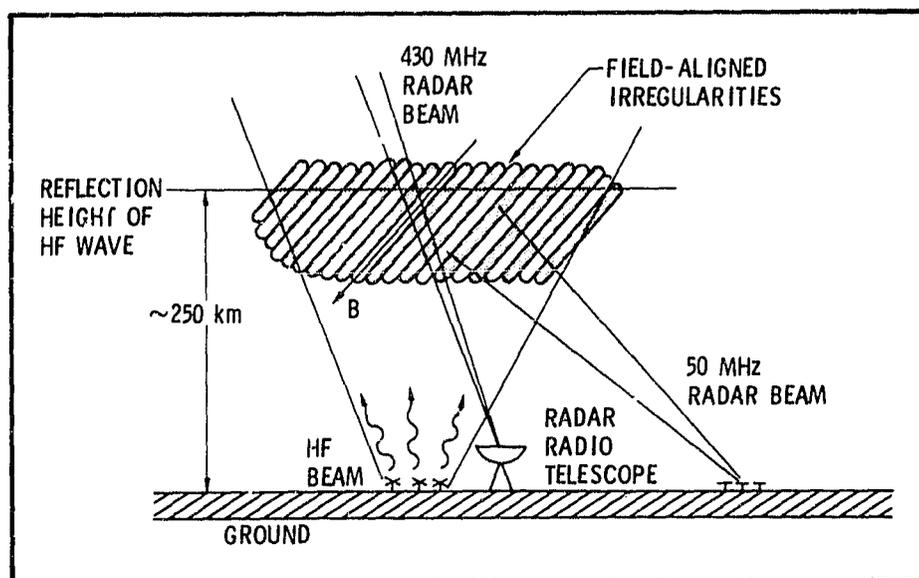
Similar measurements have been conducted in Scandinavia in collaboration with European research teams, using a high-power HF facility located in northern Norway, to artificially perturb the auroral ionosphere. Data from the high-magnetic-latitude experiments can be compared to the similar mid-magnetic-latitude data from Arecibo Observatory to help determine the function of the geomagnetic field in controlling the energy-transfer process from the incident heated

high-power HF wave to the ionospheric plasma.

Chemical release experiments have been conducted at the equatorial zone as part of an international sounding rocket campaign. The program included water-vapor releases and barium releases designed to deplete the ambient plasma to stimulate and control naturally occurring depletions that develop during magnetic storms. Using a VHF radar, the sharp reduction in plasma concentration can be traced by plasma irregularities that form along the sides of the ionospheric "hole." Information on the temporal development of the irregularities and their spatial motion is important for understanding the energy-balancing mechanisms that control the natural interaction between the ionosphere and the magnetosphere through the global current systems in the equatorial zone.

In addition to the studies of artificially produced disturbances, the JSC radar has been used in auroral studies and measurements of naturally occurring ionospheric turbulence in the equatorial zone. The portable JSC radar is an important tool in the overall comprehensive study of the solar-terrestrial linkage being undertaken by NASA and other government agencies.

Ionospheric modification experiments.



Hypervelocity Impact Studies of Composite Materials

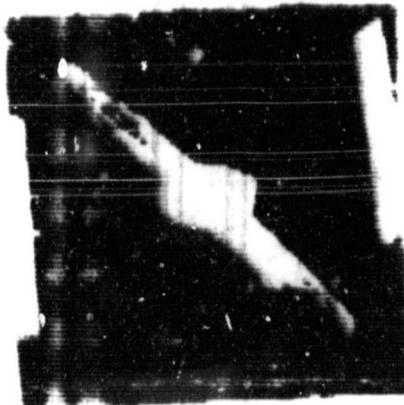
TM: Jeanne Lee Crews/SN3
Reference OSSA 11

Commercially available composite materials such as graphite/aluminum, boron/epoxy, graphite/epoxy, and Kevlar/epoxy are being used in aerospace applications on an increasing scale (e.g., airplane wing panels; the Orbiter payload bay doors and high-pressure tanks). These materials and other composites under development are replacing aluminum and magnesium for certain types of structures because of their unique physical properties (i.e., high stiffness coupled with low thermal deformation) and directional strength properties tailorable to the application.

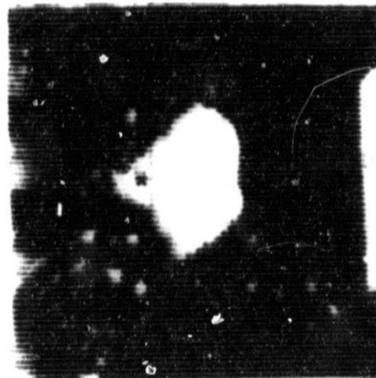
Their use for the primary surfaces of long-duration space structures will result in exposure to meteoroid and space debris impacts at average relative speeds (U) between 10 and 20 km/sec. To investigate the resistance of composite materials to hypervelocity impacts, a small light gas gun was built. The gun can fire small (5 mg) projectiles at velocities ranging from 3.5 to 6.5 km/sec. The major objective of this work is to evaluate the use of a number of composite materials as spacecraft structural components exposed to micrometeoroid and space debris impacts. Hypervelocity impact data will be analyzed to evaluate (1) impact resistance of various composite materials as a function of thickness, layup density, directional properties, epoxy content, temperature, loading, angle of impact, etc., and (2) debris generation potential and particle size distributions of composite materials.

The first test series using a symmetric layup of graphite epoxy is being analyzed. The first stage of the damage assessment has concentrated on the development of various techniques for assessing the damage inflicted to a composite plate from impact and penetration by a foreign object of known properties, traveling at hypervelocity. The damage assessment techniques include visual evaluation and classification of the mode of the damage and scanning of the plate with an ultrasonic scanning device, which, when suitably calibrated, records the extent of the damaged area of the plate. The damaged plate is subsequently cut with a high-speed diamond saw through the thickness and in planes containing the damage crater. The new surfaces are suitably polished and then carefully examined under a microscope. The purposes of these examinations are to record any special characteristics of the damage and to quantify wherever possible the results of the scanning process by identifying the extent of major structural degradation such as delamination and severe matrix damage. Some of the first results of this effort are shown.

Scan of specimen 6A (symmetric layup) at 63 dB (back side). $U = 5.1$ km/sec.



Scan of specimen 12AM (symmetric layup with cloth faceplates) at 65 dB (front side). $U = 6.32$ km/sec.



Through-thickness damage of specimen 8A (magnification $\sim 12\times$). The front side is at right edge. $U = 4.9$ km/sec.



Beam Plasma Discharge Studies

PI: Andrei Konradi/SN3
Reference OSSA 12

Energetic electron beams injected from sounding rockets, satellites, and the Space Shuttle have been used in tracer and environment perturbation experiments. To understand all the effects produced, it is important to know the interaction of the electron beam with the space plasma environment in its immediate vicinity. The beam plasma discharge (BPD) studies currently conducted at Johnson Space Center in cooperation with W. Bernstein of Rice University were initiated with a twofold goal: (1) to explore BPD in terms of parameters governing the discharge for the purpose of replicating and explaining certain features of flight experiments and (2) to study and determine the physical processes involved in BPD production.

After decommissioning of the large vacuum chamber at Johnson Space Center in 1981, a smaller BPD device was built and put in operation for the purpose of continuing beam-plasma interaction studies. It consists of a 1-m-diameter stainless steel tank, which provides a beam path length of 2.6 m. The base pressure is 5×10^{-7} torr and can be increased in a controlled fashion to 1×10^{-3} torr. A set of coils provides a variable axial magnetic field intensity to 38 G. A Pierce diode electron gun with a perveance of $1 \times 10^{-6} \text{ AV}^{-3/2}$ provides an electron beam with energies to 2.5 kV. Beam plasma discharge was easily achieved in nitrogen, argon, and helium. Since the parameters of the experimental device deviated markedly from those previously available in the large chamber, the first study involved the verification of previously obtained scaling laws governing BPD ignition. The measurements indicate that the empirical ignition criteria determined earlier in the large chamber apply in the small device but do not fit when used for extrapolation between the large and the small geometry. Thus, for

$$I_c = k \frac{E^{3/2}}{B\rho L} \quad (1)$$

where I_c , E , B , ρ , and L are critical ignition current, beam energy, magnetic field intensity, neutral pressure,

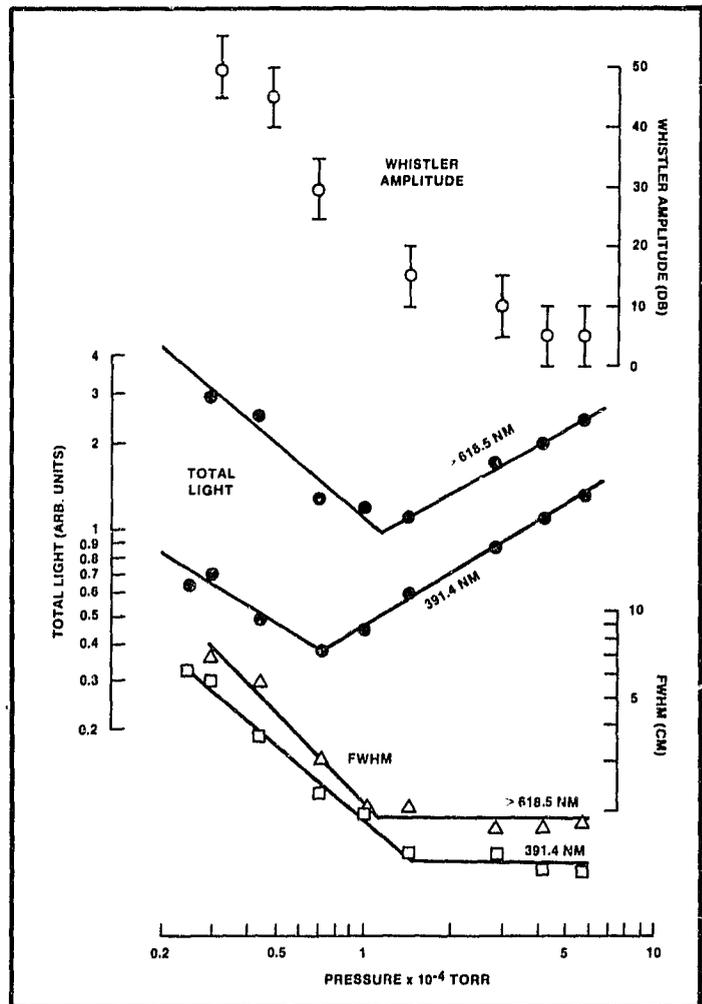
and beam path length, respectively, we find that the value of the proportionality constant k for the small chamber exceeds that for the large chamber by more than an order of magnitude.

Recent exploration of the BPD low-pressure regime, which was inaccessible in the large chamber, has yielded results that replicate flight observations made during beam injection experiments in the lower ionosphere: (1) at altitudes from 140 to 220 km, the beam-associated 391.4-nm intensity is relatively independent of altitude despite the decreasing nitrogen abundance and (2) the radial extent ($\perp B$) of the perturbed region populated by beam-associated energetic electrons significantly exceeds the nominal gyrodiameter for 90° injection. The marked change in some BPD characteristics at fixed energy, current, and magnetic

field intensity with a decrease in the neutral density is illustrated. At pressures below about 1×10^{-4} torr, the whistler amplitude increases drastically as do the total light output and the width of the discharge region. This particular pressure is peculiar to the experimental device used in the laboratory and is quite different for the unbounded environment of the ionosphere. We tentatively believe that the transition occurs at a point separating the collisionless regime from the collision-dominated regime.

Current work is focused on finding the beam plasma interaction region as a function of distance from the electron gun and investigating the BPD details in terms of radiofrequency emissions and to determine the distribution function of the resulting plasma.

Typical results of beam plasma discharge studies.



Sonic Boom Studies

TM: John Stanley/SN3
Reference OSSA 13

Space Shuttle environmental effects have been a major consideration since the conception of the program. One of the areas monitored has been sonic boom effects. Although the sonic boom associated with supersonic aircraft has been studied in depth and is relatively well understood, the Shuttle differs significantly from these aircraft in both geometric and operational characteristics, particularly during launch. The need for an experimental data base to verify or modify existing theories with respect to these differences is well recognized.

Overpressure levels have been measured during Space Shuttle landings at Edwards Air Force Base. During the STS-7 launch from Kennedy Space Center, seven sonic boom data acquisition systems were deployed on boats in the Atlantic Ocean to measure the intensity and extent of the Shuttle launch sonic boom footprint. Also, a portable, standalone, remote sonic boom monitoring system is being tested.

While traveling at supersonic speeds during launch, the Space Shuttle both accelerates and pitches over. The combination of linear and angular accelerations results in a region in which the acoustical energy is focused, as shown in the ray tracing. This region intersects the Earth resulting in a parabolic "focus zone" that

extends laterally 45 to 60 n. mi. to cutoff. Lateral cutoff is reached when the shock wave is refracted upward by the denser atmosphere.

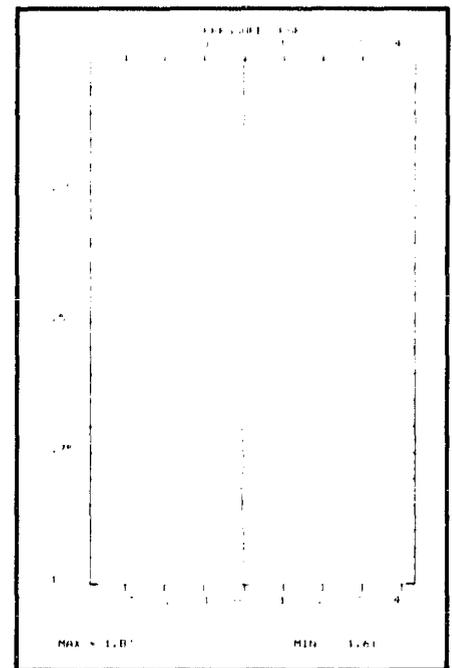
The data acquisition system used in this operation consists of four microphones with essentially a flat frequency response between 0.01 Hz and 10 kHz. Signals from these microphones are amplified, conditioned, and recorded on magnetic tape together with a time code and a voice track. The maximum overpressure received at each station is shown in the footprint illustration.

A remote monitoring system that can be deployed by one person also has been developed. The expense of measuring sonic booms will be greatly reduced by use of this system. Digitized pressure data are recorded in a memory bank until occurrence of an overpressure exceeding a predetermined trigger level, and duration within predetermined limits is detected. The data loop is then stopped with the captured data remaining in memory, time is annotated, and the next memory bank is selected. The remote system was tested during STS-7 launch and STS-8 landing with good results. A pressure signature recorded during STS-8 landing shows the classic "N-wave" shape associated with supersonic aircraft.

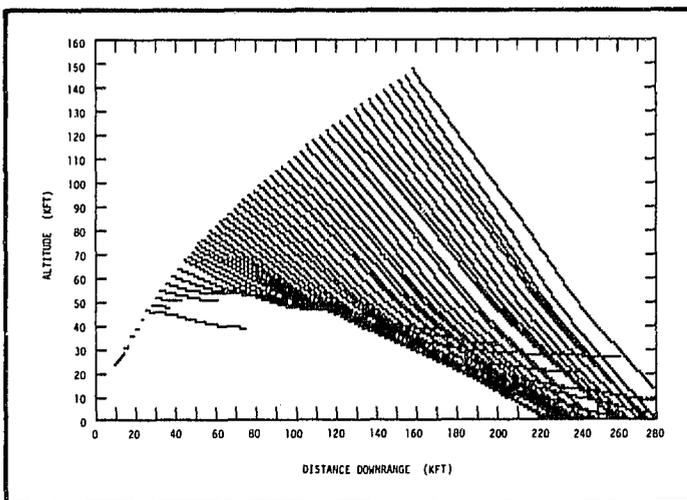
Future activities planned include the deployment of four boats during the STS-9 launch. Each boat will have

one data acquisition system and at least one remote monitoring system. Four remote systems also will be deployed in specially designed buoys, resulting in eight measurement locations. This operation will serve the dual purpose of adding to the experimental data base and enabling a comparative test between the systems. Other future activities will include monitoring the first landing in Florida by using both systems with subsequent landings being monitored using only the remote system. Launch measurements are also planned for Vandenberg Air Force Base when launch operations commence there.

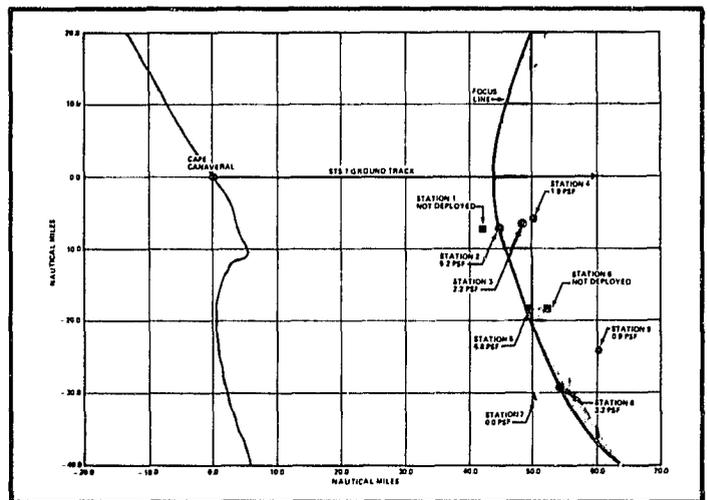
STS-8 landing sonic boom signature.



STS-7 ascent sonic boom ray tracing (actual winds).



STS-7 ascent sonic boom footprint.



Interplanetary Meteoroids

PI: Herbert Zook/SN3
Reference OSSA 14

Interplanetary meteoroids are sensed, or recorded, by way of a variety of techniques which include (1) observing "shooting stars" in the terrestrial night sky, (2) measuring impact crater size distributions on the Moon or on returned lunar rocks, and (3) recording "hits" on in-space meteoroid detectors attached to a number of different spacecraft. Some meteoroids fall to Earth and are collected as meteorites. From these observations, we have amassed considerable knowledge about meteoroid trajectories, densities, size distribution, and chemistry. The derived orbits for meteoroids show that most almost certainly have been derived from comets and asteroids. Thus, meteoroid science can be considered as part of the science of comets and asteroids.

However, after meteoroids have been displaced from their parent bodies, additional evolution usually takes place before they are observed by man. This evolution includes fragmentation due to interplanetary collisions as well as meteoroid orbit changes resulting from gravitational perturbations and from solar radiation pressure. These evolutionary processes need to be better understood to confidently trace the chain of events from observed meteoroid back to parent object.

It was shown in 1973 that the Pioneer 8 and 9 spacecraft were sensing a large flux of very small meteoroids that were leaving the solar system, never to return. Diameters for these meteoroids were deduced to be less than about $1 \mu\text{m}$. It was quickly recognized that these meteoroids were leaving the solar system under the influence of solar radiation pressure. In 1975, it was further deduced that mutual collisions in space between the larger meteoroids at distances less than 1 AU from the Sun were probably responsible for producing these particles (called beta-meteoroids).

It had already been noted by 1973 that the spatial density of microcraters on lunar rocks sharply increased for all impact pit diameters less than

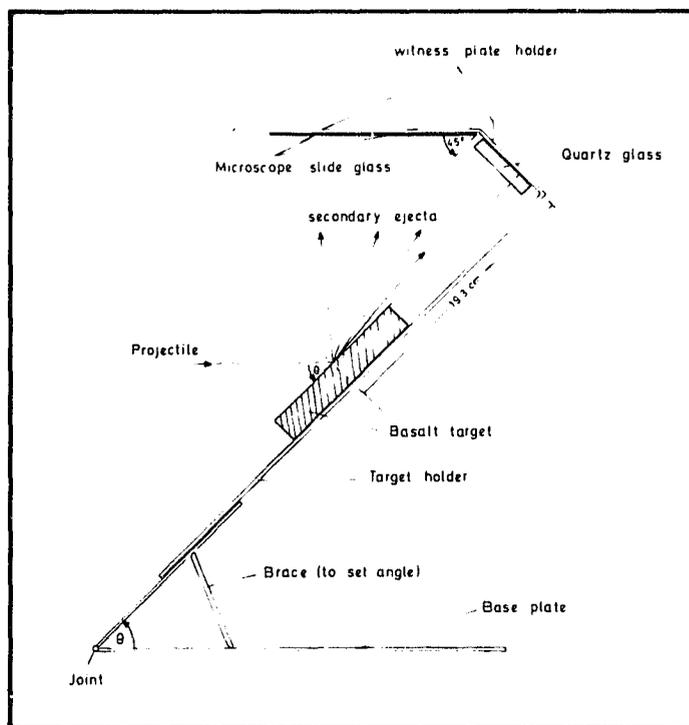
about $8 \mu\text{m}$. It seemed quite reasonable at that time to ascribe this high density of small pits as being due to impacts by beta-meteoroids. In 1978, however, it was shown that the number of small impact pits relative to large impact pits was excessively large for the preservation of mass balance under the mutual-collision hypothesis. An earlier 1975 study had examined the number of micrometer-size craters that were produced by the high-speed ejecta from hypervelocity impacts at normal incidence into glass targets. Extrapolation of these results to meteoritic velocities on the Moon strongly indicated that such impacts by meteoroids could not begin to produce the observed number of micrometer-sized craters on lunar rocks. Thus, we had arrived at a dilemma: no reasonable source could be found to produce the very small lunar microcraters.

In 1982 and 1983, new studies of hypervelocity impacts at oblique angles (7° , 15° , 30° , 45° , 60° , and 90°) onto basalt targets were performed by Johnson Space Center using light gas guns in the United States and in Germany. Glass witness plates were

placed downstream to record the cratering caused by the high-speed ejecta from such targets. The target and witness plate setup used for the tests performed in Freiburg, West Germany, is shown. The result of these new tests is that, properly averaged, more than two orders of magnitude more small craters were produced on the downstream witness plates at these oblique angles than were produced at normal incidence. The secondary craters so produced are very similar in appearance to the micrometer-size craters on lunar rocks. Thus, it is now believed that most lunar impact craters smaller than about $8 \mu\text{m}$ in diameter are caused by impacts of high-speed lunar ejecta and are not due to impacts of beta-meteoroids.

The dramatic increase of high-speed ejecta observed with oblique impacts compared to normal impact suggests that oblique impacts may also be capable of ejecting material from planets. Perhaps meteorites from the Moon and from Mars could be so ejected, as has been earlier suggested by other Johnson Space Center investigators. There are doubtless also lunar grains in our stratospheric dust collections.

Experimental setup used at Freiburg, West Germany, to examine secondary impact cratering at a variety of oblique impact angles.



**Space Sciences and
Applications
Life Sciences**

Summary

Office of Space Sciences and Applications

Life Sciences

Summary

ORIGINAL PAGE IV
OF POOR QUALITY

During fiscal year 1983, the Space Shuttle test flights STS-5 to STS-8 were completed. Life Sciences activities during this Shuttle phase, commonly known as the transition phase, have continued to focus on streamlining medical operations for the future routine operational Shuttle phase. Initial conceptual development of plans for a space station has had a small in-house beginning. Johnson Space Center (JSC) has conducted a broad range of medical research in support of the following Life Sciences Program goals:

1. To ensure the long-term health, well-being, and performance of humans in space, to characterize the medical constraints of space flight, and to enable participation by a broad segment of the population

2. To use the space environment as a means of increasing fundamental knowledge in medicine and biology

3. To conduct the research and technology development necessary for maintaining life in space on a self-sustaining basis for long periods

In 1983, the major research activities were a continuation of those directed to the goal of long-term health, well-being, and performance of humans during space-flight missions.

An in-house Medical Sciences Space Station Working Group, established in June 1982, continued to explore "Medical Operations and Life Sciences Activities on Space Station"; NASA Technical Memorandum 58248 with that title was published in October 1982. In May 1983, the space station ideas were put forth at the Aerospace Medical Association meeting in Houston. Planning activities have continued. This effort should be supportive of the overall space station planning conducted by NASA Headquarters.

In September 1983, the working group began NASA Technical Memorandum 58255 entitled "Space Sta-

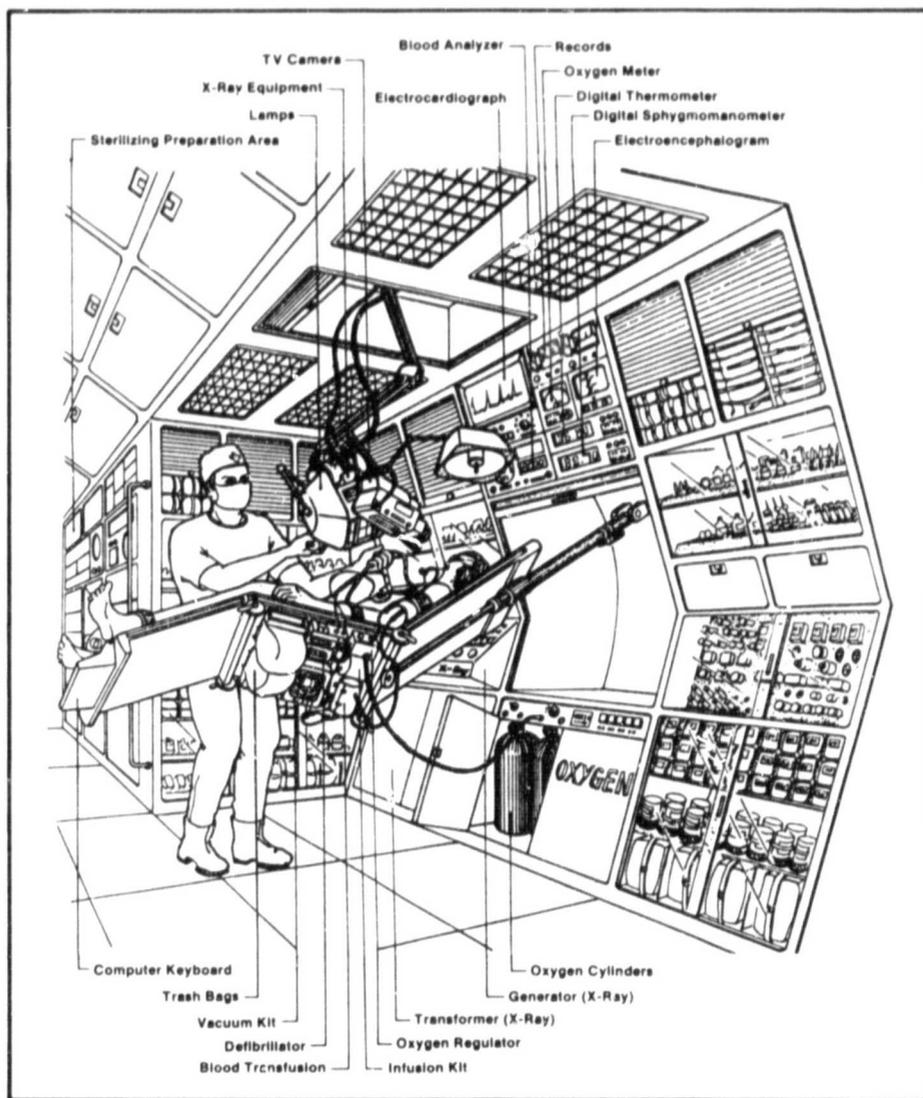
tion Medical Sciences Concepts." Sixteen medical sciences areas are discussed and illustrated by conceptual sketches, an example of which is shown.

In-house efforts have helped identify changes in physiology occurring after a human no longer is under the effects of gravitational force. Impor-

tant among these efforts are the following changes:

1. Otolith organs send out uncharacteristic signals to which the central nervous system must adapt.
2. Proprioceptive input is greatly diminished.
3. Muscles of locomotion and posture begin to respond to underuse.

Space station medical clinic.



4. Portions of the skeleton normally needed for ambulation and standing begin to lose bone mineral.

5. The increased availability of the constituents of bone and muscle requires renal, gastrointestinal, and hematologic adjustments.

6. Labile portion of extracellular fluid is removed as it is no longer needed.

7. Fluid adjustment tends to unload the heart, decreasing its end diastolic volume and causing cardiac muscle changes.

1983 Physiological Investigations

Since the onset of manned space flight, NASA has been a leader in the biomedical community for motion sickness research. It has been theorized that understanding the neural adaptations to changes in the gravitational vector direction will lead to a better understanding of motion sickness both on Earth and in orbital flight. An increased emphasis and effort to understand the causes and to prescribe countermeasures has been indicated by the establishment of the new NASA Space Biomedical Re-

search Institute (SBRI) supported by the Universities Space Research Association (USRA) Division of Space Biomedical Branch. An early study report of the institute has examined the central nervous system-mediated physiologic adaptation responses through an operational Biobehavioral Training Facility. The USRA's Division of Space Biomedicine will continue to work in concert with JSC in determining the causes of space motion sickness.

Another effort under the new SBRI is to use the parallel swing tests. The test employs a four-pole pendulum that produces "linear" and/or angular (roll) oscillation. Two types of responses are examined: linear self-motion detection thresholds and perceived self-motion path. The data are relevant for the hypothesis that changes in established otolith responses contribute to the symptoms of space adaptation. Other space motion sickness studies have been undertaken. These include the screening of drugs such as sublingual scopalamine as a countermeasure for the prevention or curtailment of space motion sickness.

Another effort is to use an echocardiography technique to better understand and quantify the physiologic alteration produced in the heart during space flight. Work has begun to examine altitude decompression sickness, caused by the formation of bubbles of nitrogen in the body following changes in pressure from the Shuttle cabin (14.7 psi) to the Shuttle pressure suit (4.3 psi). During 1983, 173 manned chamber tests and other tests have been conducted to validate bends prevention procedure.

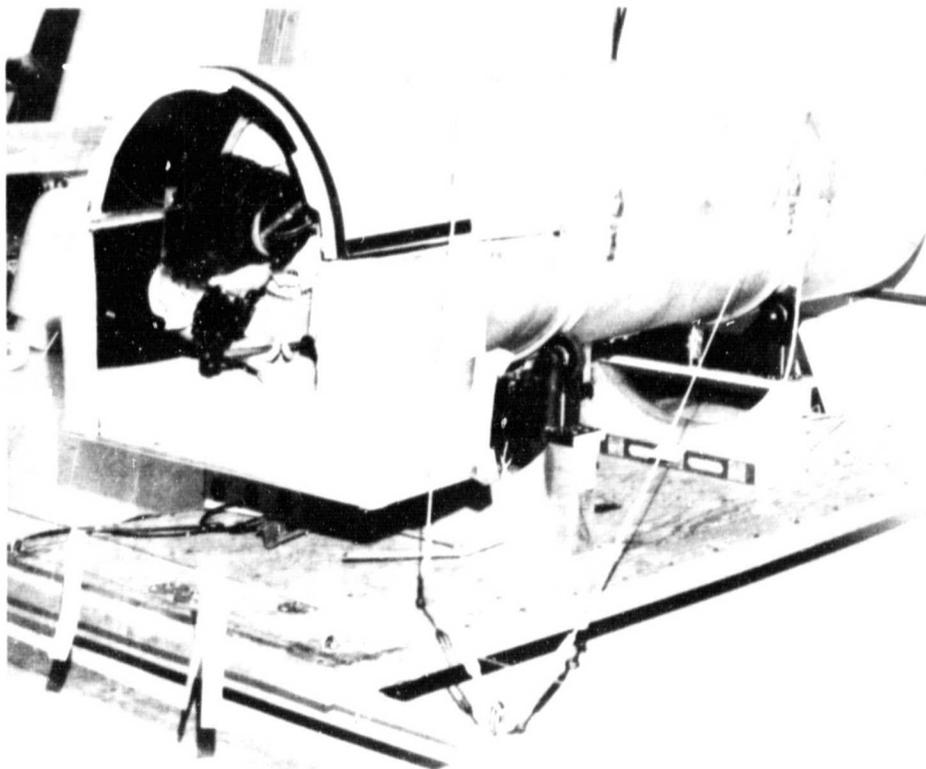
The disuse of the human skeleton and lack of stress on the skeleton produce disuse osteoporosis. This effect is especially seen in body support areas. In microgravity, the astronaut no longer uses the postural or leg muscles. If the early data produced in this program are substantiated during long-duration space flight, a program to minimize this bone loss would have to be developed before long-term missions could be safely undertaken.

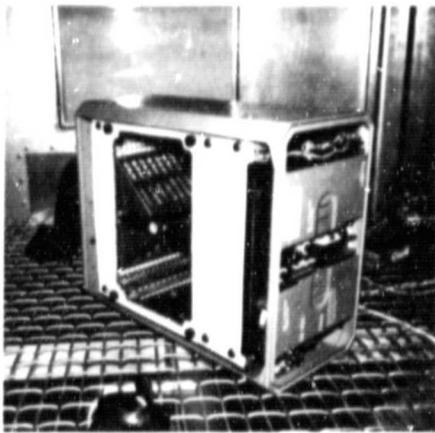
Another study related to the effect of microgravity on bones is examining bone loss by using dual-photon absorptiometry of spinal mineral density. Until recently, bone densitometry has only been measured in peripheral cortical bones. Now, with the new technique, errors that may have resulted from irregular body contour and soft tissue inhomogeneities may be identified. The Mazess machine, recently introduced into at least 50 centers around the nation and the world, has enabled the accumulation of baseline data. At JSC, normal population data are being determined so that, eventually, a longitudinal study of astronaut skeletal dynamics can be measured throughout their working careers.

As part of the current program, an animal enclosure module was evaluated on STS-8. This study represents the first attempt to fly animals in the crew compartment of a U.S. space vehicle.

Also as part of the STS-8 flight, a study of bioprocessing in space was undertaken. Electrophoresis—the separation of materials in solution by the influence of an electric field acting upon differentially charged molecules—has been shown to be enhanced by use of microgravity in the Shuttle. Separation of human embryonic kid-

The parallel swing test employs a four-pole pendulum that produces "linear" and/or angular (roll) oscillations.





Space Shuttle animal enclosure module

ney cells and rat pituitary cells was accomplished in flight

With the future space station in view and long-term flights under active consideration, emergency medical care in space has had its beginning. The chance of an illness requiring sophisticated medical care occurring in flight will increase with larger crews and longer flight durations. In 1983, work on the rehydratable intravenous system has been examining means to polish spacecraft fuel cell "waste" water to sterility equivalent to USP water. In addition, a first approximation of a minor surgery station has been flown in a KC-135 zero-g aircraft.



Minor surgery work station in the NASA KC-135 zero-g aircraft.

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**Space Sciences and
Applications
Life Sciences**

Significant Tasks

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Shuttle Echocardiography

TM: Michael W. Bungo/SD3
Reference OSSA 15

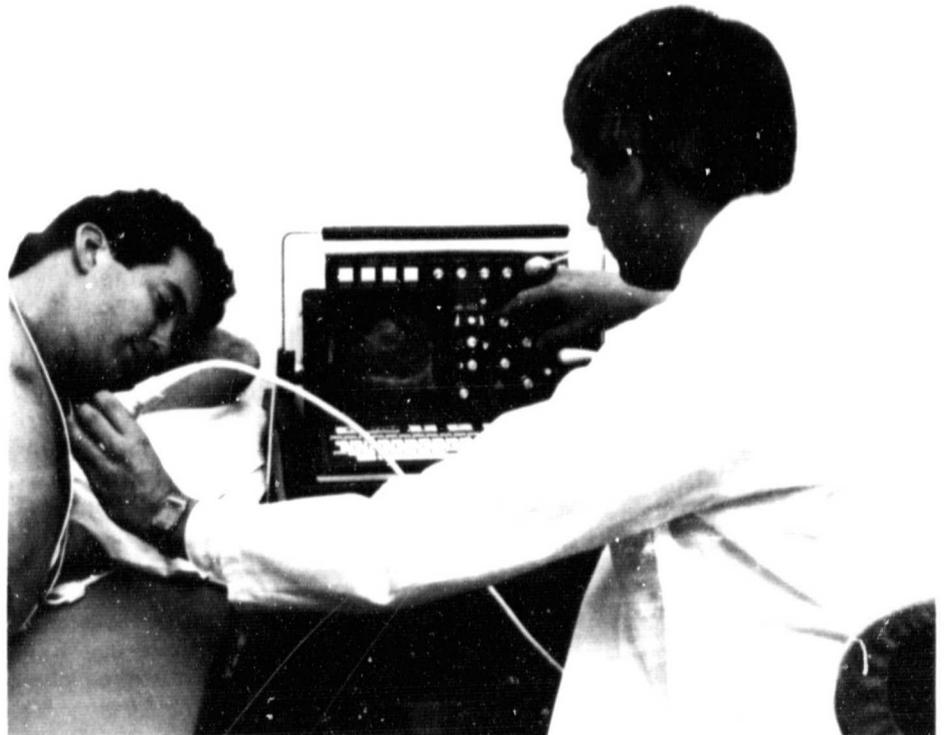
Exposure to weightlessness produces several adaptive phenomena in human physiology. One of the more pronounced changes occurs in the cardiovascular system which has now been relieved of the hydrostatic pressure gradients imposed by gravity. Intravascular volume, and to some degree interstitial volume, moves from the lower extremities to a central and cephalad position. From bed-rest studies, used as a simulation of microgravity, transient increases in right heart pressures, pulmonary vascular congestion, subsequent left heart dilatation, and renal diuresis have all been observed. The hemodynamics during space flight remain largely uncategorized. From Skylab experiments, it was documented that volume depletion did occur and that heart size was indeed reduced after flight. This decrease in intracardiac volume is accompanied by several other changes in the cardiovascular system's regulating mechanisms. The end result is a greater susceptibility to orthostatic stress. Even the simple stress of standing has produced syncope (fainting) in some returning Shuttle crewmembers.

To better understand and quantitate the physiologic alterations produced in the heart during space flight, echocardiographic examination of Shuttle crewmembers was instituted during the last year. A commercially available ultrasound scanner was employed in standard clinical fashion, and pre-flight and postflight real-time cardiac sector scans were obtained by Johnson Space Center on as many crewmembers as possible. Analysis of the data was performed in conjunction with Ames Research Center and Stanford University. Data are being reviewed for statistical significance; however, it is apparent that the volume deficit imposed by space flight remains uncorrected for at least a week after flight, and that possible decreases in cardiac mass might accompany these changes but without a symptomatic decrement in cardiac performance indices.

Plans are being initiated to expand this data acquisition to include in-flight parameters and to use these findings in deriving therapeutic or prophylactic adjuvants for cardiovascular deconditioning.

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Echocardiograms are obtained before and after flight in the resting subject. The examination is simple, painless, and yields considerable data on the performance of the heart.



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Operational Biobehavioral Training Facility

TM: Sam L. Pool/SD
PI: Leonard Gardner
Reference OSSA 16

Space adaptation syndrome refers principally to central nervous system-mediated physiologic adaptation responses to the microgravity environment of space. These responses have included a variety of symptoms and signs which in many ways resemble the pathophysiology of terrestrial motion sickness. It is important to acknowledge that the symptoms reported by about half the astronauts are time-limited in that they spontaneously remit in about 2 to 3 days, during which adaptation to the new environment is achieved. However, while present, these symptoms affect the crewmember's well-being and to some extent work scheduling and productivity. Symptom profiles vary in quality and intensity and have not been adequately treated by pharmacologic countermeasures. Studies conducted by the Ames Research Center and by the U.S. Air Force suggest the use of nonpharmacologic countermeasures; specifically, preflight biobehavioral training in physiologic self-regulation with emphasis on autonomic nervous system-mediated changes which are part of the pathophysiological response to provocative motion stimuli.

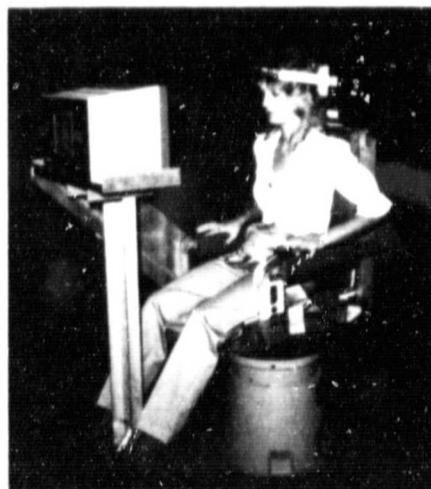
To investigate the efficacy of this approach in ameliorating the symptoms of space adaptation syndrome, an operational biobehavioral training facility has been established at Johnson Space Center. It incorporates psychophysiological monitoring and biofeedback capability of various physiologic parameters which are activated by provocative motion stimuli and which correlate with the onset of subjective discomfort and symptoms of motion sickness. Biofeedback techniques may be combined with various clinically effective complementary behavioral training techniques. Combined biological-behavioral approaches have been shown to increase training efficiency and to maximize the extent and durability of the learned voluntary control of psychophysiological responses. This general biobehavioral approach focuses on the "output side," that is, on the body's physiologic response to motion stimuli, irrespective of the specific precipitating stimulus or of the intervening neural processing mechanisms. In space adaptation syndrome, the precipitating stimulus, weightlessness, cannot be avoided or manipulated; additionally, the mediating neural mechanisms are neither sufficiently understood nor subject to manipulative control. Thus, countermeasures focused principally on the "output side" may prove to be the most effective ameliorating approaches, at least in the short term. The biobehavioral training approach has the additional advantage of posing no risk to trainees and of being readily available for evaluation as a countermeasure.

Biobehavioral countermeasures are not viewed as a panacea for space adaptation syndrome; rather, they might be viewed best as short-term palliatives, useful until other efficacious countermeasures are available, or perhaps as continuing adjunctive treatment. Concomitant use of pharmacologic agents and biobehavioral training techniques has been shown to be effective in reducing therapeutically effective dose levels. Such reduction is especially important when drugs of choice have undesirable side effects since these also often are diminished. Many of the drugs suggested as anti-motion-sickness countermeasures are not likely to be effective

in ameliorating the typical "sopite" symptoms (cognitive lethargy) unless they induce such side effects. Thus, behavioral training may continue to be advantageous in both the long and the short term by promoting a possible synergistic effect in a combined pharmacologic-biobehavioral countermeasure.

The focus of this biobehavioral training facility is to help maximize operational efficiency. The unpleasant and possibly debilitating symptoms of space adaptation syndrome jeopardize a crewmember's energetic vitality and physical well-being as well as operational schedules and productivity. Active physiologic self-regulation and integral personal control strategies may prove to be effective in precluding or mitigating these symptoms and their untoward effects on mission operations.

Biobehavioral training. During continuous rotation, the subject is provided on-line information on physiological functioning. Intermittent provocative head movements induce psychophysiological responses which presage the development of motion sickness. Training consists of the subject learning to integrate the physiologic feedback information with behavioral techniques to achieve control over the induced psychophysiological responses and thereby to preclude the progressive symptom development of motion sickness.



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Scopolamine Assay Development and Application

PI: Nilitza M. Cintron-Trevino/SD4
Reference OSSA 17

The potential incidence of space motion sickness constitutes a major concern to the successful operation and efficient performance of crewmembers during future Shuttle missions. For this reason, major research efforts are currently directed toward the development of effective countermeasures which will allow for the prevention and/or curtailment of this microgravity-induced syndrome. Scopolamine, an anticholinergic agent with a potent antiemetic effect, has been selected as one of the primary candidates for evaluation as a prophylactic drug for use during space flight. Despite its clinically widespread use, no direct and sensitive method has been available to assay the extremely low levels of scopolamine found in biological fluids after therapeutic doses. The lack of such an analytical capability has presented major impediments to the reliable assessment of scopolamine's pharmacokinetic properties relative to its pharmacodynamic actions and to its suitability for use in space.

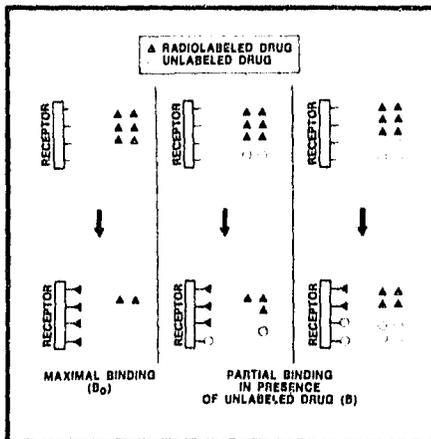
A direct and relatively simple procedure for the quantitation of low picogram levels of scopolamine in both plasma and urine has been developed in the Biomedical Laboratories at the Johnson Space Center. The method consists of two distinct steps performed in sequence: a preparative extraction step involving reverse-phase liquid chromatography and an analytical determinant step involving a muscarinic radioreceptor assay. The latter is based on the antimuscarinic properties of the drug and its capability to compete with tritiated [³H] methyl scopolamine for specific receptor binding sites. The overall recovery of scopolamine throughout the entire procedure is consistently 85% to 95% when the drug is added in varying amounts to normal human plasma and urine. Using labeled drug of high specific radioactivity, the assay has been shown to reliably detect scopolamine concentrations in body fluids as small as 25 pg/ml. This demonstrated high level of sensitivity coupled with the simplicity of sample preparation and analysis provides the basis for achieving the pharmacokinetic and pharmacodynamic characterization of scopolamine.

Initial kinetic studies applying the developed procedure have been performed in conjunction with ongoing studies directed at evaluating the comparative efficacy and applicability of various scopolamine dosage forms for use during space flight. Salient among the formulations examined have been the scopolamine transdermal system, the buccal Synchro tablet, and the sublingually administered scopolamine. An example of plasma scopolamine concentrations following transdermal administration to normal human subjects is shown.

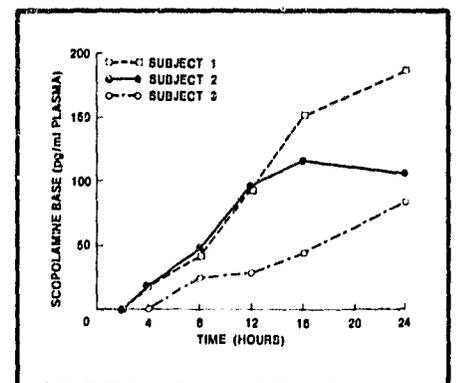
Further efforts in this area will be directed toward the stringent evaluation of the pharmacokinetics and relative bioavailability of the drug in subjects under normal-gravity condition and in subjects under simulated weightlessness (e.g., bed rest). These studies will provide critical information on the changes in drug pharmacology which occur as a result of the body's responses to the imposed hypokinetic/hypodynamic conditions. Complementing these ground-based studies, in-flight information will be obtained from similar drug plasma and urine data collected under zero-g conditions during proposed space-flight experiments.

Together, the results of ground-based and in-flight studies are anticipated to provide the information needed for physicians to prescribe effective and predictable therapeutic regimes to crewmembers in upcoming Shuttle missions.

Competitive binding principle underlying the radioreceptor assay.



Plasma scopolamine concentrations following transdermal administration to normal human subjects.



Space Adaptation Syndrome— Parallel Swing Tests

TM: John W. Harris/SD3
Reference OSSA 18

The sensory conflict theory of space motion sickness etiology suggests that conflicting or unexpected sensory signals result in the medical symptoms, spatial disorientation, and nausea reported by a significant number of astronauts during flight. In weightlessness, the greatest source of conflicting or unexpected sensory information is the absence of normal Earth gravity acting on the otolith organs of the inner ear. The process of adaptation to rearing of stimuli in weightlessness appears to involve alterations of otolith receptor signals and of the integration of otolith signals with signals from other spatial orientation receptors. These alterations should result in perceptual, oculomotor, and postural response changes that are observable, at least transiently, following recovery from the weightless environment. Self-motion detection thresholds and perceived self-motion path during linear motion are among the perception responses expected to be altered by weightlessness.

A Detailed Supplementary Objective was performed for the STS-8 mission to compare immediate postflight responses to linear and angular movement with those obtained before flight. Two types of responses were examined: linear self-motion detection thresholds and perceived self-motion path. The primary operational problem addressed is reentry disorientation. The data are relevant for the hypothesis that changes in vestibular otolith responses contribute to this disorientation. Also, the data are relevant for the sensory conflict theory of space motion sickness and may be used to help refine test protocols for future Spacelab flights.

The apparatus employed was the Miami University parallel swing. This swing is a four-pole pendulum that produces "linear" and/or angular (roll) oscillation at 0.26 Hz. The observer was restrained in an aluminum cylinder that enclosed a styrofoam body mold.

Head restraint was provided by ear pads and a bite board. The observer was placed in the restraint in the prone position and his head was dorsal-tilted about 45°. Linear motion was in the direction of the observer's Y body axis and roll motion was around the Z axis.

Observations with one astronaut/observer yielded two findings. First, linear self-motion detection thresholds were elevated nearly threefold at L + 2.5 hours relative to preflight baseline (the observer was less sensitive to motion). Second, perceived self-motion during sinusoidal roll differed immediately after flight relative to preflight perception. At L + 2.5 hours, roll was perceived primarily as linear translation. Both the linear motion detection thresholds and the perceived self-motion during roll returned to baseline at the L + 66 hours observation.

Changes in self-motion perception during roll are interpreted as follows. On Earth, information from the otolith receptors is used by the brain to signal: (1) body/head tilt and (2) linear motion. During extended exposure to weightlessness, all otolith receptor output is interpreted by the brain as linear motion; tilt interpretations are meaningless in zero g. Immediately following return to Earth, the brain persists in interpreting otolith output as linear motion. Consequently, head/body tilt during roll is perceived as linear self-motion.

The observations reported here have clear implications for understanding astronaut reports of spatial orientation disturbance during reentry as well as for comprehending disturbance during the initial exposure to weightlessness.

Miami University of Ohio parallel swing



Detection of Incipient Altitude Decompression Sickness With Doppler Sensors in Flight

TM: James M. Wallgora/SD3
Reference OSS 77

Altitude decompression sickness is caused by the formation of bubbles of nitrogen in the body following a change in ambient pressure. The change in pressure from the Shuttle cabin (14.7 psi) to the Shuttle pressure suit (4.3 psi) is great enough to create a potential for decompression sickness. Doppler bubble detectors can be used to detect presymptomatic bubbles in the pulmonary artery.

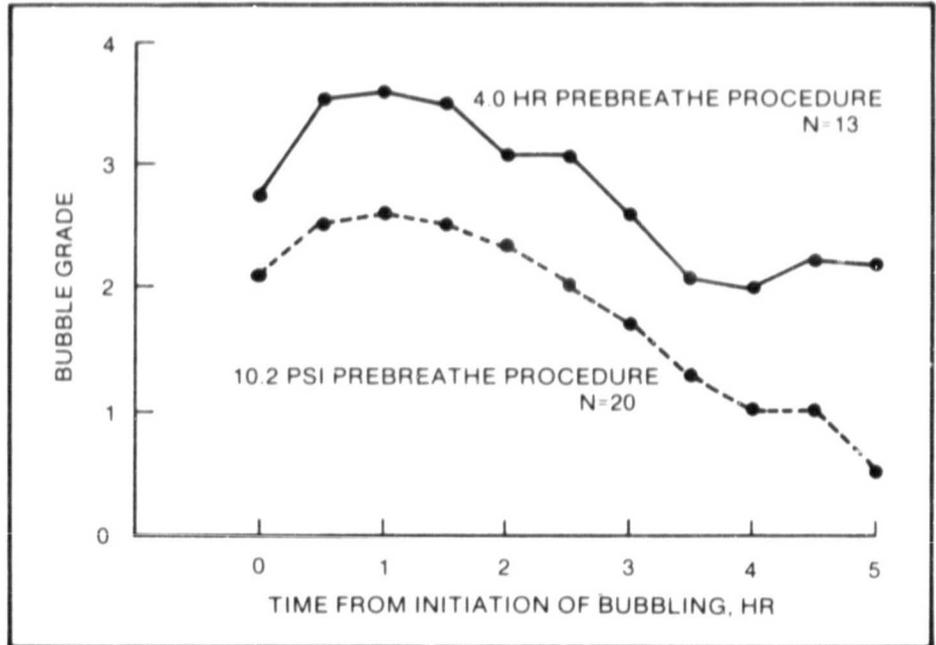
Off-the-shelf Doppler detectors were used in an extensive (173 manned chamber runs) test program at Johnson Space Center to validate a bends prevention procedure. The procedure reduces the time requirement for an oxygen prebreathe before extravehicular activity by using a change in cabin pressure 12 hours before extravehicular activity. The Doppler sensor data were very significant in verification of this procedure. The lower grade of bubbling associated with the 10.2-psi bends prevention procedure and the virtual disappearance of bubbles over a 6-hour period is illustrated. The use of the Doppler sensor in an altitude chamber is shown.

Current Doppler sensors are very sensitive to movement of the heart within the chest wall and must be held in place by a technician. One of our current goals is to develop a sensor which could be fastened in place inside a pressure suit and monitored during chamber runs or extravehicular activity. A study using the Doppler

sensor in the KC-135 zero-g environment for 130-second periods has shown that the heart moves much less in zero g than in one g. This fact should potentiate the use of a Doppler sensor during zero-g extravehicular activity.

Current investigations center on specific Doppler designs which will result in a Doppler sensor that can accommodate some movement of the heart in the chest wall and still detect presymptomatic bubbles.

Bubble grades using two different decompression sickness prevention techniques.



Doppler measurements being made at altitude.



Rectilinear Bone Densitometry

TM: Victor S. Schneider/SD3
Reference OSSA 20

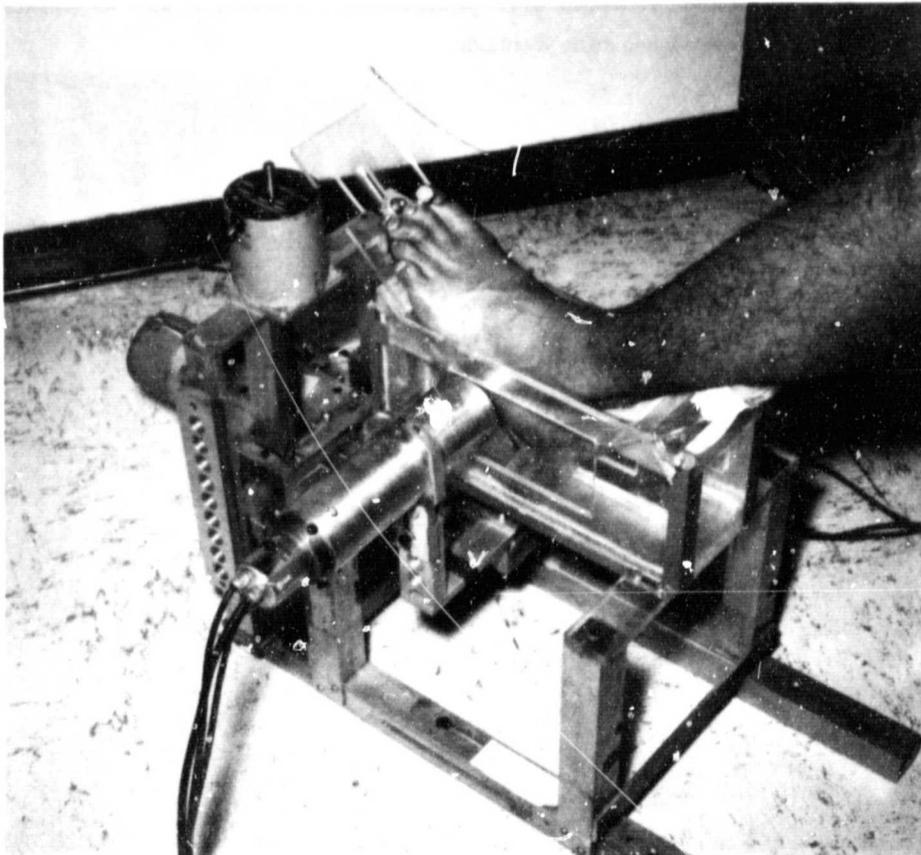
Disuse osteoporosis occurs in the human skeleton when there is a lack of stress on the skeleton. This occurrence is seen both on Earth and in space travel. On Earth, gravity constantly affects the amount of strain the bones and muscles overcome with daily activities. This effect is especially seen in areas of the body that support the individual, i.e., the postural and leg muscles as well as parts of the upright skeleton, the spine, and legs. In zero g, the astronaut no longer uses the postural or leg muscles against gravity and significant atrophy of these muscles occurs. Skeletal changes occur as well; these changes usually occur in trabecular bone, which in part can be found at the ends of the long bones. The heel bone, the calcaneus, is made up of more than 90% trabecular bone in its central area.

Using a specially designed iodine-125 gamma-ray transmission scanning densitometer, calcaneal mineral has been measured in earthbound humans and in astronauts who have flown in space as well as in astronauts who have not yet flown. Three astronauts who have spent more than 30 days in space have lost significant calcaneal mineral, having lost 4.5%, 7.9%, and 7.4% of their calcaneus during their time in space. All the astronauts who have spent 30 days or more in space were reevaluated 5 years after their long-duration flight, and eight of nine astronauts had lost calcaneal mineral when compared to values before their space flight. Although the mineral loss observed has not been of clinical importance, since at least 30% to 40% of the bone would have to be lost before one would be concerned with spontaneous fractures, the data do lend support to the hypothesis that space flight may have a direct effect on the human skeletal system.

If these early data are substantiated, a program to minimize this bone loss would have to be developed before long-term missions could safely be undertaken.

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Rectilinear calcaneus bone densitometry using the specially designed densitometer.



Dual-Photon Absorptiometry Spinal Mineral Density Determination

TM: Victor S. Schneider/SD3
Reference OSSA 21

The human skeleton is made up of two forms of bone: the first type, which is found in the shaft of the long bone, is called compact or cortical bone; the other type of bone is found at the end of the long bones and in the body of the spine and is called spongy or trabecular bone. During space travel, during inactivity, or in the postmenopausal state, bone is lost predominantly from the spongy or trabecular area and this loss may be 10 to 20 times faster than seen in the compact bone. Until recently, bone densitometry has only been measured in peripheral cortical bones, where little or no change is seen over short periods of time. Dr. Richard Mazess of the University of Wisconsin at Madison developed a bone densitometer that can evaluate the bone mineral in the spine. The machine uses a radioisotope which emits two distinct photon energies. The dual-photon absorptiometry enables quantitative assessment of skeletal bone mineral in regions of the body that were previously inaccessible using single-photon absorptiometry. The use of dual-photon energy minimizes errors that result from irregular body contour and soft tissue inhomogeneities. In theory, to analyze a given number of substances, attenuation measurements at the same number of discrete photon energies are required, since the simultaneous equations obtained by applications of Lambert's law can be solved only if there are as many independent equations as unknowns. Since the attenuation coefficients are correlated, the number of substances that can be determined is limited. Use of two photon energies, therefore, allows discrimination of two substances in a given system. Clinically, a two-component system can be defined as consisting of bone mineral and soft tissue. Using the radioisotope gadolinium-153, which has proton energies of 44 and 100 keV, equations can be derived for the determination of quantitative bone mineral when used for dual-photon scanning.

Determination of bone mineral content is usually performed over the lumbar spine, specifically looking at lumbar spines 2 to 4. The choice of proper centrum edges confines analysis to the centrum zone and eliminates transverse processes. The bone mineral content is the most useful for diagnostic application since small and osteopenic spines are fracture prone. The total bone mineral density (i.e., bone mineral content per unit projected scan area) normalizes bone mineral content for bone size. It is most useful for serial measurements on the same individual over time since variation due to exact reposition can be minimized. Similarly, the central density (determined in the central centimeter of the centrum) is useful for serial determinations; it is less influenced by choice of centrum edges and hence can provide more reliable long-term results.

The bone mass represents the mineral mass at the sample site. Approximately 60% of the weight of hydrated bone is due to bone mineral, and 38% of the bone mineral is calcium. The nonmineral components of bone include fat, collagen, and water of hydration. The composition of bone mineral is essentially invariable, whereas nonmineral components of bone and of surrounding soft tissue are subject to considerable variation between individuals with time.

The Mazess machine has recently been introduced into at least 50 centers around the nation and the world. Appropriate baselines and clinical data are being accumulated. At the Johnson Space Center, normal population data are being determined so that a longitudinal study of astronaut skeletal dynamics can be measured throughout their working careers.

Dual-photon absorptiometry spinal mineral density determination.



Animal Enclosure Module

TM: Malcolm C. Smith, Jr./SD3
Reference OSSA 22

The mid-deck animal enclosure module (AEM) was flown on STS-8 to test the efficacy of the AEM in supporting healthy animals without compromising crew safety and comfort. This study represents the first attempt to fly animals in the crew compartment of a U.S. space vehicle, and ground testing was accordingly rigorous.

Six specific pathogen free male albino rats (Lewis Wistar strain), age 56 days and weighing approximately 275 g at launch, were to be used for flight. A group of six control and six flight backup animals was required. These germ-free rats were stabilized with a "cocktail" of *Lactobacillus spp* 4 days before shipment from the vendor's facility to the Kennedy Space Center. Only 15 of the germ-free rats were available, and these were subsequently divided into one group of 6 flight animals, one group of 6 backup flight animals, and one group of 3 control animals. Testing to assure that the crewmembers would not be exposed to obnoxious or noxious odors and pathogenic microorganisms was accomplished. In-flight crew involvement in the experiment was limited to activating lights to maintain nominal circadian rhythms, preparing a 10-minute video tape on days 2 and 5, and observing animal behavior daily. At no time did the crew handle the animals outside the AEM.

Average preflight and postflight body weight changes in the flight animals and in the various controls are not remarkable if taken as a whole. Flight animals lost an average of 11 g in side A (3.7%) or gained an average of 3 g in side B (1.3%). Controls gained an average of 5, 29, and 2 g (1.7%, 11%, 0.6%). However, it is fair to say that the flight rats failed to gain weight at their expected rates and some even lost weight, whereas the ground-based control animals either gained weight as expected or gained slightly less than expected.

Flight rats were at a disadvantage in that their food supply was glued to the sides of the cage and was slightly more difficult to access than the food for the controls. Flight animals consumed an average of 175 g of food (other than potatoes), whereas controls consumed 223 g. Control group KSC-1 did not gain at the expected rate, probably because this group was anesthetized for a blood sample. Control group ARC-5 did not gain at their expected rate because this group was disturbed by transfer from Kennedy Space Center to Ames Research Center and they had no food supply for about 24 hours.

Postflight examination of the flight animals revealed that they were in good physical condition. They were alert and were actively grooming themselves and each other. Their supply of water in the raw potatoes was exhausted on side A and nearly exhausted on side B. Their hair coats were lightly stained with food probably derived from rubbing against the food

bars. Postflight examination of the cage and in-flight video tapes indicates that the airflow through the cage was not adequate to quickly pull urine, feces, and debris out of the cage area and onto the exhaust filter grid.

The AEM successfully maintained six healthy rats for the duration of the STS-8 mission (6 days). Improvements in the water supply (to provide a margin of safety of at least 20%) and the rate of airflow through the AEM are highly desirable. The AEM can be used for a variety of flight experiments requiring small laboratory animals without affecting crew time, crew safety, and crew comfort.

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Mid-deck animal enclosure module.



STS-8 Animal Enclosure Module Results

Group, no.	Body weight, g		Average body weight change		Food consumed, g	
	Preflight	Postflight	g	%	Potatoes	Other
Flight						
Side A, 3	293	282	-11	3.7	1170	196
Side B, 3	228	231	+3	1.3	1162	165
Controls ^a						
KSC-1, 3	278	283	+5	1.7	1054	216
KSC-4, 3	264	293	+29	11.0	1059	252
ARC-5, 3	292	294	+2	.6	1155	202

^aKSC-4 animals were true controls. A blood sample was obtained from KSC-1 animals on launch day, and ARC-5 group was transported to Ames Research Center on launch day.

Emergency Medical Care In Space

TM: James S. Logan/SD2
Reference OSSA 23

Future space efforts will require larger crews and longer mission duration. Men and women other than astronauts will routinely compose part of the crew. Therefore, the chance of an illness requiring sophisticated medical care occurring in flight will increase. Many medical conditions could be treated in flight providing basic diagnostic and therapeutic medical equipment is available. Johnson Space Center is keenly interested in developing medical diagnostic and therapeutic equipment to support space station missions.

Intravenous (IV) access is an essential requirement for acute emergency medical care. Weight and volume considerations preclude IV fluids from being transported and stored in the usual manner. Therefore, plans were made to develop a rehydratable IV system for use onboard the Orbiter that could also be used on a space station.

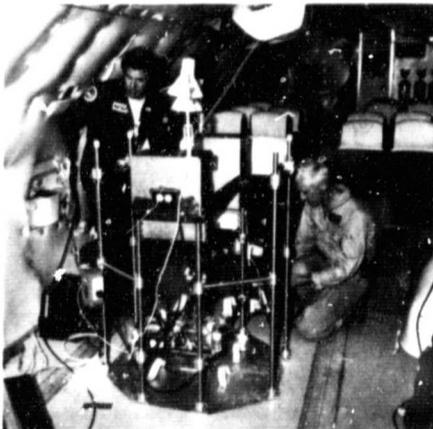
The Shuttle fuel cells provide power for the Orbiter. Hydrogen and oxygen are combined to produce electrical energy. Water is formed as a byproduct of this reaction. The Umpqua Research Company designed and built an in-flight rehydratable IV system. The heart of the system is a purification cartridge which polishes fuel cell "waste" water to sterile water specifications. After approximately a liter of water is purified, 20 ml of a concentrated electrolyte solution is added to the purified water to make a liter of normal saline. Lactated Ringers solution requires that 30 ml of another concentrated electrolyte solution be added to the aforementioned liter of sterile water. The purification cartridge employs an iodinated resin, separate anion and cation exchange resins, and an activated carbon filter to polish potable water. The IV system is designed to administer IV fluids with flow measurement and control in the weightless state. The entire system can be "worn" by a crewmember.

A minor surgery station designed for use in flight is being evaluated in a KC-135 aircraft. The specially modified KC-135 flies Keplerian trajectories, which generate 30 seconds of weightlessness per parabola. The surgical station includes a restraint system for surgeon and patient, a sterile area for surgical instruments held in place magnetically, and a system to keep the operative field free of debris. In addition, a zero-g air/fluid separator to be used for medical suction is being evaluated.

Plans are underway to develop in-flight clinical laboratory, hematology, microbiology, urine analysis, and diagnostic imaging capabilities for use onboard future space vehicles.

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Site of minor surgery station in KC-135 test aircraft.



Physician evaluation of restraint system for a prototype zero-g minor surgical station.



Bioprocessing in Space

TM: D. R. Morrison/SD5
Reference OSSA 24

Electrophoresis—the separation of materials in solution by the influence of an electric field acting upon differentially charged molecules—has long been an effective tool on Earth to isolate small quantities of proteins and other biomolecules by means of a batch process. Usually, the solution of materials to be separated is embedded in a gel to minimize the heat-induced mixing that spoils the separation. A Continuous Flow Electrophoresis System (CFES) uses a flowing, thin layer of a carrier solution to sweep along a continuous stream of a protein solution. While flowing, variously charged proteins move apart in the electric field imposed transversely across the layer and are separately collected at the upper end of the chamber. By keeping the layer very thin and by providing precise cooling, convective mixing is minimized. Even so, for effective processing in normal gravity, the density of the sample stream and of the carrier fluid must be nearly identical. Since the density of most proteins is greater than that of the carrier fluid, if the concentration of the protein in the sample is excessive, gravity causes the sample to collapse around the inlet port of the device. Therefore, on Earth, the sample must be diluted to less than 0.2% protein. In space, the sample can be concentrated to 25% protein. By merely increasing the protein concentration, 125 times more material can be separated in null gravity per unit time than in normal gravity.

In addition, in space, gravity-driven convection currents cease to operate and the thickness of the layer and the size of the sample inlet can be increased from approximately 0.5 mm to 1 mm. By doubling the diameter of the inlet, four times as much cross-sectional area is gained. Therefore, with the 125 times greater concentration, about 500 times more material can be separated per unit time in null gravity than in normal gravity. Moreover, higher voltages (which produce more heating) and longer residency times (slower carrier fluid flow) can be

employed in space because of the lack of buoyancy-driven mixing.

The advantages of null gravity for the CFES separation of proteins are even greater in the separation of cells. Johnson Space Center, under a Joint Endeavor Agreement with McDonnell-Douglas, used the CFES during the STS-8 mission to separate human embryonic kidney cells.

The embryonic kidney is composed of a heterogeneous mixture of cells with different functions. Different cells produce different specific biomolecules (e.g., hormones, enzymes, and other chemical messengers). The goal of the cell separation experiment was to isolate cells that produce a high quantity of a desired substance and then to culture the isolated cells and obtain the substance from the growth medium. The main substance of interest is urokinase, an enzyme that is used to dissolve blood clots. However, JSC is also examining the various fractions for other substances produced in the kidney (e.g., erythropoietin, tissue activator, nonspecific viral inhibitors).

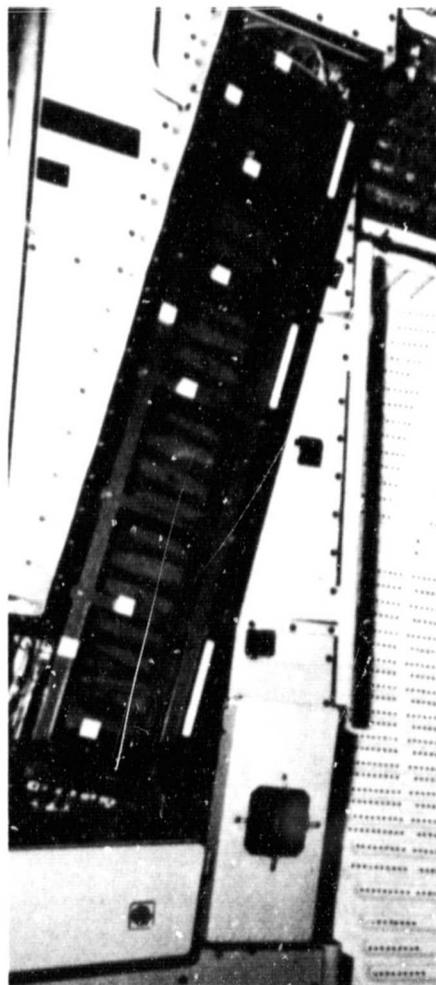
In addition, pituitary cell samples were separated on STS-8 for the purpose of obtaining quantities of growth-hormone-producing cells sufficient for biological assays. Radioimmunoassay, the standard assay for growth hormone, fails to detect more than 90% of the biologically active forms of the hormone. The space separation study will help investigators determine forms of the hormone that are active in the body.

The potential of the CFES is great. For example, many diseases are caused by a deficiency of a specific biomolecule. The disease might be treated by

simply replacing the biomolecule if a sufficient quantity can be obtained. The CFES affords that opportunity. Perhaps as important as the production of pharmaceutical agents is the research potential. Many important biomolecules have only recently been discovered because they are present in the body in only minute quantities, the detection of which requires exquisitely sensitive techniques. By processing large quantities of starting material, one may obtain enough to perform a bioassay but at the expense of destroying the sample. The exploitation of the CFES for cell separation in space with subsequent culture may provide enough material with which to work.

The NASA is working toward the time when cells will be separated, continuously cultured, and the desired products separated—all using the CFES in space.

The CFES installed in the Shuttle Orbiter.



**Space Sciences and
Applications**
**Earth Sciences and
Applications**

Summary

Office of Space Sciences and Applications

Earth Sciences and Applications

Summary

Land-Related Earth Science

Global habitability is a theme of the NASA Earth Sciences and Applications research program. Its goal is to understand long-term physical, chemical, and biological trends and changes in the Earth's environment, including its atmosphere, landmasses, and oceans. This understanding will, of necessity, involve major international participation and will be coordinated insofar as possible with national research programs and those of international agencies. The program will specifically investigate the effects of natural and human activities on the Earth's environment by measuring and modeling important nutrient cycles, and will estimate the future effects on biological productivity and habitability of the Earth by humans and other species. The program will involve space and suborbital observations, land- and sea-based measurements, laboratory research, and supporting data management technologies over a 10-year or longer period.

The state of planet Earth is not static; it is ever changing through natural causes. The Earth has a great capacity to restore itself, but it is a finite capacity. Of concern are the subtle interactions which might affect the planet's capability to sustain and renew the quality of air and water and the integrity of the global biological and chemical cycles essential for life. Scientists believe that significant changes can occur on the Earth on a time scale of mere decades, yet our ability to mount countermeasures, should we wish to, requires similar or longer time scales. An understanding of the overall system is essential if we are to live successfully with global change. Although the time scales for changes are decadal, the need for the body of knowledge is urgent if enlightened policy decisions are to be made.

Global changes which impact the habitability of the Earth are principally of two kinds: changes that relate to biological productivity and changes that affect human well-being. Both involve cycles of energy, water, and essential chemicals through the atmosphere, land, and oceans.

On time scales of a decade, the ocean, the atmosphere, and the biosphere function as a closely integrated system. Physical, chemical, and biological processes are tightly coupled, and progress in our understanding will require an interdisciplinary research effort of broad scope and content. Understanding will require space observations to provide global perspective; investigations of specific ecosystems both on the ground and from space to enhance our appreciations for the overall function of the biosphere; studies of representative estuarine and coastal systems to define the transfer of materials from land to ocean; studies of horizontal and vertical motions in the ocean, recognizing the importance of these motions for climate and their role in regulating the flow of materials to the depths of the ocean; studies of the atmosphere, its chemistry, its physics, and its motions; and theoretical and laboratory investigations to synthesize new information serving as a guide to the acquisition of new data.

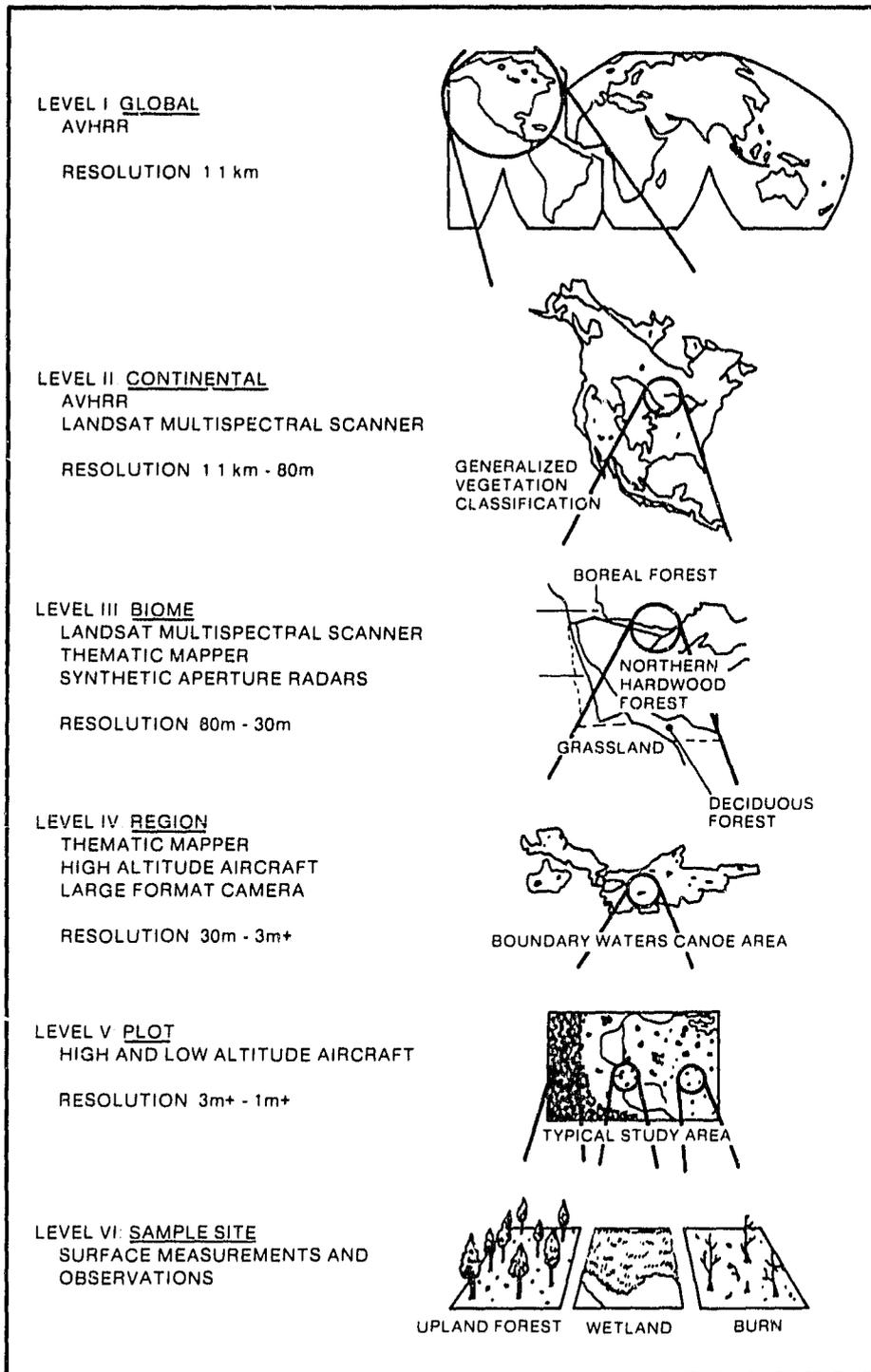
Current Johnson Space Center Earth Sciences and Applications activity is particularly focused on vegetation-related interdisciplinary science investigations involving multistage, multisensor remote sensing in a two-pronged approach. One effort is aimed at a top-downward, coarser level measurement, mapping, and modeling of vegetation biomass and productivity to reduce the uncertainty in vegetation areal extent from the current factor of three to six to less than a factor of two. The other effort is

aimed at a bottom-upward, refined level measurement, mapping, and modeling of vegetation biomass and productivity to support the accuracy required for further improved predictive modeling of energy balance, evapotranspiration, climate model interface, hydrological, and other biogeochemical processes. The relation of spatial resolution in multistage sensing with vegetation classification scheme level is illustrated.

A related activity is aimed at approaches more directly connected with studying the land interaction with atmosphere and climate. Some of the quantities to be studied in these cases are illustrated, with general circulation and climate models driving many of the studies.

The relationships between remote sensing data and land surface characteristics have been studied extensively. Landsat data acquired for more than a decade have led to the establishment of increased understanding of the Earth and its fragile environment. Despite this understanding, a significant number of unknowns remain. One of the more important unknowns is a reliable estimate of the areal extent and distribution of vegetative types. Currently, scientists attempting to model global biogeochemical processes, to which vegetation is a significant contributor, are led to use estimates based on factors such as soils and climate. The large uncertainty in these estimates, when extrapolated to global scales, results in comparative values between similar models that may differ by one or more orders of magnitude.

With a problem of this scope, it appears obvious that remotely sensed data, having a large synoptic view, afford a mechanism for providing a base of information to begin understanding large-scale science issues, and, as stated earlier, some success



Relation of classification level and spatial resolution.

has been achieved. However, for research conducted on continental scales, a major problem is the lack of a controlled standard for comparison and/or quantitative evaluation. Johnson Space Center research over the past few years in large area crop inventory provides a base of under-

standing necessary to develop concepts for the research approaches in remote sensing for global Earth sciences. Current research goals are to discover the spatial distribution, areal extent, variability, and rates of change of various types of vegetation through the use of satellite remote

sensing as well as other data for the purpose of quantifying and better understanding the errors in existing estimates of global land biological productivity and biomass, identifying the biomes and regions contributing most to the uncertainty in global land biological productivity and biomass, and improving the accuracy of existing estimates of global land biological productivity and biomass.

Remote sensing using satellite data provides an approach to discovering the true spatial distribution, areal extent, and rates of change of various vegetation types, as well as of the spatial variability in the characteristics of these vegetation types. This approach could be accomplished by using globally available coarse-resolution digital imagery data from the Advanced Very High Resolution Radiometer (AVHRR) carried onboard the National Oceanic and Atmospheric Administration series of polar orbiting meteorological satellites to provide an initial coarse map of global vegetation and then using samples of data from the Landsat multispectral scanner and thematic mapper, the Shuttle Imaging Radar (SIR), and the Large Format Camera to locally "calibrate" the AVHRR-based map. Such an approach should also include the use of ground-acquired data where available. Satellite data provide a number of advantages for this purpose: the data are globally available and thus provide the initial basis for a globally consistent description of the Earth's vegetative cover, the data are relatively inexpensive in comparison to other sources of data and to the value of the information which can be extracted, and the satellite data base provides enough of a historical perspective to at least begin to assess changes in vegetative cover.

Currently available satellite data acquisition systems and data analysis techniques are not truly adequate for performing this task; for example, in parts of the humid tropics, it will probably be necessary to use imaging radar systems to provide the calibration samples for the AVHRR-based map. Imaging radar systems more advanced than the current SIR-A and SIR-B will probably be required. On the other hand, currently available data and analysis techniques are clearly adequate to assess the vege-

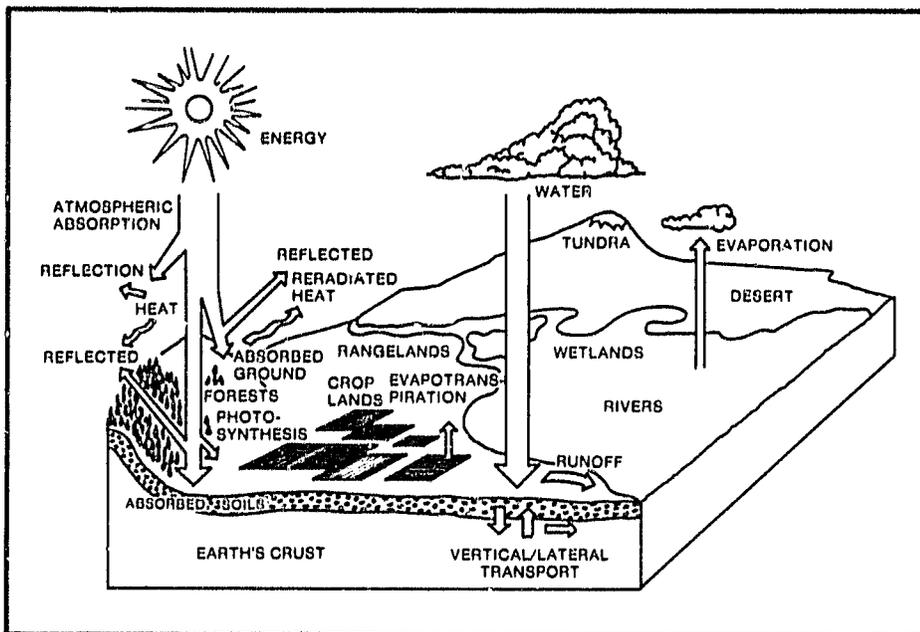
tation types at some useful level in many parts of the world over many important biomes. Therefore, we can begin to improve our understanding of global land biological productivity and biomass while we are developing the analysis approaches (and the sensing systems) needed to finish the job.

Available resources are inadequate to enable initial efforts on a global basis, even if the current technology were adequate to do so. Therefore, it is necessary to select some regions or biomes for initial focus in analysis and/or techniques development. Naturally, these biomes and regions should be the major contributors to the current uncertainty in important vegetative biophysical characteristics such as biomass and biological productivity. In fact, the current status of modeling these quantities does not support accurate selection of biomes and regions for our initial focus; however, it is quite clear that tropical forests, boreal forests, grasslands, and, perhaps, temperate forests will be important contributors to the uncertainties.

Space Shuttle Earth Observations

Spectral information in photographs is limited to the visible and reflected infrared portions of the spectrum, but in combination with detailed spatial information in the image, the trained human brain can detect and identify many different features on the ground. Examples are manmade objects, agricultural crops, clumpy distribution of vegetation in rangeland, texture of tree canopies in forests, and physiographic features such as flood plains and gullied areas.

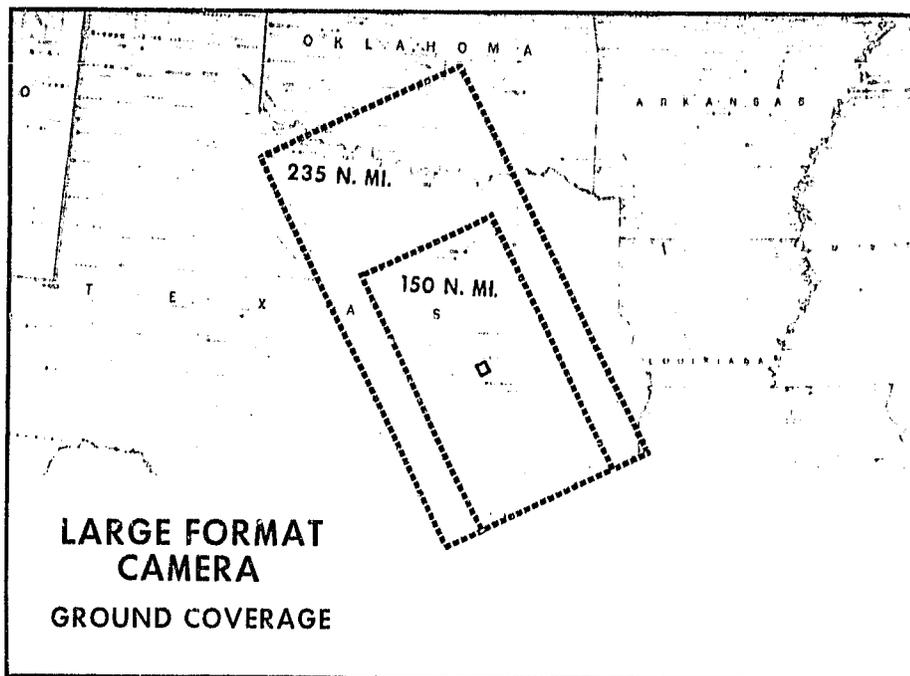
A metric camera with a 12-in-focal-length lens, imaging on a 9- by 18-in. format, will be operated on two Shuttle flights during calendar year 1984. The U.S. Geological Survey, the Defense Mapping Agency, and the National Oceanic and Atmospheric Administration will evaluate the system for usefulness and efficiency in preparing topographic maps. Areal coverage of each frame of photography varies with the altitude of the spacecraft, but it is large by any standards. Ground resolution will vary with altitude as well as film type; it is in the range of other Earth resources satellite sensors.



Land interaction with atmosphere and climate.

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Large Format Camera ground coverage.



The returned-film format and stereoscopic coverage provide a great improvement in map accuracy over other types of sensors.

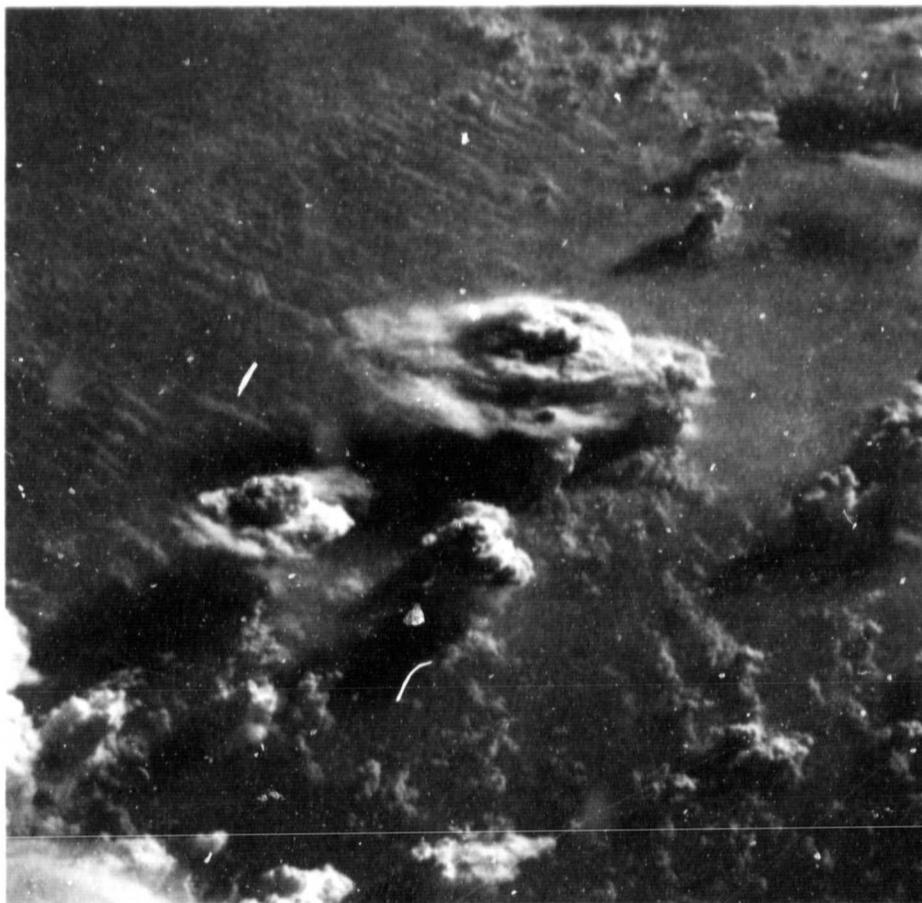
Small-scale photographs have two properties useful for studies of features on regional, continental, and global scales. Geometry of a vertical

photograph is the same as that of a map to a first approximation. Experimentation has begun with registration of digital remote sensor data from scanners and radars to determine improvements in classification of land surface materials by comparing data from the same, relatively homoge-

neous areas. Photograph-registered data can then be registered to the ground by means of map projections.

It is expected that information derived from Large Format Camera photographs will be a valuable adjunct to digital data for inventory and monitoring of ecological features. In 1984, in-house work at Johnson Space Center will concentrate on the information content of black-and-white, color, and color infrared film with emphasis on vegetation types and landforms.

An additional source of remote sensing information now being exploited is the handheld-camera capability onboard each Space Shuttle flight. The space crew makes maximum use of targets of opportunity to complement imagery from other Earth-viewing sensor systems or to note unusual changes observed from orbit. The example shows thunderheads over Zaire. Cloudtops of heights above 50 000 ft cannot be photographed with conventional aerial cameras. An oblique stereopair made from orbital altitudes enables the detailed analysis of such mesoscale meteorological features. Stereoscopic analysis combined with satellite radiometer measurements of cloudtop heights provides much more information about the dynamics of the circulation responsible for severe thunderstorms.



Handheld-camera orbital photograph of thunderheads over Zaire.

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Space Sciences and Applications

Earth Sciences and Applications

Significant Tasks

Techniques for Vegetative Feature Extraction

PI: V. S. Whitehead/SC4
Reference OSSA 25

The broadening of emphasis from crops only to all forms of vegetation has required a rethinking of past approaches used in the inventory and condition assessment of cultural vegetation. Vegetation in the context of the theme "global habitability" implies worldwide inventory and mapping of categories important to the physical, chemical, and biological processes that determine our environment. Temporal and spatial scales are shifted toward larger values than when crops alone are considered. The concept of "pure" picture elements may require revision as the spatial scale is expanded, and the manner in which specific sensors are applied to this problem may differ. Some technology developed for inventory of specific crops can be directly applied to this problem; even more can be applied if some assumptions or techniques are modified, but some techniques applicable to specific crops do not apply to natural vegetation. Consequently, as a first step in meeting the long-term objectives of developing remote observation analysis methods which will incorporate differing spatial and temporal resolution and of determining the information content of available sensors to support global vegetation inventory and mapping, this year's effort has emphasized determination of the degree to which technology developed for crops can be extended to the more general problem.

A three-sensor view of the Lake Chicot, Arkansas, area, acquired on September 23, 1982, is shown. The Advanced Very High Resolution Radiometer (AVHRR) provides daily worldwide coverage and a workable data rate, but poor resolution. The thematic mapper (TM) provides high resolution but has a very high data rate and short history of record. The multispectral scanner (MSS) has resolution between AVHRR and TM and has a decade-long history of acquisition. This set of sensors provides a basis for a multistage sampling approach to monitoring variables for global modeling. Preliminary plans, which include sampling stratification and aggregation designs, are being developed.

The investigation to assess the capabilities of the AVHRR for vegetative monitoring has focused on the development of technology as well as an evaluation of the sensor's information content to provide a synoptic view that will permit the classification of land surface into regional-level major ecosystem classes. Procedures that estimate or correct for the atmosphere have been evaluated. Thus, a good understanding of the conditions and limitations for use of the sensor has been attained. Preliminary analyses have also been performed to estimate the feasibility of using AVHRR data to distinguish land surface characteristics for use in a multistage sampling approach to land cover inventory and mapping. Results generally indicate that good separability exists between Level 1 Anderson land use classes. Preliminary results of a study to determine the information content

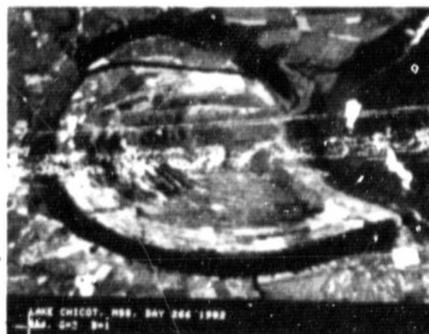
of multiple aspect views from AVHRR indicate that some information exists on the nature of the non-Lambertian vegetative canopy in the multiple viewing angle data.

The assessment of the usefulness of the TM consisted initially of preliminary evaluations of its overall performance and continued with more extensive investigations into its information content for land cover monitoring and inventory. The preliminary analysis of the sensor's engineering performance was consistent with prelaunch expectations. Furthermore, the study confirmed the existence of at least four independent dimensions of information in the seven-dimensional spectral band space. An insight to the relative contribution of individual bands to the ability to discriminate between specific ground covers has also been provided.

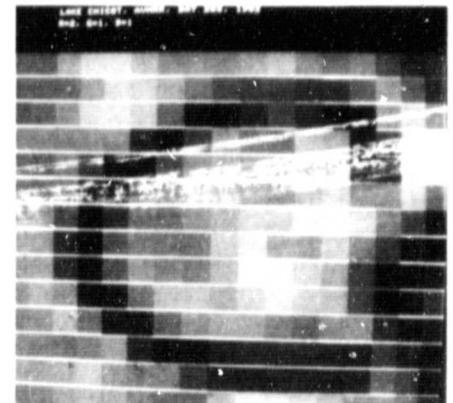
A transformation of TM data from the six reflective bands—termed the TM Tasseled Cap—was also developed based on analysis of both simulated and actual TM data from vegetation and soil classes. This transformation captures most scene-class-related data variation in three features which have direct association to the physical characteristics of those scene classes. Two features define a plane which is comparable to the MSS data plane, whereas the third feature represents a new dimension of information closely associated with the longer infrared TM bands. This transformation provides substantial data volume reduction with minimal loss of information and enhances our ability to understand and interpret TM data.



Thematic mapper, 1 048 576 pixels



Multispectral scanner, 43 674 pixels



Advanced Very High Resolution Radiometer, 238 pixels

Large Area Change in Biomass

PI: J. Dragg/SC4
Reference OSSA 26

The rapid growth of human populations, technology, and energy consumption has placed unprecedented demands on the global environment as well as on a number of human institutions. There is increasing concern that the environmental demands are sufficiently severe as to have potentially disastrous consequences on a global scale. It is evident that a substantial effort must be made to understand the current status of the global environment, the changes that are occurring, and the likely effects of proposed or anticipated policies. One major element of the overall effort must be to determine the state of the global environment at some epoch date and to establish the capability to detect and quantify changes from that epoch status.

Land use change is the major element of land biomass change, and lack of current global land use inventories is a major source of uncertainty in existing global land biomass estimates. Although it appears that biomass can be estimated directly from Landsat data for some major vegetation classes, these relationships clearly do not hold for other classes. Thus, land use information is required to conduct a biomass inventory and monitor change in biomass. Despite Landsat's synoptic view, formidable volumes of data are required to cover the global landmass, especially if it is recognized that multiple Landsat images of a given scene will be needed for many purposes.

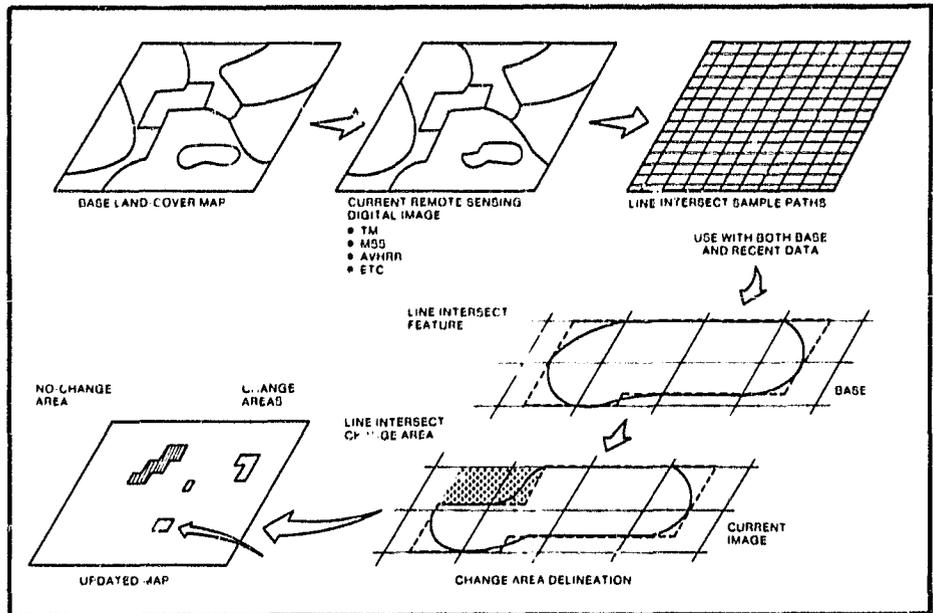
Significant advances have been made during the Large Area Crop Inventory Experiment (LACIE), LACIE Transition, and Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing projects in efficient sampling for large area surveys and reliable estimation of the proportions of specific agricultural classes. During 1983, initial advances were made in extending these technologies to enable monitoring large area change in biomass. Specifically, theoretical comparisons were made between two

versions of line intersect sampling (systematic and random spacing) and cluster sampling. Line intersect sampling is optimal for detection of change, but the probability for detecting a change is independent of whether systematic or random spacing is used. The efficiency of change detection was theoretically quantified. For the same number of pixels, line intersect sampling is 100 times more likely to detect change. A primary research data base has been established for initial development and test of a direct proportion estimator. Each observation records concurrent spectral, ground

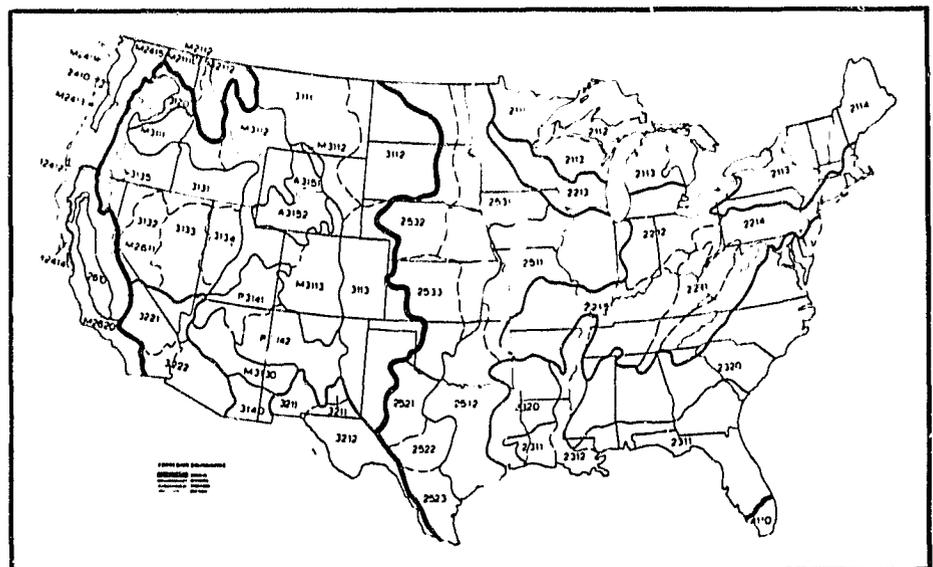
truth, meteorological, and ancillary data for sampled multispectral scanner pixels. The data represent 19 different ground cover types sampled over 8 U.S. province-level ecoregions.

During fiscal year 1984, sampling and class separability and proportion estimation research will continue with initial studies on the approximate balance of use of varied sensors such as the Advanced Very High Resolution Radiometer, the Landsat multispectral scanner, the Landsat thematic mapper, and Shuttle and aircraftborne instruments.

Line Intersect sampling for change detection.



Ecoregions of the United States, U.S. Forest Service, Department of Agriculture, 1976. (Courtesy of Robert G. Bailey.)



Soils Research

PI: D. R. Thompson/SC4
Reference OSSA 27

The Johnson Space Center soils research program is directed toward developing quantitative relationships between soil properties and spectral response to estimate specific soil physical, chemical, and interpreted properties related to biological productivity, biogeochemical cycles, and hydrological cycles.

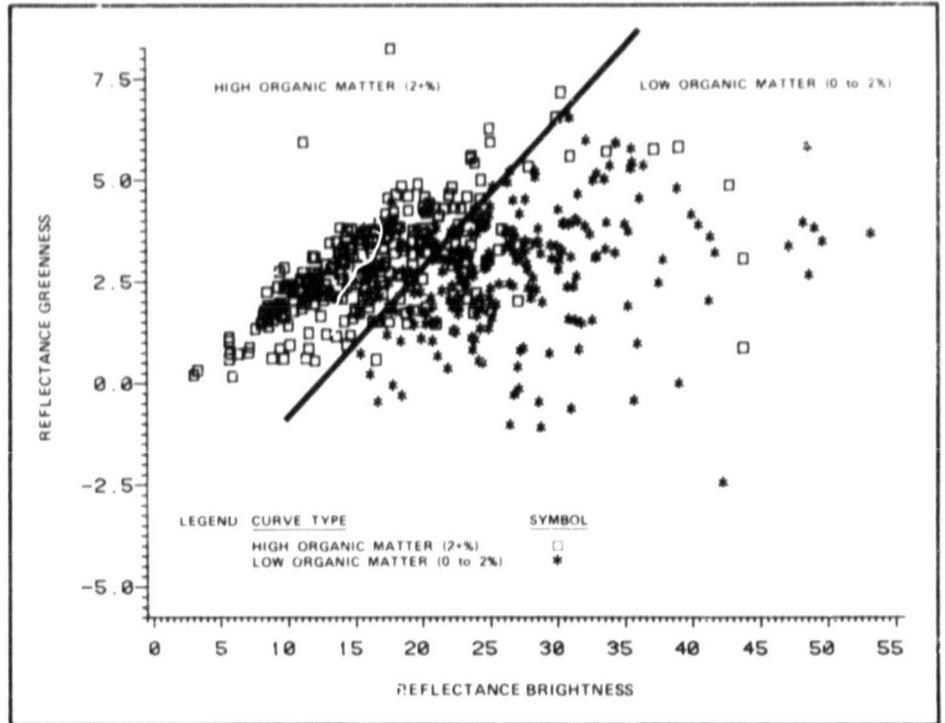
Within the past year, significant progress was made in the soils area. Laboratory soil reflectance measurements were used to simulate Landsat multispectral scanner digital counts for clear and turbid atmospheres and were found to be within the range of values for soils seen in Landsat data. Reflectance curve forms representing genetically homogeneous soil properties were found to be separable in greenness and brightness vector space. Organic matter content could be stratified into 0% to 2% and greater than 2% with 80% accuracy. This technique of converting reflectance data from controlled experiments to simulated Landsat digital counts will enable researchers to account for the effect of soil on vegetation-spectral relationships, to conduct sensitivity analyses of the effect of soils on spectral models, and to develop a better understanding of the relationships of spectral and physical-chemical properties of soils.

Landsat thematic mapper data were evaluated over two different regions (Mississippi River alluvium and glacial till in Webster, Iowa) for field soil effects on vegetated landscapes and to determine whether thematic mapper spectral bands provide information for soil association maps. Results from these studies indicate that the thematic mapper bands provide information that is related to the soil properties. Within the alluvium, the 0.76- to 0.90- μm , the 1.55- to 1.75- μm , and the 10.4- to 12.5- μm bands were most useful in identifying soil association boundaries located by the U.S. Department of Agriculture general soil maps. Within the glacial till region, aircraft thematic mapper simulator and Landsat 4 thematic

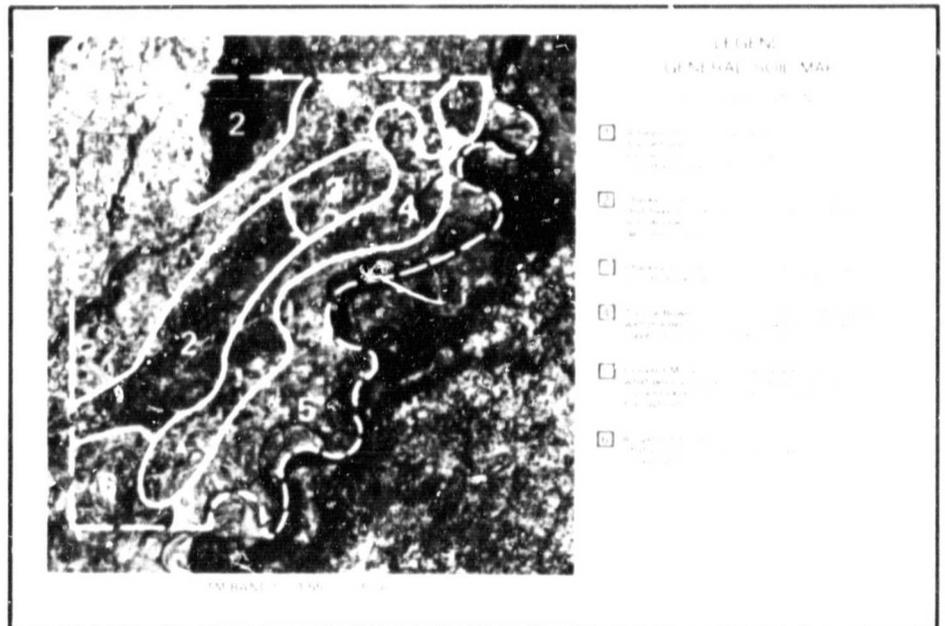
mapper data acquired over soils ranging from bare to fully vegetated cover indicated that key soil properties (i.e., soil moisture regime) could be separated throughout the growing season. The September 3 thematic mapper data, even with greater than 90% vegetated cover, separated the soil moisture regimes with 72.5%

accuracy for soil covered by corn and 68% accuracy for soils covered by soybeans. These results indicate that the improved spectral and spatial resolution of thematic mapping offers the potential to separate important soil properties even in regions with similar soils and under a dense vegetation canopy.

Location of reflectance spectra curve types of high and low organic matter in greenness and brightness vector space.



Mississippi County, Arkansas, general soil map.



Geographic Information Systems Research

PI: Robert G. Musgrave/SC6
Reference OSSA 25

The Johnson Space Center has a major research role in land-related Earth science activities. As a consequence of this research activity, various data types are collected in formats ranging from state-of-the-art digital imagery to handwritten notes. A major challenge confronting the information scientist is the presenting of analysis capabilities and these data to the science user community in an accessible and coherent manner.

Over the past 3 years, JSC has put in place a modern science computing facility specifically developed to support the needs of both local researchers and remotely located investigators. To fully realize the potential of this science computer facility, a major focus of the information sciences has been the developing of mechanisms to make analysis capabilities and data available to researchers. This process has been evolutionary, starting with the installation of analysis software and a com-

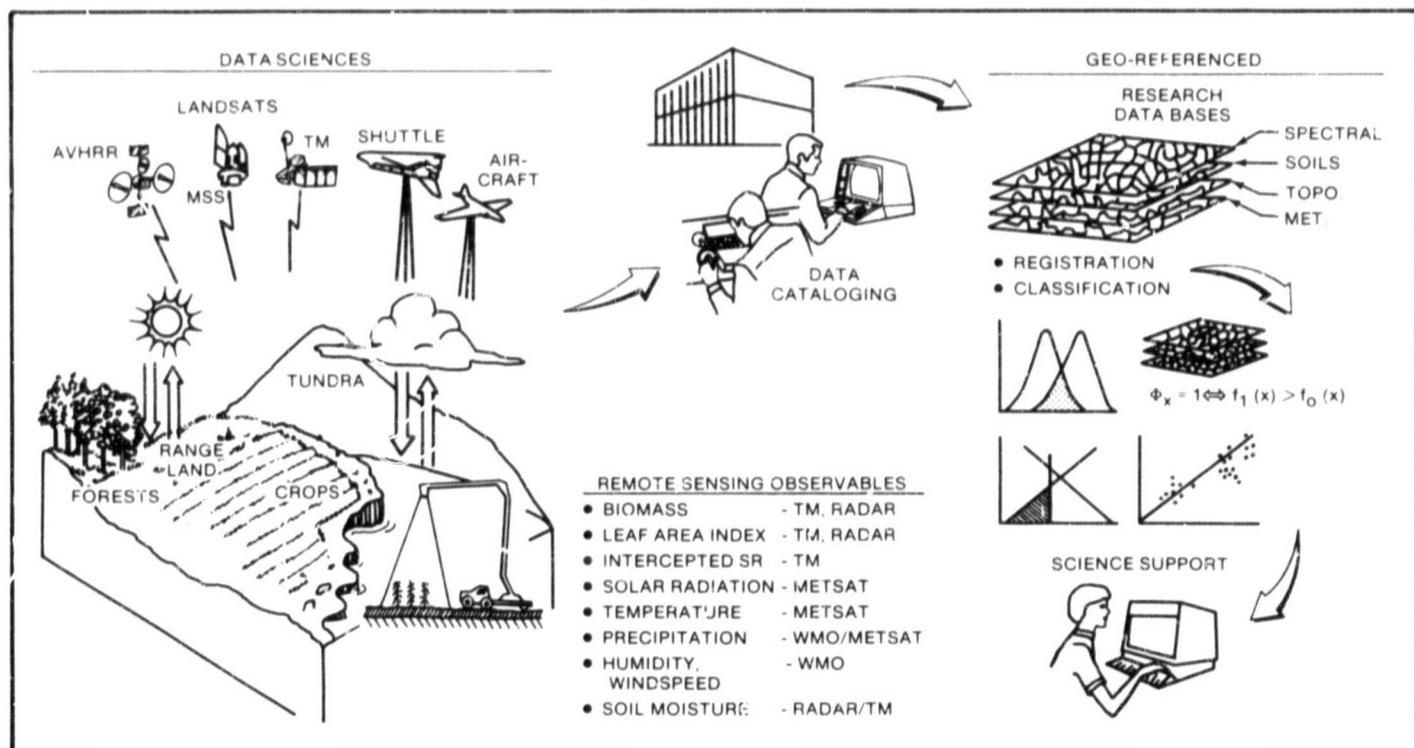
mercial Data Base Management System that provides accountability and supports a "relational" query system that enables interactive interrogation of the information holdings. The Data Base Management System has been expanded to support an extended catalog system that references our remote sensing data holdings and can be readily and simply interrogated. This catalog system is the first of its kind among the centers participating in the land research program, and its availability will hopefully enable other program participants to avert costly duplication of expensive data sets.

The logical follow-on to the Data Base Management System and the catalog system is the development of an improved Geographic Information System that not only accommodates the many disparate information types collected during our research and correlates them to a common geographic reference base but also provides the key distinguishing function of convenient and efficient user-directed analysis. Under the current system, an investigator must access each data type independently and, in effect, serially interface the data with his software application. Many complex

models being developed to describe the forces at work in an ecosystem require simultaneous access to many independent variables. This requirement dictates that the data be electronically correlated and rectified to a common base so that each information source is precisely registered to the same area. The concept of the Geographic Information System development is illustrated. Note that data are available from different sensors at varying resolutions covering different spectral bands. These must be merged with ancillary data, which can include point observations on the ground together with other information. Solving the problems of presenting these data of varying spatial representation and resolution comprises a significant research undertaking.

The thrust of the information management activities for fiscal year 1984 will be the refining of the Geographic Information System concepts and the building of a working prototype that supports the models being developed for the Earth Sciences and Applications Division's biospheric research activities.

Research information science.



East Texas Radar Experiment

TM: D. L. Amsbury/SC4

PI: Narish Mehta

Reference OSSA 28

The East Texas Radar Experiment has as a long-term objective the goal of determining how well various classes of vegetation can be separated in a southern temperate forest. Classes of forest characterized by species, age, and stand density were selected as a test bed for this research. The short-term objectives are to use scatterometers (nonimaging radars) for selection and design of imaging radars. Two aircraft flights in September 1981 provided data from multispectral, dual-mode scatterometers; multimode, X-band synthetic aperture radar; thematic mapper simulator; and color infrared photographs. Landsat multispectral scanner data were obtained earlier.

The multiparameter scatterometer data have been analyzed using a simple single-feature, two-class separability measure. L-band (20 cm), cross-polarization (HV) data are useful for separating trees from other features and in discriminating between individual tree classes and nontree classes such as clearcut and grassland. Separability between various tree classes is best demonstrated by C-band (6 cm), cross polarization (HV), and by Ku-band (2.3 cm), like polarization (VV). An example of the latter is illustrated. Radar backscatter in decibels is plotted against the number of readings for pine and hardwood classes. Incorrect classification is about 14%.

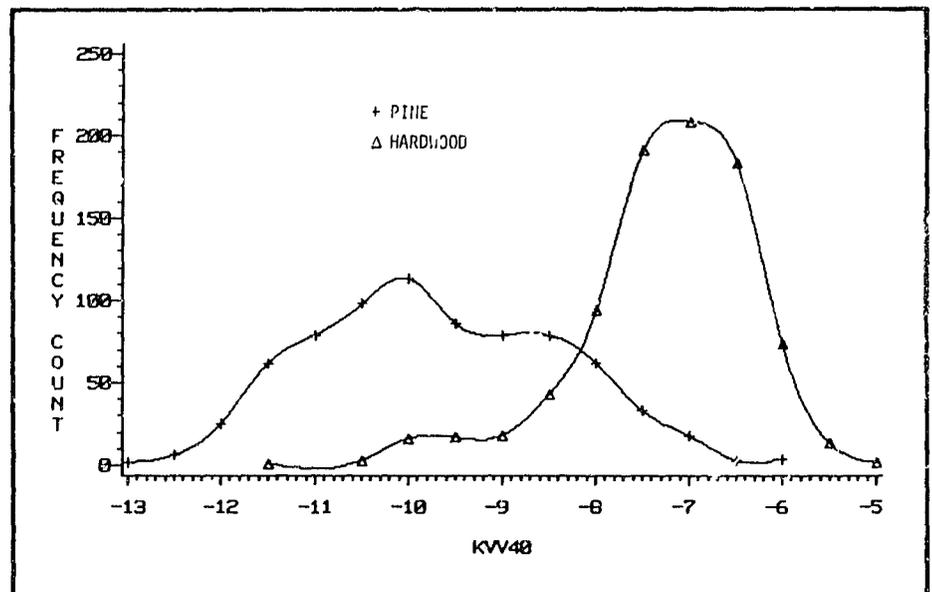
The digitally processed X-band synthetic aperture radar images are of poor quality for classification studies. Approximately half the optically processed synthetic aperture radar images have been digitized using a digitizing camera. Application of an unsupervised mixture decomposition algorithm (CLASSY) to a few of the digitized images has yielded mixed results.

The multiparameter scatterometer data will be further analyzed to determine class separability by using multiple channels as compared to a single channel. We will also study homogeneous fields within the test site to characterize their radar signatures.

The X-band synthetic aperture radar data require digital reprocessing to obtain better quality images, which are necessary for a sound classification study. We are in the process of deciding whether the synthetic aperture radar preprocessing should be done in house or by an outside contractor. In addition, the airborne thematic mapper simulator measurements must be preprocessed to conduct a synergistic study of optical and microwave data for forest classification. The JSC is in the process of determining the most cost-effective approach to this processing activity.

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Radar backscatter histogram: pine versus hardwood.



Thematic Mapper Research

TM: Jon Erickson/SH3
Reference OSSA 30

In anticipation that the Landsat thematic mapper (TM) would be launched during the middle of the 1982 crop year, the NASA Ames Research Center was requested to obtain thematic mapper simulator (TMS) data using a C-130 aircraft over a 5- by 6-n. mi. Corn Belt site during the spring and early summer before launch of Landsat 4. It was hoped that several TM data takes could be acquired from midseason to harvest, augmenting the early season TMS data and providing an entire season of multitemporal acquisitions.

Three dates each were acquired with the thematic mapper simulator (June 7, June 23, and July 31) and the thematic mapper (August 2, September 3, and October 21) for a 9- by 11-km sample segment in Webster County, Iowa. The initial TM acquisition (August 2) over the test site did not have bands 5, 6, and 7 since the cold focal plane was not active on this date. However, the other TM and TMS acquisitions contained all the TM bands. This region of Iowa is predominantly corn (44%) and soybeans (38%) and has a narrow range of planting dates and therefore a narrow range of crop stages. The U.S. Department of Agriculture Statistical Reporting Service (SRS) collected crop inventories and periodic observations of crop condition using 1982 U-2 photography at 1:24 000 scale. These ground data were digitized in a raster scan to 1/6 of a TM pixel and registered to the September 3 TM scene. Moreover, periodic observations of crop stage, crop condition, fertilization, etc., were recorded by SRS each 7 days for more than 100 fields. These data were placed in a data base such that they could be referenced to the TM and TMS digital data by field number.

The August 2, September 3, and October 21 scenes of Webster County, Iowa, were multitemporally registered using TM band 4 and an edge-correlation technique. Tests of the

registration accuracy were conducted by measuring the line and pixel offsets in 40 regions (40 pixels by 40 lines each) in the image. The root-mean-square accuracy of the registration from August 2 to September 3 was about 0.25 pixel, and the accuracy of the registration from the August 2 to the October 21 image was 1 pixel. The TMS data were manually registered to the TM scene on August 2 using a tie-point registration routine.

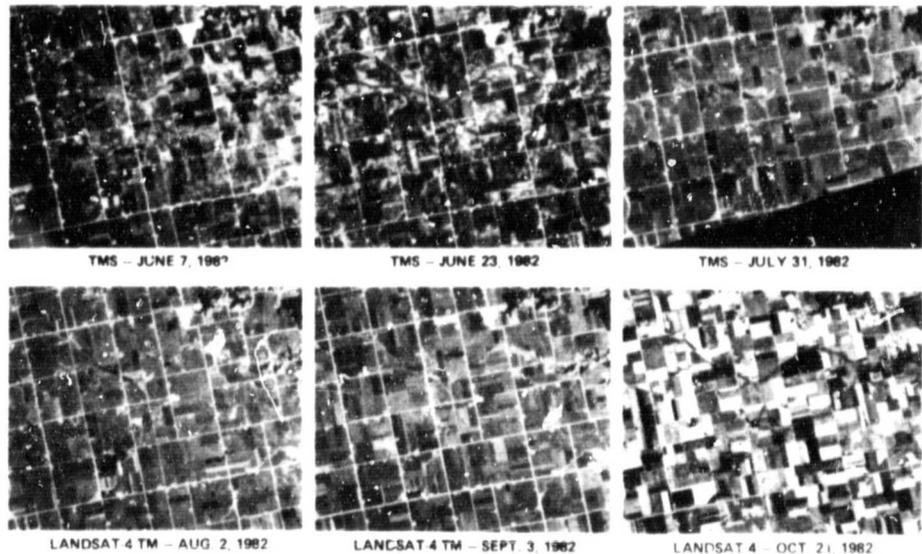
These data were analyzed to determine the effect of the additional TM spectral bands in the middle and thermal infrared and the increased TM quantization levels on corn/soybean separability. The measure of the separability used in this study was the Fisher information measure. The Fisher information measure was calculated using all seven bands and with the four visible/near-infrared bands. The middle infrared bands provided a separability on July 31 comparable to that present on September 3 (the best separability date using only the bands in the visible and near infrared wavelengths). This result corroborates results obtained using helicopter spectrometer data collected in 1981 for this same sample segment. Moreover, early in the crop year (June 23), bands 1 and 3 (blue and red) were the best single bands. Later (August 2), bands 5 and 7 (middle

infrared) were best; in early September, both middle infrared and near infrared (bands 4 and 5) were best. During harvest (October 21), the thermal infrared (band 6) was the best single band.

To evaluate the effect of quantization, the Fisher information measure was calculated using individual bands as a function of the number of quantization levels. The results indicated no significant change in separability when the 256 levels present in the thematic mapper data were reduced to 64 levels (as used on the multispectral scanner).

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Multitemporal sequence of thematic mapper (TM) band images from segment 893, Webster County, Iowa (1982). Includes Landsat 4 TM and aircraft TM simulator (TMS) data.



Artificial Intelligence

PI: Thomas W. Pendleton, Jr./SC5
Reference OSSA 31

The Johnson Space Center effort in artificial intelligence (AI) began as a result of our interest in applying AI technology to the interpretation of remotely sensed imagery. It has become clear, however, that other activities can benefit from the application of AI technology, especially the use of expert systems, which is one of the most successful areas of endeavor in the AI community. The goal of this effort has thus become one of developing a research capability incorporating existing AI software, which will result in a computer environment and the associated expertise to pursue the application of AI technology.

Through a cooperative effort with the University of Massachusetts, the computer vision research test bed VISIONS was acquired and installed on a local VAX 11/780 computer. This system supports research in image understanding and interpretation and pro-

vides a means for building expertise in the use of LISP, the AI programming language of choice, and a vehicle for obtaining experience in the building of expert systems.

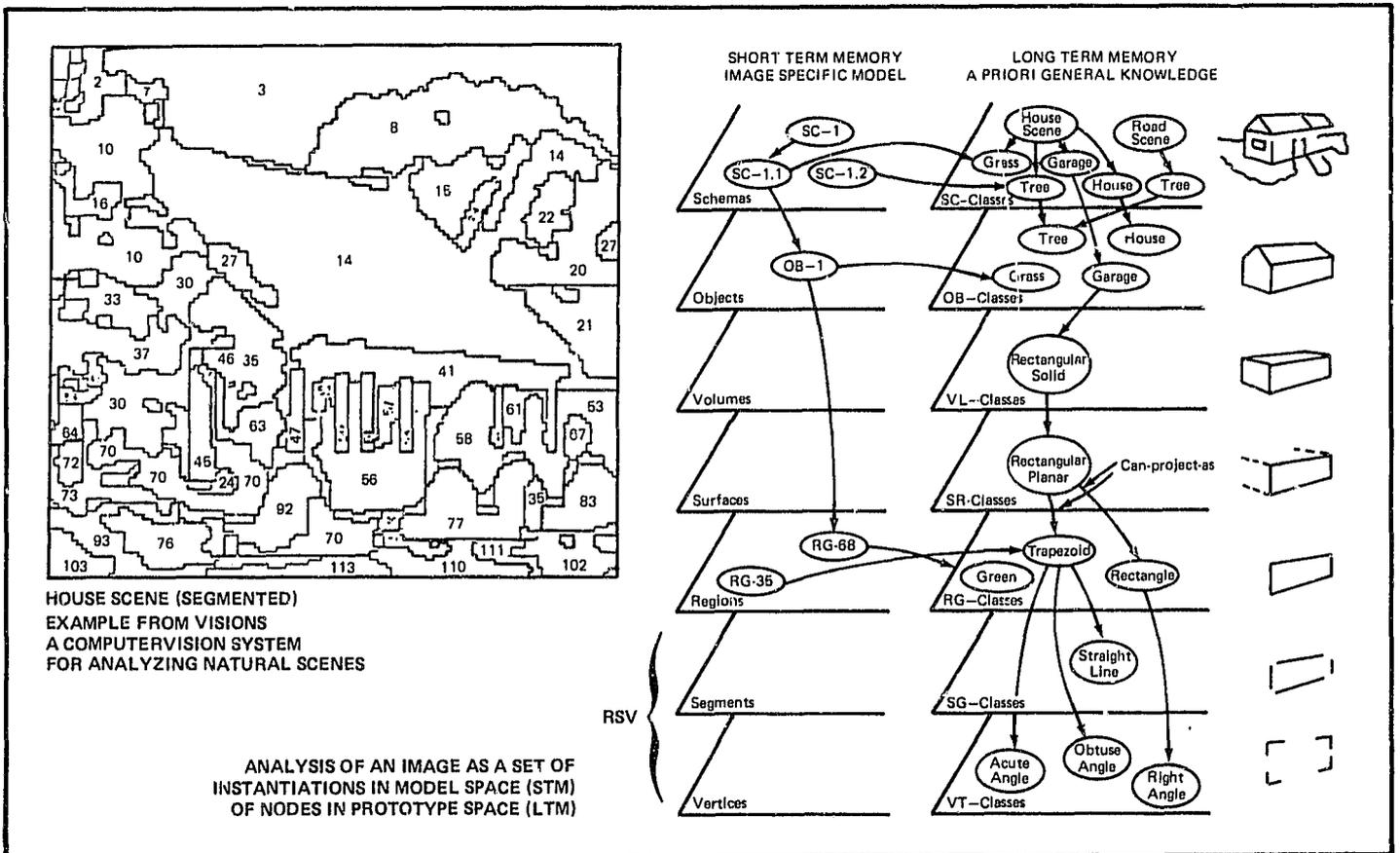
As illustrated, the VISIONS system is an interpretation system in which the lowest levels of information derived from a scene are merged using a priori general knowledge to produce, at the highest level, a scene segmentation with each segment labeled appropriately. For example, in the scene being considered, the VISIONS program would recognize edges, vertices, line segments, etc., from the image operators and general knowledge contained in the low-level-processing portion of the system. These elements would be combined into surfaces, volumes, and objects using higher level processing and would be recognized as grass, trees, houses, etc., in the context of the knowledge being employed in the VISIONS program for the type of image. Combinations of objects would then be interpreted as scenes based on the particular schemata employed for

the image being interpreted. By employing a different knowledge base and different schemata, the VISIONS program can be applied to research in the interpretation of other images.

The VISIONS system is designed as a research tool for algorithm development and, as such, provides a flexible, interactive environment in which experiments with many image operators can be easily performed, since specific low-level-processing routines are easily added to the system. VISIONS is constructed so that low-level image segmentation is done with FORTRAN subroutines and the higher level merging and labeling of segments is done using LISP. Development of high-level-processing schemata is facilitated by a graph processing language GRASPER developed in LISP at the University of Massachusetts.

Research using the VISIONS test bed is contributing to the understanding and development of knowledge-based computer systems for remote-sensing and space-flight support.

Application of VISIONS, a computer vision research test bed.



Shuttle Imaging Radar

PI: Gary Graybaal/SK
Reference OSSA 32

It is the goal of the NASA synthetic aperture radar global biological scientific research to improve the understanding of vegetative characteristics and processes, to expand and also improve access to a comprehensive research information base, and to incorporate predictive simulation modeling of changes. This research will provide an improvement in the understanding of the effects on global biological productivity and life support cycles of long-term changes in physical, chemical, and biological processes.

The Shuttle Imaging Radar (SIR) systems represent a series of evolutionary steps which began in 1978 with the Seasat synthetic aperture radar. The second step, which used the SIR-A instrumentation, was conducted in November 1981, as part of the second test flight of the Space Shuttle *Columbia*. The third step (SIR-B) is scheduled for launch on the seventeenth flight of the Space Shuttle. A fourth and major expansion of the SIR synthetic aperture radar instrumentation (SIR-C) has been proposed by the Johnson Space Center.

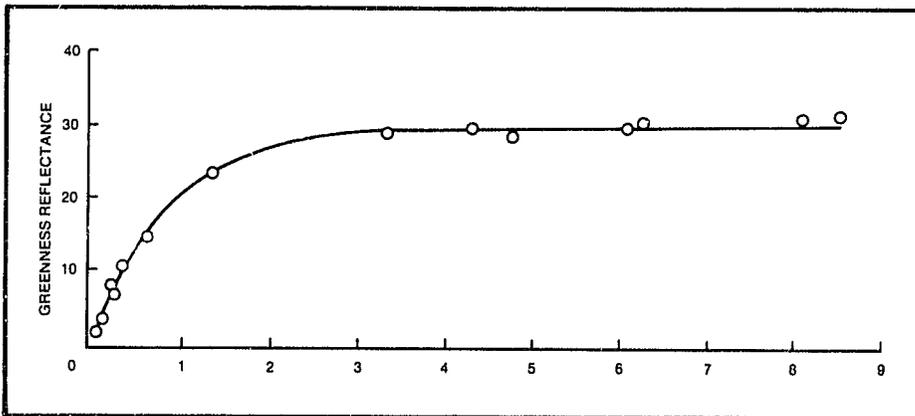
The synthetic aperture radar imagery which has been acquired with Seasat and SIR-A and the imagery to be acquired with SIR-B for the most part are related to the scientific requirements set forth by the geo-

science research community. The use of the visible/infrared wavelengths is limited to sensing leaf area index below an index of about 2. The curve then flattens with very little response to increased leaf area index from that point. The radar sensor potentially has a larger range of sensing the leaf area index as shown in the truck-obtained plot data. With the ability to use leaf area index factors with an expanded range, various models now exist to predict the biomass of vegetation and biological productivity.

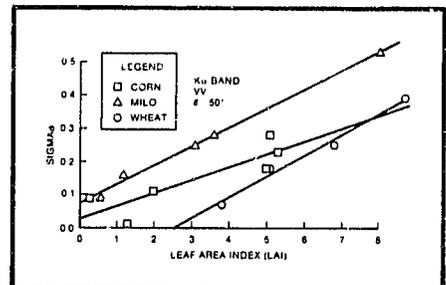
The SIR-A sensor system was an L-band (23.5 cm, 1.278 GHz) system and acquired data in the HH polarization mode at a fixed, nominal incidence angle of 50°. The orbital data were recorded optically, and only a small percentage of the images were converted to digital images. Approximately 8 hours of data were acquired during orbital operations. The SIR-B sensor system will also acquire L-band (23.5 cm, 1.278 GHz) data in the HH polarization mode. The angle of incidence can be varied from 15° to 60°. The SIR-B sensor will acquire approximately 25 hours of data which can be converted to digital images. Current plans are to convert 2 hours of the data to digital images and 8 hours of the data to optical images within the first year following the flight. All digital data acquired by SIR-B will be transmitted to the ground through the Tracking and Data Relay Satellite (TDRS) system. However, TDRS access is limited to about 30% of the time because of blockage by the Orbiter itself.

The JSC proposal for a SIR-C synthetic aperture radar system called for multiple frequency, multiple incidence angle, and multiple polarization. In addition, the provision of data recording media onboard the Shuttle to increase the on-orbit data acquisition was a key component of the Johnson Space Center configuration. The on-board data recording will eliminate a key restriction on data acquisition for science investigation sites related to orbital tracks for which the TDRS access is limited because of blockage by the Orbiter.

Plot of leaf area index using visible/infrared data.



Plot of radar backscattering coefficient (SIGMA₀, m²/m²) versus leaf area index (m²/m²) for three crops at 17 GHz, with VV polarization, and at a look angle θ of 50° from the nadir. Data obtained using truck-mounted sensor.



Space Shuttle Earth Observations Project

PI: John L. Kaltenbach/SC5
Reference OSSA 33

Meaningful handheld-camera photography of the Earth has been acquired on NASA manned space missions since early in the Gemini Program. Although most of this photography has been gathered on a noninterfering basis, the results have proven most useful in contributing to the Earth science disciplines. The principal value of this photography is attributable to its availability on a repetitive basis with varying lighting conditions and viewing angles (ranging from vertical to high oblique) and to its capability to complement imagery from other Earth-viewing sensor systems, such as Landsat. In addition, the presence of man as detector and observer of phenomena transient in geographic position or time has proved extremely valuable.

The Space Shuttle Earth Observations Project (SSEOP) provides a continuing program for obtaining and using handheld photography of the Earth for scientific purposes. Objectives of the Space Shuttle Earth Observations Project are (1) to define and implement Earth observation opportunities with participating science discipline specialists, (2) to provide Earth observations support to Shuttle crewmen in the areas of training, documentation, and mission operations, and (3) to provide operation of the Shuttle Earth-Viewing Imagery Facility.

The Shuttle missions continue to provide spectacular handheld photography from Hasselblad 500 EL 70-mm NASA modified cameras, using interchangeable 50-, 100-, and 250-mm-focal-length lenses. Hundreds of Earth-viewing photographs have been taken on each of the Shuttle missions, and, in many instances, overlapping stereophotography has been obtained. These photographs are being cataloged and indexed for each mission, with the intent to make the resulting documents available to the public through the Earth Resources Observation Systems Data Center.

The SSEOP supports several specialists in the scientific disciplines of

geology, oceanography, and meteorology. These discipline specialists are responsible for identifying their areas of interest, presenting science familiarization information to the astronauts, and briefing each flightcrew on specific sites to be observed and photographed during their mission. The site information provided to the SSEOP Team by the investigators is compiled into an Earth Observations Manual for preflight study by the Shuttle crews. Real-time mission support including weather information is provided to inform the flightcrew daily of sites that will be within view and to alert them of special event phenomena such as active volcanoes, duststorms, and major weather disturbances.

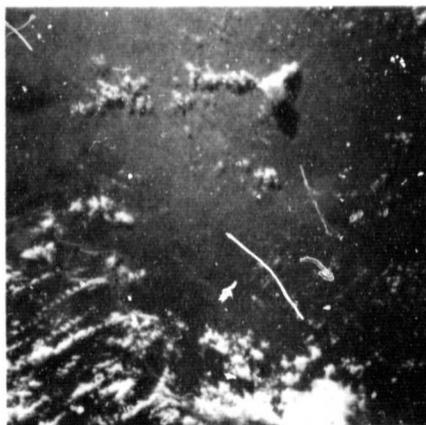
Examples of photography taken by crewmen during space flights are shown. Internal waves, or solitons, in the South China Sea, near Hainan Island, China, are illustrated. Photography of the ocean from space has revealed patterns of surface roughness indicative of large-scale circulation features in the ocean basins. Solitons are subsurface shock waves propagated from the entrance of constricted, shallow seas adjacent to deep ocean basins. Although the existence of solitons had been theorized, Vance Brand's Apollo-Soyuz photograph provided physical confir-

mation. Other internal wave systems, such as those produced by tidal cycles, have been photographed by Space Shuttle astronauts.

An oblique view across the Karakoram Fault in China is illustrated. This major strike-slip fault separates the Tibetan Plateau from the Indian high ranges. Oblique views of geological structures from orbital altitudes supplement the information gained from geometrically rectified satellite (Landsat) and mapping camera (Large Format Camera) images. Astronauts can be trained to recognize significant geological structures and to make stereoscopic photographs of these features. Such photographs supply geologists with an orbital perspective including a variety of viewing angles and illumination conditions.

The presence of a human observer can result in the documentation of previously unobserved phenomena, the selection of enhanced views of known features, and the ability to selectively collect data of features that are transient in either time or geographic position. Thus, handheld photography is a valuable source of information to augment that collected by systematic instruments such as the Landsat multispectral scanner and thematic mapper, the Shuttle Imaging Radar, and the Advanced Very High Resolution Radiometer.

Internal waves, or solitons.



Karakoram Fault.



Index

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Index

Reference Number	Significant Task
	Office of Space Flight
OSF 1	Remote Manipulator System Control Technology Funded by: Advanced Development (UPN-906) Technical Monitor: Henry J. G. Kaupp, Jr./EH2 Task Performed by: Charles S. Draper Laboratory Incorporated Contract NAS 9-16023
OSF 2	Automated Rendezvous, Proximity, and Docking Funded by: Advanced Development (UPN-906) Technical Monitor: Bob Brown/FM Task Performed by: Lyndon B. Johnson Space Center
OSF 3	Satellite Services Standard Interfaces Funded by: Advanced Development (UPN-906) Technical Monitor: Gordon Rysavy/EB Task Performed by: Lyndon B. Johnson Space Center
OSF 4	Integrated Atmospheric Revitalization System Test Funded by: Advanced Development (UPN-906) Technical Monitor: Nick Lance/EC3 Task Performed by: Lyndon B. Johnson Space Center
OSF 5	Distributed Data Management System Funded by: Advanced Development (UPN-906) Technical Monitor: W. L. Swingle/EH Task Performed by: Lyndon B. Johnson Space Center
OSF 6	Tethered Vehicle Dynamics and Analysis Funded by: Advanced Development (UPN-906) Technical Monitor: Milton C. Contella/EH2 Task Performed by: Lyndon B. Johnson Space Center
OSF 7	Tethered Orbital Refueling Funded by: Advanced Development (UPN-906) Technical Monitor: Ken Kroll/EP4 Task Performed by: Martin Marietta Aerospace Company
OSF 8	Catalytic Recombination on Thermal Protection Material During Reentry Funded by: Advanced Development (UPN-906) Technical Monitor: Carl D. Scott/ES3 Task Performed by: Lyndon B. Johnson Space Center
	Office of Aeronautics and Space Technology
OAST 1	Low-Earth-Orbit Energy Storage Using Regenerative Fuel Cells Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: J. Dale Denais/EP5 Task Performed by: General Electric Company Contract NAS 9-15831 Life Systems, Inc., Contract NAS 9-16659
OAST 2	Thermal Management for On-Orbit Energy Systems Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: J. Gary Rankin/EC2 Task Performed by: Grumman Aerospace Corporation Contracts NAS 9-15965 and NAS 9-16781 Vought Corporation Contracts NAS 9-14907 and NAS 9-16582 Hughes Aircraft Company Contract NAS 9-16581 Rockwell International Contract NAS 9-16782

Reference Number	Significant Task
OAST 3	Atomic Oxygen Interaction Studies Funded by: Space Research and Technology Base (UPN-506) Technical Monitors: Lubert J. Leger/ES5 and James T. Visentine/ES5 Task Performed by: Lyndon B. Johnson Space Center
OAST 4	Construction/Docking Technology Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: William K. Creasy/ET5 Task Performed by: Grumman Aerospace Corporation Contract NAS 9-16276
OAST 5	Atmospheric Carbon Dioxide Removal Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: Robert J. Cusick/EC3 Task Performed by: Hamilton Standard Contract NAS 9-13624
OAST 6	Automated Subsystems Control Technology Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: Nick Lance/EC3 Task Performed by: Honeywell Systems and Research Center Contract NAS 9-16895
OAST 7	Advanced Autopilot for Manned Spacecraft Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: Terry D. Humphrey/EH4 Task Performed by: Charles Stark Draper Laboratory Incorporated Contract NAS 9-16023
OAST 8	Flight Operations Data Management System Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: William V. Bates, Jr./DF7 Task Performed by: McDonnell Douglas Technical Services Company Contract NAS 9-16715
OAST 9	Strength and Motion Modeling Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: B. J. Woolford/EN44 Task Performed by: University of Pennsylvania Contract NAS 9-16634
OAST 10	Programmable Mask Technology Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: Harry Erwin/EE6 Task Performed by: Hughes Aircraft Company Contract NAS 9-16922
OAST 11	Refining of Nonterrestrial Materials Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: David S. McKay/SN4 Task Performed by: Lockheed Engineering and Management Services Company Contract NAS 9-15800
OAST 12	Advanced Carbon-Carbon Standoff Panel Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: Donald M. Curry/ES3 Task Performed by: Vought Corporation Contract NAS 9-16330

**Office of Space Sciences and Applications
Solar System Explorations**

OSSA 1	The Chemistry of Micrometeoroid Experiment Funded by: Planetary Geochemistry and Geophysics (UPN-153) Principal Investigator: Friedrich Horz/SN4 Task Performed by: Lyndon B. Johnson Space Center
OSSA 2	Volcanic Dust in the Stratosphere Funded by: Planetary Materials (UPN-152) Principal Investigators: James L. Gooding/SN2 and Uel S. Clanton/SN2 Task Performed by: Lyndon B. Johnson Space Center
OSSA 3	The Earth's Early Crust and Mantle Funded by: Planetary Geochemistry and Geophysics (UPN-153) Principal Investigator: William C. Phinney/SN4 Task Performed by: Lyndon B. Johnson Space Center

Reference Number	Significant Task
OSSA 4	Development of an Analytical Method for Determination of Hydrogen in Lunar Materials Funded by: Planetary Materials (UPN-152) Principal Investigator: Everett K. Gibson, Jr /SN4 Task Performed by: Lyndon B. Johnson Space Center
OSSA 5	Lunar Base Studies Funded by: Planetary Geochemistry and Geophysics (UPN-153) Technical Monitors: Wendell Mendell/SN3 and M. B. Duke/SN Task Performed by: Eagle Engineering Company, Incorporated
OSSA 6	Spectral Properties of Submicron Powders of Iron Oxides and Oxyhydroxides Funded by: Planetary Geochemistry and Geophysics (UPN-153) Principal Investigator: Richard V. Morris/SN4 Task Performed by: Lyndon B. Johnson Space Center
OSSA 7	Experimental Trace-Element Geochemistry Funded by: Planetary Geochemistry and Geophysics (UPN-153) Principal Investigator: Gordon A. McKay/SN4 Task Performed by: Lyndon B. Johnson Space Center
OSSA 8	Trapped Solar Gases in a Lunar Meteorite Funded by: Planetary Materials (UPN-152) Principal Investigator: D. D. Bogard/SN4 Task Performed by: Lyndon B. Johnson Space Center
OSSA 9	In Situ Measurements of Stratospheric Ozone Funded by: Upper Atmospheric Research (UPN-147) Principal Investigator: Donald E. Robbins/SN3 Task Performed by: Lyndon B. Johnson Space Center
OSSA 10	Radar Studies of Active Experiments in the Ionosphere Funded by: U.S. Air Force (UPN-971) Principal Investigator: R. Jerry Jost/SN3 Task Performed by: Lyndon B. Johnson Space Center
OSSA 11	Hypervelocity Impact Studies of Composite Materials Funded by: Advanced Programs and Plans (UPN-506) Technical Monitor: Jeanne Lee Crews/SN3 Task Performed by: Lockheed Engineering and Management Services Company Contract NAS 9-15800
OSSA 12	Beam Plasma Discharge Studies Funded by: Space Plasma Physics Program (UPN-389) Principal Investigator: Andrei Konradi/SN3 Task Performed by: Lyndon B. Johnson Space Center
OSSA 13	Sonic Boom Studies Funded by: Shuttle Program Office (UPN-925) Technical Monitor: John Stanley/SN3 Task Performed by: Lockheed Engineering and Management Services Company Contract NAS 9-15800
OSSA 14	Interplanetary Meteoroids Funded by: International Solar-Polar (UPN-838) Principal Investigator: Herbert Zook/SN3 Task Performed by: Lyndon B. Johnson Space Center
Life Sciences	
OSSA 15	Shuttle Echocardiography Funded by: Life Sciences (UPN-199) Technical Monitor: Michael W. Bungo/SD Task Performed by: Technology Incorporated Contract NAS 9-14880
OSSA 16	Operational Biobehavioral Training Facility Funded by: Life Sciences (UPN-199) Technical Monitor: Sam L. Pool/SD Principal Investigator: Leonard Gardner Task Performed by: Universities Space Research Association Contract NAS 9-16842

Reference Number	Significant Task
OSSA 17	<p>Scopolamine Assay Development and Application Funded by: Life Sciences (UPN-199) Principal Investigator: Nitza M. Cintron-Trevino/SD4 Task Performed by: Lyndon B. Johnson Space Center Northrop Services Incorporated Contract NAS 9-15425</p>
OSSA 18	<p>Space Adaptation Syndrome--Parallel Swing Tests Funded by: Life Sciences (UPN-199) Technical Monitor: John W. Harris/SD3 Task Performed by: Lyndon B. Johnson Space Center Universities Space Research Association Contract NAS 9-16842</p>
OSSA 19	<p>Detection of Incipient Altitude Decompression Sickness With Doppler Sensors in Flight Funded by: Life Sciences (UPN-199) Technical Monitor: James M. Waligora/SD3 Task Performed by: Technology Incorporated Contract NAS 9-14880</p>
OSSA 20	<p>Rectilinear Bone Densitometry Funded by: Life Sciences (UPN-199) Technical Monitor: Victor S. Schneider/SD3 Task Performed by: Lyndon B. Johnson Space Center Technology Incorporated Contract NAS 9-14880</p>
OSSA 21	<p>Dual-Photon Absorptiometry Spinal Mineral Density Determination Funded by: Life Sciences (UPN-199) Technical Monitor: Victor S. Schneider/SD3 Task Performed by: Lyndon B. Johnson Space Center Technology Incorporated Contract NAS 9-14880</p>
OSSA 22	<p>Animal Enclosure Module Funded by: Life Sciences (UPN-199) Technical Monitor: Malcolm C. Smith, Jr./SD3 Task Performed by: Lyndon B. Johnson Space Center Ames Research Center</p>
OSSA 23	<p>Emergency Medical Care in Space Funded by: Life Sciences (UPN-199) Technical Monitor: James S. Logan/SD2 Task Performed by: University of Texas at Houston Contract NASW 3744 Umpqua Research Company Contract NAS 9-16337 Narco Bio-Systems Contract NAS 9-16727</p>
OSSA 24	<p>Bioprocessing in Space Funded by: Life Sciences (UPN-199) Technical Monitor: D. R. Morrison/SD5 Task Performed by: Lyndon B. Johnson Space Center</p>
Earth Sciences and Applications	
OSSA 25	<p>Techniques for Vegetative Feature Extraction Funded by: Resource Observation (UPN-677) Principal Investigator: V. S. Whitehead/SC4 Task Performed by: Lyndon B. Johnson Space Center</p>
OSSA 26	<p>Large Area Change in Biomass Funded by: Resource Observation (UPN-677) Principal Investigator: J. Dragg/SC4 Task Performed by: Lyndon B. Johnson Space Center</p>
OSSA 27	<p>Soils Research Funded by: Resource Observation (UPN-677) Principal Investigator: D. R. Thompson/SC4 Task Performed by: Lyndon B. Johnson Space Center</p>
OSSA 28	<p>Geographic Information Systems Research Funded by: Resource Observation (UPN-677) Principal Investigator: Robert G. Musgrove/SC6 Task Performed by: Lyndon B. Johnson Space Center</p>

Reference Number	Significant Task
OSSA 29	<p>East Texas Radar Experiment Funded by Resource Observation (UPN-677) Technical Monitor D L Amsbury/SC4 Principal Investigator Narish Mehta, Lockheed Engineering and Management Services Company Task Performed by Lyndon B Johnson Space Center</p>
OSSA 30	<p>Thematic Mapper Research Funded by Resource Observation (UPN-677) Technical Monitor Jon Erickson/SH3 Task Performed by Lyndon B Johnson Space Center</p>
OSSA 31	<p>Artificial Intelligence Funded by Resource Observation (UPN-677) Principal Investigator Thomas W. Pendleton, Jr /SC5 Task Performed by Lyndon B Johnson Space Center</p>
OSSA 32	<p>Shuttle Imaging Radar Funded by Resource Observation (UPN-677) Principal Investigator Gary Graybeal/SK Task Performed by Lyndon B Johnson Space Center</p>
OSSA 33	<p>Space Shuttle Earth Observations Project Funded by Shuttle Program Office (UPN-925) Principal Investigator John L. Kaltenbach/SC5 Task Performed by Lyndon B. Johnson Space Center</p>