NASA Technical Memorandum 102 161

Johnson Space Center
Research and Technology
Annual Report 1989

NASA
National Aeronautics and
Space Administration

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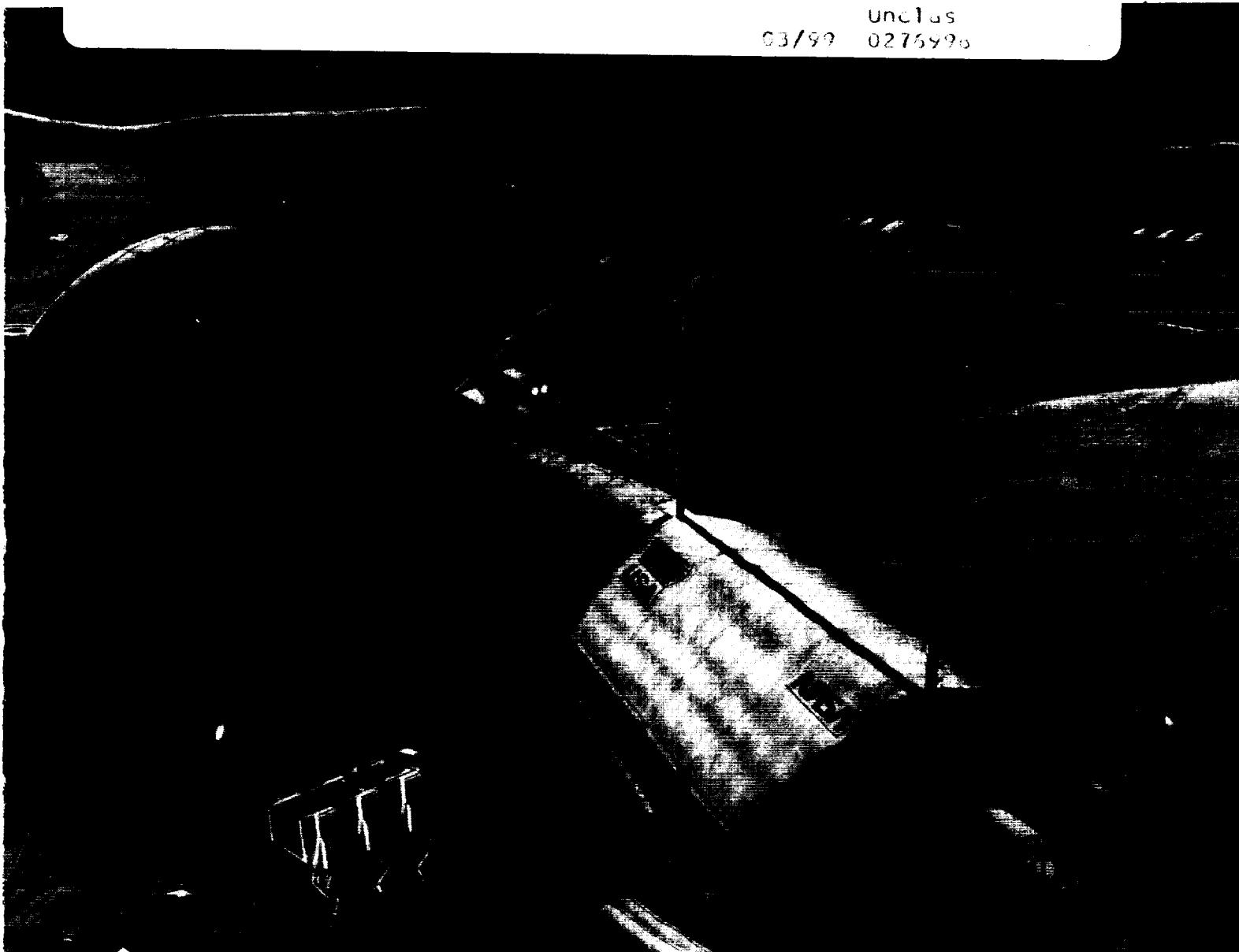
Johnson Space Center

Research and Technology

Annual Report 1989

March 1990

Preface

The Johnson Space Center (JSC) Research and Technology (R&T) Report is prepared annually to highlight the Center research and technology activities during the past year. The report is the responsibility of the New Initiatives Office, which has been established to place explicit emphasis on research activities at JSC.

Although JSC is a NASA development center, it is conducting significant space-related research. Achievement of the goals attendant with the expanded commitment to space exploration places increased demands on the quality and quantity of supporting research. The intent of this report is to inform Research and Technology Program managers and their constituents of significant accomplishments that promise practical and beneficial program applications. While not inclusive of all R&T tasks, the scope of the report represents a comprehensive summary of JSC's activities during 1989.

The development of this report represents a coordinated effort with JSC line organizations, most notably the Administration Directorate, Space and Life Sciences Directorate, and Engineering Directorate. Their efforts as well as those of the individual authors are commended and are recognized as essential contributions to this report. Personnel listed below have written the section summaries and coordinated the technical inputs for their respective sections of the report. Detailed questions may be directed to them or to the principal investigators listed in the Index.

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Medical Sciences

Summary

Medical Sciences

The Johnson Space Center (JSC) Space and Life Sciences Directorate conducts a broad range of applied medical programs in support of Life Sciences goals, specifically: ensuring the health and performance of humans in space, first by characterizing the medical consequences of spaceflight, and second by developing research and technology programs to aid life in space for extended periods and by exploiting the unique properties of the space environment to increase and improve fundamental knowledge in medicine and biology.

With NASA's successful return to manned spaceflight in 1988, the frequency of Shuttle flights is increasing. Research and operational activities continue in an effort to categorize the physiological changes that occur in the spaceflight environment, and to determine the effects of these changes on the health and performance of the crew.

Implementation of the Extended Duration Orbiter (EDO) Medical Program was initiated in February 1989. The goal of this program is to ensure crewmembers' health and safety by protecting their ability to perform egress, entry, and landing after extended duration Space Shuttle flights. Discipline working groups have been formed to address environmental and physiological concerns and create scientific and technical requirements for extending the duration of flight. External advisors in these groups include experts from industry and universities in the areas of environmental health, muscle and exercise physiology, neurophysiology, cardiovascular physiology, and fluid and electrolyte physiology. The NASA, contractor, and advisor teams in each discipline are devising and implementing studies in their respective areas that will, by building upon each other, lay the foundation for the development of flight countermeasures and countermeasure hardware.

Requirements definition and medical hardware development continue for Space Station Freedom. Systems requirements for the Crew Health Care Subsystem are presently under review by McDonnell-Douglas Aerospace Corporation, Space Station's prime contractor. Air and water quality specifications and monitoring requirements have been baselined, with prototype test instruments to be tested onboard the Space Shuttle next year. The National Research Council has contracted to assist NASA in establishing long-term contamination exposure limits. Two candidate Health Maintenance Facility units are being evaluated; a Medical Analytical Laboratory unit and a Digital Radiographic Imaging System. Standards are also being developed for a computer information bus that will allow in-flight medical devices to communicate with each other.

Plans for establishing a lunar outpost and manned flight to Mars are also underway. Life scientists have begun to set priorities and assemble an overall strategy. The success of these new exploration programs will depend upon the research and technological knowledge gained from experience with the Space Shuttle and Space Station programs. Issues of particular importance will be self-sufficiency; prevention of deconditioning by use of countermeasures, artificial gravity, or some combination thereof; protecting crews from radiation; human factors considerations; and development of self-contained, recyclable life support systems. It is recognized that the key to success of these exploration programs is a better understanding of the mechanisms of physiological deconditioning.

Both the EDO and Space Station programs will require operational capabilities for in-flight analysis. The technologies described in this report are directed toward maintaining crew health and productivity, responding to medical emergencies, monitoring the internal environment, developing data acquisition and analysis techniques, and developing and evaluating potential physiological countermeasures.

The Internal Environment: Habitability Issues

Efforts are underway in the JSC Biomedical Operations and Research Branch in the areas of environmental health, toxicology, microbiology, and water quality to develop and identify effective strategies and advanced technologies to ensure spacecraft habitability. Both ground-based and onboard monitoring and analytical techniques are being evaluated that will maintain the toxicological and microbiological safety of air, surfaces, water, and the crew themselves in the closed space craft system. In preparation for longer duration flights, the JSC Toxicology Group is revising the current method of calculating Spacecraft Maximum Allowable Concentration (SMAC) values for potentially toxic exposures in order to calculate safe exposure limits for periods up to 30 days. A water storage and distribution system designed to simulate a spacecraft system is in its 18th month of a 2-year test run. Preliminary results indicate that Microbial Check Valves (MCVs), which maintain iodine levels in this system, are of crucial importance in minimizing microbial contamination of the water supply. In a related application, the Water and Food Analytical Laboratory has devised a microbial filter assembly from two MCVs as a "quick-fix" solution to reduce over-iodination in the Shuttle potable water supply.

Facilities and Equipment Development

The simulated spacecraft water system mentioned above serves as a testbed for operational issues to be considered in the design of such a system for Space Station. The JSC Microbiology Group has developed

and tested a microbial gramstaining device suitable for use in flight

The JSC Medical Operations Branch continues to upgrade Space Station's Health Maintenance Facility. This year an improved Medical Restraint System was developed that addresses problems of earlier prototypes, such as instability during vigorous procedures, degrees of motion required, and providing a means of restraining the medical officer without interfering with mobility. Medical Operations has also designed a computerized medical expert system that will provide data handling along with diagnostic and therapeutic assistance to crew medical officers during flight. This system will incorporate characteristics of existing medical reference systems, communication systems, and advice systems.

The Exercise Countermeasures Project (ECP) is evaluating novel equipment designs for exercise and monitoring devices capable of providing multi-modal operations in microgravity. Two exercise devices are currently in fabrication: the first, the Universal Exercise Machine (U.S. Patent no. 4679786), is an omnifunctional exercise device capable of at least four-modes of exercise with quantifiable workloads.

The second device is a modified treadmill that includes an improved restraint capable of delivering individualized workloads. Videos will be tied in to the same computer that controls an exercise device, enabling the video scene to change with the activity level of the exercising person. For example, if a crewmember's exercise prescription requires a steadily increasing workload on a bicycle-ergometer, the accompanying video could reflect pedaling uphill, or being passed by other cyclists. The use of incentive videos is an important factor in maintaining motivation for regular exercise over long periods of time, both on the ground and in flight.The ECP has also developed a reaction-time device that simulates typical Shuttle tasks (reaching overhead

and flipping switches in response to auditory or visual stimuli). This device will be used to evaluate changes in reaction and reflex times after exposure to microgravity and its analogs (e.g., bed rest, casting).

In a joint project between the Space Biomedical Research Institute and the Project Engineering Branch, a collapsible Lower Body Negative Pressure Device (LBNPD) was completed and successfully flown on STS-32 in January, 1990. This stowable device is designed to apply negative pressure (approximately 50 mm Hg below ambient pressure) to a subject from the waist down as shown in the illustration.
The Lower Body Negative Pressure (LBNP), in combination with saline loading, will be used as a countermeasure to the orthostatic intolerance displayed during reentry and landing (see below).

Other engineering projects include the design of a personal infrared telemetry system, a flexible, unobtrusive device that can be used in flight to monitor and collect up to 64 channels of biomedical data from free-roving astronauts. A prototype for the second-generation Life Sciences Laboratory Equipment microcomputer has also been completed. This new computer uses multiple processors, including a central exchange, and greatly increases speed, flexibility, and computing power. Further advantages include compartmentalization of software via modular programming techniques which allows flexibility for upgrades, experiment change-outs, and easy maintenance.

The use of pressurized space suits during Extravehicular Activities (EVAs) involves some risk to the crewmember from nitrogen bubbles in the bloodstream (Venous Gas Emboli, or VGE), and decompression sickness. The JSC Space Biomedical Research Institute's Environmental Physiology Laboratory developed an empirical model which will assist in the determination of efficient prebreathing procedures. This laboratory also conducted studies to evaluate a proposed

alternative to the prebreathing procedure: the use of a more highly pressurized space suit.

At the cellular level, the Biotechnology Program continues its development of a space bioreactor designed to sustain mammalian cell cultures. This complete tissue culture system which consists of a rotating tissue culture vessel, an external media-perfusion loop, and a computer-control system, simulates some of the fluid mechanical conditions of microgravity while maintaining compatibility with microgravity. The high-fidelity tissue models that can be raised in this device will aid in the understanding of normal and cancerous tissue function; they can also potentially improve techniques for producing pharmaceutical products and reduce dependence upon animals for tissue toxicity assessment.

Adaptation to Microgravity and Countermeasure Development

Biochemical studies are being performed to elucidate the role of the hormone Atrial Natriuretic Peptide (ANP) in maintaining fluid and electrolyte levels at the level of cellular binding sites in the blood-brain barrier. Cephalic fluid shift is also being quantified on a different level using retinal image analysis. This new technique was verified during bed rest studies; future plans include parabolic flight tests and image transmission from remote sites.

At the organismal level, studies are planned to characterize the effects of microgravity upon metabolic function at the gastrointestinal, hepatic, renal, and hematologic levels. It is anticipated that these studies will be crucial in predicting how microgravity alters the pharmacological absorption, distribution, metabolism, and excretion of nutrients and drugs, and, therefore, how it affects therapeutic intervention strategies.

The ECP is beginning a task analysis that will quantify the physical work required to egress the

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Space Shuttle in routine and emergency situations. Ground-based studies will evaluate the effect of simulated microgravity on the ability to perform egress from a Shuttle mockup. This group is also developing strategies to quantify the physical requirements (strength, endurance, coordination, nutritional status, etc.) for other tasks onboard Shuttle and Space Station. These results will form the basis for evaluation of the efficacy of proposed countermeasures.

Work continues in the characterization of the phases of cardiovascular adaptation to microgravity and development countermeasures for safe return. Potential candidates for one effect of cardiovascular deconditioning, orthostatic intolerancence, include pre-reentry fluid loading and in flight LBNP treat-ments; a ground-based study is currently underway to determine the most effective combination of these two protocols.

The JSC Neuroscience Laboratories continue to explore the neural base of posture and gait, vestibular contributions to perception and orientation, and space motion sickness. Accomplishments this year include the development of an opaque corneal contact lens that, in combination with video analysis, provides a noninvasive, precise technique to measure eye movements, which in-turn provides an indirect means of assessing vestibular integrity. An associated project is a computer program that performs data acquisition, digitization, and analysis of eye and head movements; this program can be used to study the influence of spaceflight on visual tracking and the function of the vestibuloocular reflex.

In the biobehavioral arena, classic electrophysiological measures (evoked response potentials) are being applied in a novel approach in an effort to associate a physiological marker with early changes in memory or attention patterns. Work is also underway in this area to determine the behavioral characteristics that will define optimal crewmember combinations in the isolation and close quarters of long spaceflights.
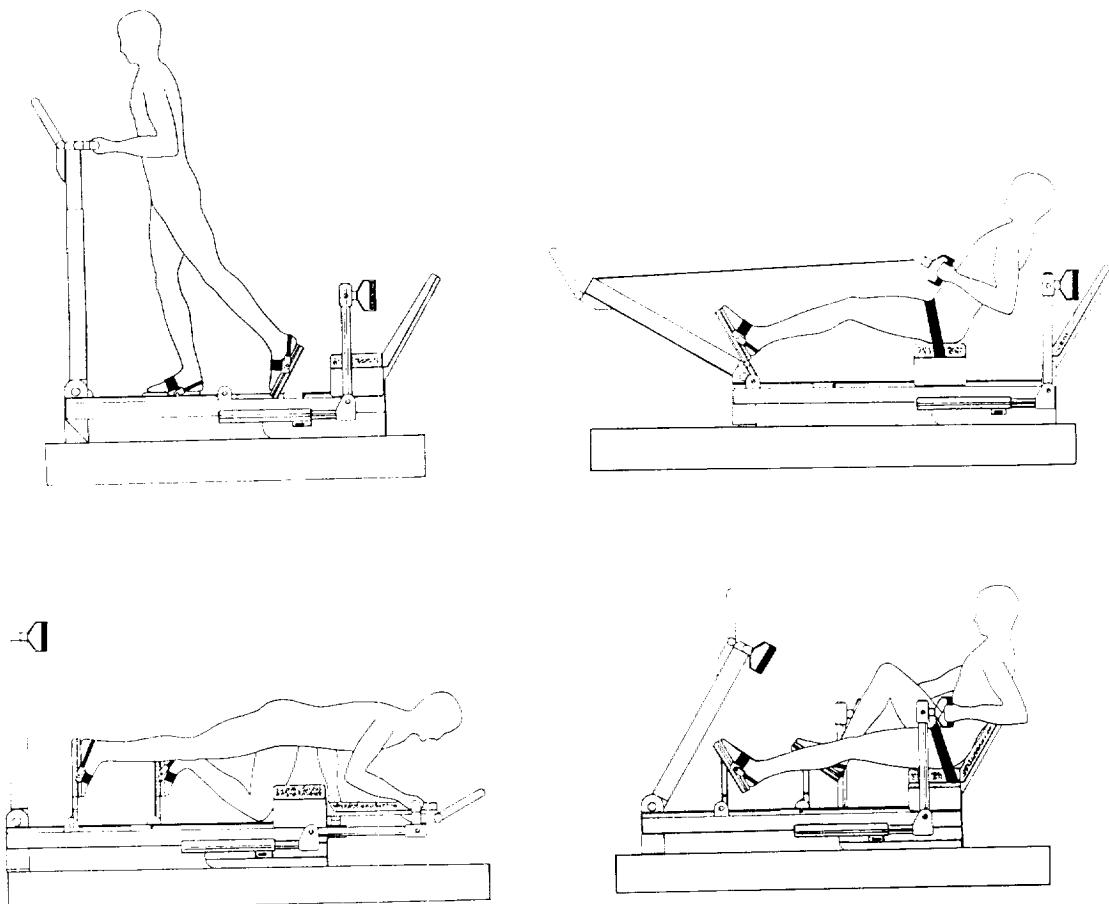
Proposed omnifunctional exercise device for use in microgravity.
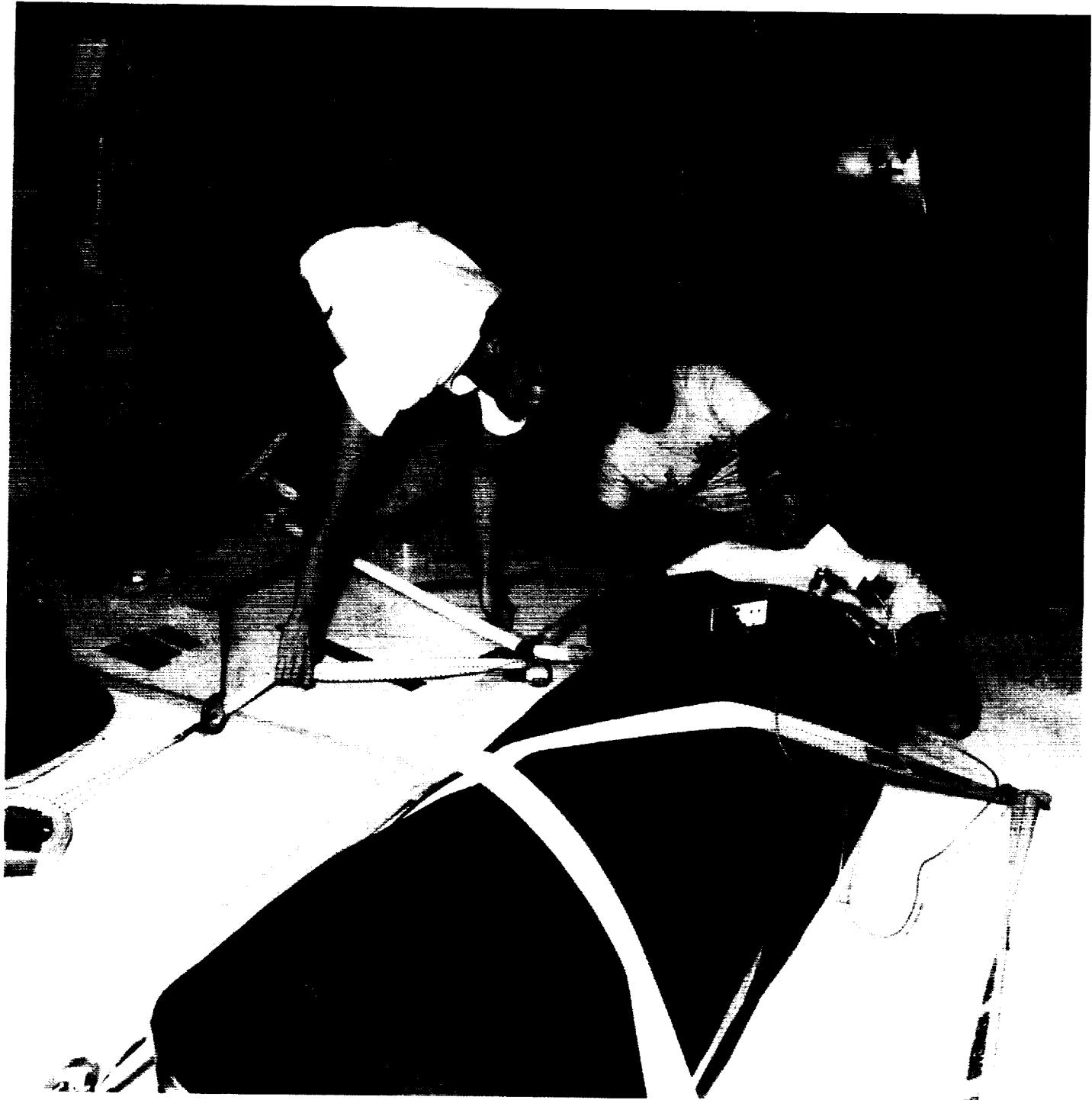
Lower body negative pressure device during KC-135 testing.

Medical Sciences

Significant Tasks

Advanced Medical Decision Support Onboard Space Station Freedom

TM: Joey B. Boyce, M.D./SD2
PI: Salem O. Zerti, M.S./SD2
Reference MS 1

A computerized Medical Decision Support System (MDSS) is being developed to provide data handling, and diagnostic and therapeutic assistance to crew medical officers. The Health Maintenance Facility (HMF) for Space Station Freedom will have medical care capabilities beyond those of any previous manned space program. The computer is becoming a regular and essential medical instrument in modern medical practice. The medical information systems that are now emerging from the research laboratories can be generally grouped into three categories. "Medical reference systems" store medical information, retrieve it selectively, and display it; "communications systems" retrieve medical information from medical instrumentation and store it into the patient's medical record; "advice systems" apply the information to help doctors diagnose a patient's condition or to propose, monitor, and help manage a course of treatment. The present emphasis at NASA/Johnson Space Center (JSC) in designing such systems for the HMF is on the development of software methods that can represent medical information and expertise in a machine and make it readily available to a trained user.

In the U.S. presently, physicians have started to use national literature data bases or bibliographic retrieval systems. They have been introduced to store full text of papers and allow pertinent sentences to be found within any paper. The HMF reference system goes a step beyond the standard U.S. medical reference systems in that it will also contain schematics of hardware components of the HMF as well as real-time video display of medical procedures. Other high-resolution graphics displays (e.g., burns and skin diseases) are also included in high-resolution graphics as they are represented in the textbooks. We currently have a prototype without video display that includes several medical textbooks and static color graphics. Our next project goal is to develop real-time color video display and numerous video segments to show the CMO how to perform certain medical procedures.

While medical reference systems provide access to stored information, communication systems provide access to real-time information generated by the medical instrumentation onboard the HMF. The Medical Information Bus (MIB) is a proposed Institute of Electronics and Electrical Engineering standard being developed by NASA and other parties. Presently, individual integration of medical instruments is an expensive process, because each instrument requires a custom software and hardware interface. The MIB will allow medical instrument manufacturers to use a standard hardware and software interface to connect to a bedside or intensive care unit computer. Instruments designed in compliance with the MIB standard can then be integrated with the computer system without any hardware modification. Our engineers, in cooperation with the standards committee, have developed a prototype MIB and have shown the versatility of the design.

The MIB is also designed to integrate the data from the various subsystem instruments into an electronic patient medical record contained in the MDSS. The MIB will reduce the amount of data input required by the CMO and allow for automatic instrument data access to the ground Space Station Control Center. It will also significantly reduce errors in reentering this data.

The last major category of medical information systems being developed for the HMF is advice systems which apply stored information to the solution of particular real-world problems. These advice systems vary in the style of interaction with the user. A critiquing system reacts to the user's current thinking — a proposed course of action of diagnostic hypothesis — and suggests alternatives if necessary. A consultation system, on the other hand, generates independent analyses and recommendations, which users can compare with their own thoughts. A third style of interaction, more suited to our application, is an expert consultation system that provides patient-specific diagnostic hypotheses. In addition, it can be an electronic textbook, listing the patient characteristics reported to occur in a given disease or, conversely, reporting which of its stored diseases can be associated with a given characteristic. Also, as a medical spreadsheet, it can combine a few characteristics or diseases and determine the implications. Such systems have been shown to perform almost as well as academic physicians in diagnosing difficult cases.

Development of these software segments for reference, communications, and advice systems relies heavily on the rapidly developing field of medical informatics for adaptation of the latest programs for specific NASA needs. Several programs that have been developed at the University of Pittsburgh (QMR-Quick Medical Reference), the LDS Hospital in Salt Lake City, Utah (HELP-Health Evaluation through Logical Processing), the University of Florida (CPLM-Clinical Practice Library of Medicine), and at other sites under evaluation for possible use in the HMF MDSS.

Because it is desirable to lessen the user-interface time, MDSS is being developed to integrate the above three systems and provide a continuous interaction between the three segments and the user. The picture below illustrates an example interaction with the system. The

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CMO called up a crewmember's X-ray and medical record. For this hypothetical display, the crewmember's complaints were suggestive of lobar pneumonia, so the CMO asked the system to search a textbook for a discussion of the radiographic evidence of lobar pneumonia.

In addition to the above three categories, MDSS will incorporate a number of logical subprograms called frames. Their purpose is to monitor all available data, such as medications, laboratory test results, and vital signs, for each patient and keep watch for any alert conditions. When any such condition is identified, MDSS issues a warning message to the CMO. These frames will also be responsible for signaling physical exams, blood gas analysis, drug-to-drug interaction, and tasks not covered by the other components.

The ultimate development of such a computerized "end-to-end" medical system will provide state-of-the-art medical decision support. Knowledge bases, algorithms, and components used in the MDSS will be the predecessors of those needed to provide medical care for future long-duration spaceflight and will provide numerous benefits to medical care on Earth.

Patient: Crew member

Complaints:

1. Aches
2. Malaise
3. Fever (39 degrees)
4. Night sweats

Fetch discussion of
    radiographs and pneumonia
From
    'Chest radiology'

III Lobar pneumonia

X-ray shows dense lobar consolidation in one or more lobes, although may show patchy localized infiltrate.

Printout from a computerized MDSS.

Development of Correlative Electrophysiological Measures for the Study of Attention and Memory Processing

PI: Jon DeFrance/SD5
      Joseph J. Degioanni,
      M.D./SD5
Reference MS 2

The assessment of performance deficits has always been a difficult task in the operational environment of NASA's spaceflight programs. Crewmembers who are well trained may display only minor deficits or incipient changes. These may be of no great consequence during a short mission, but could herald a major problem if unchecked during extended operations such as in Space Station, in a lunar colony, or on a mission to Mars. Thus, it will be desirable to detect these behavioral discrepancies early so the underlying pathophysiological processes responsible for their development may be corrected.

The addition of electrophysiological measures to a performance test battery will greatly enhance an ability to detect these deficits. Furthermore, this will provide increased diagnostic capability if correlated in a valid manner with patterns of depression, attention, or other personality disorders. The analytical approach of electrophysiological measures in this project has important advantages over earlier mapping techniques in being able to identify accurately (and remove) eye movement and blink artifacts. These artifacts have always been a source of significant contamination of brain topographic maps, especially for the assessment of frontal and temporal lobe functions.

Attention and memory function are the result of a complex interaction of discrete brain systems, and their study is optimally addressed through a multifaceted approach. This proposal, which is an extension of ongoing research, effectively combines behavioral or performance measures with simultaneously acquired electroencephalograph (EEG) and evoked potentials.

Quantitative EEG changes in various frequency bands, as well as in the evoked potentials, have recently been shown to vary predictably over a range of clinical attention disorders; those include attention deficit disorder, schizophrenia, and major depression. The P300 potential, in particular, has been the subject of much study owing to its putative role in attention and memory. The figure below shows results from control subjects (children) and those with different types of attention disorders. When compared to the control group, children having an attention deficit disorder with hyperactivity (ADD/H) showed a lower amplitude P300 component which was generally symmetric. On the other hand, those children having an attention disorder without impulsivity also demonstrated a osomewhat smaller ERP, but, more significantly, the P300 potential was shifted away from the right hemisphere. The inference that might be drawn is that these youngsters were not capable of significant right hemispheric processing activity. This fits the observation of many clinicians who claim that disorders of the right hemisphere often lead to attention disorders which are frequently of an extreme nature.

The attention and memory battery and concomitant neurophysiological measurements will be evaluated for reliability and validity by the administration of these tests to a group of 50 subjects with no history of neurological or psychiatric disorders. The protocols will also be administered to 20 volunteer patients who have been diagnosed as having a major depressive disorder, and to 20 outpatients suspected of having an attention deficit disorder. These patients are to be free of medication for at least 1 month prior to evaluation. The comparison of the profiles of the clinical groups with the normals will be important to establish the ability of the approach to discriminate abnormal mental processing and mood changes. This step is necessary to achieve the ultimate goal, which is the ability to make judgments concerning the mental health of those taking part in long-duration missions as well as make predictions about the quality of their performance.
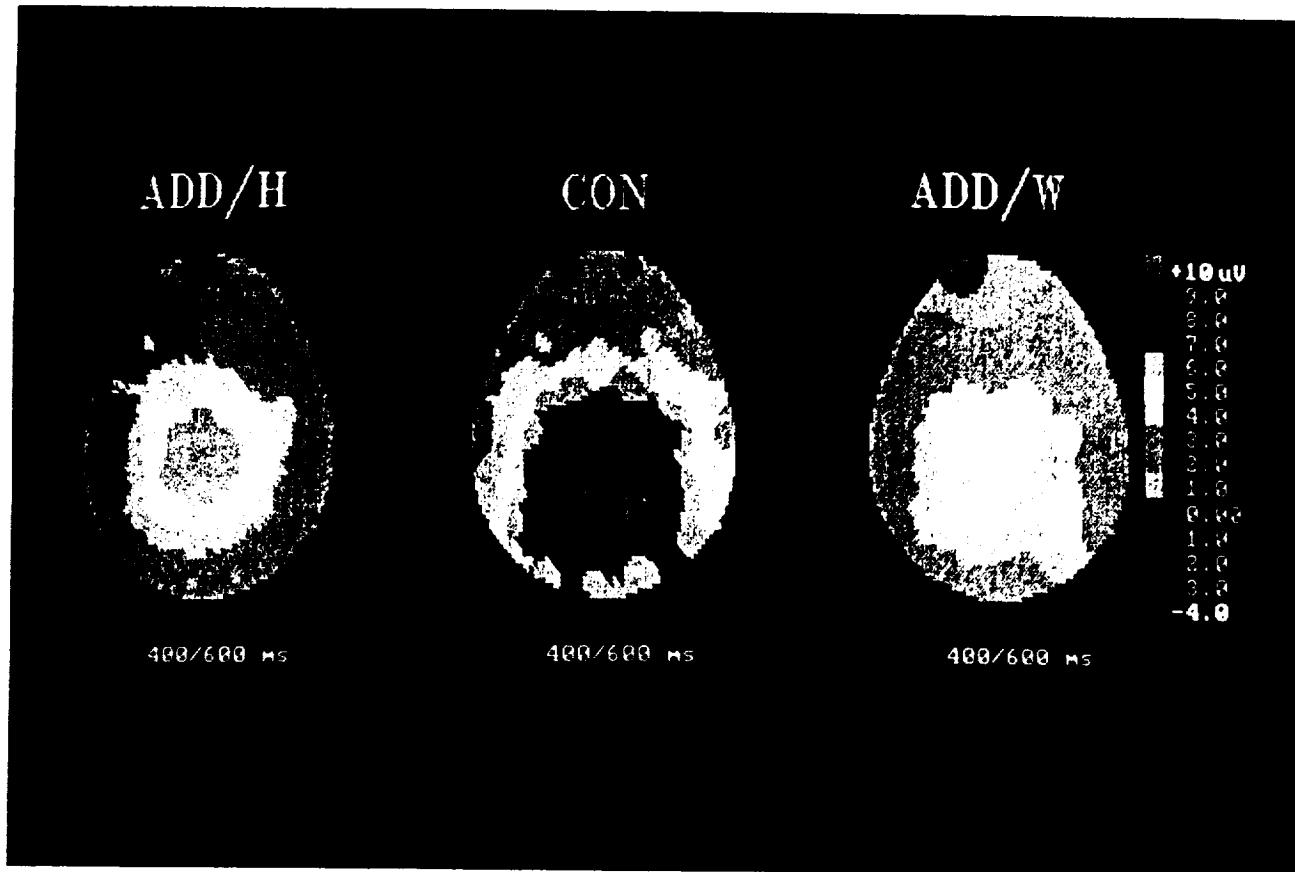
Top view cartoons showing the distribution of the P300 potential for the group average of three groups of children currently under study.

ADD/H Attention Deficit Disorder with Hyperactivity
CON control
ADD/W, Attention Deficit Disorder without Hyperactivity

The P300 components are shown for the 400 msec to 600 msec intervals.

Medical Restraint System for Space Station Freedom

TM: Joey B. Boyce, M.D./SD2
PI: Roger D. Billica, M.D./SD2
Reference MS 3

Plans for Space Station Freedom include a Health Maintenance Facility (HMF) designed to manage the medical needs of the crew in the areas of prevention, diagnosis, and treatment of illness and injury. These functions will occur not only at a fixed medical facility within the habitation module, but also will be needed for the hyperbaric chamber, for mobile emergency treatment, and for transport of ill or injured crewmembers. To provide these services, a means of support and restraint for the patient, the medical officer, and the equipment needed must be developed. To accomplish these tasks a "Medical Restraint System" (MRS) is being designed as part of the HMF project.

The MRS is being designed to fulfill multiple roles, including rescue stretcher and backboard, transport stretcher, platform for acute medical care (such as cardiopulmonary resuscitation), patient bed for long-term medical care, operating table, Xray table, physical examination table, dental chair, research and medical workstation, and hyperbaric treatment bed. In each role performed, the MRS will need to satisfy three functions to varying degrees: (1) hold the patient, (2) hold the medical attendant(s), and (3) hold equipment and connections.

The first MRS prototype consisted of a central telescoping vertical support column connected to the patient surface by a cradle-triax joint which was adjustable, using locking pins. The patient surface allowed a head section that could be raised from 0 to 90 degrees and a foot section that could be lowered similarly. Medical officer restraint and equipment attachments were accomplished using a railing along the edge of the patient surface which contained slots and holes for vertical

bars and locking pins. This prototype was tested on KC-135 parabolic microgravity flights and in ground medical simulations. Issues that required further development included patient surface stability during vigorous procedures (e.g., resuscitation, orthopedic splinting), methods of medical officer restraint to allow mobility and stability around the table while leaving the hands free, patient surface configurations needed, and degrees of motion that would be required in the three axes.

Currently, two phases of development are being pursued. A Shuttle Spacelab experiment is planned to test various options for surface configuration and range of motion, patient and attendant restraint and stability, and methods of equipment attachment. At the same time, a second prototype MRS is

being developed which incorporates a four-column support, a detachable head section of the patient surface to function as a rescue stretcher and backboard, a side rail with mobile attachments for attendant and equipment restraints, and a "floor" adapter for the assembly which can also function as a foot restraint for the attendant.

The development of a medical restraint system for Space Station Freedom has demonstrated that a multi-role system is feasible and desirable. Further definition and design is in progress which will include universal mounts for equipment, a table surface which will articulate in two joints and provide a detachable stretcher/backboard component, and a stable interface between the patient and medical attendants to accomplish a variety of tasks and procedures.

Detachable headboard
28 in.
30-44 in.
Translating surface
Frame with rail
Height Adjusting Post
Floor adaptor/foot restraint
84 in.
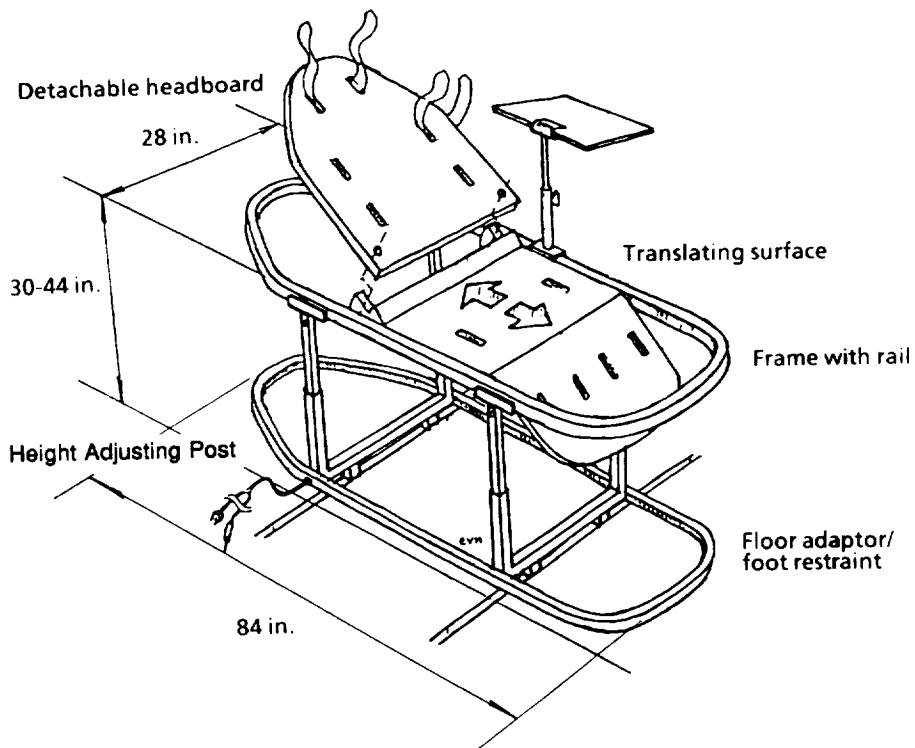
Original prototype in front of HMF mockup.
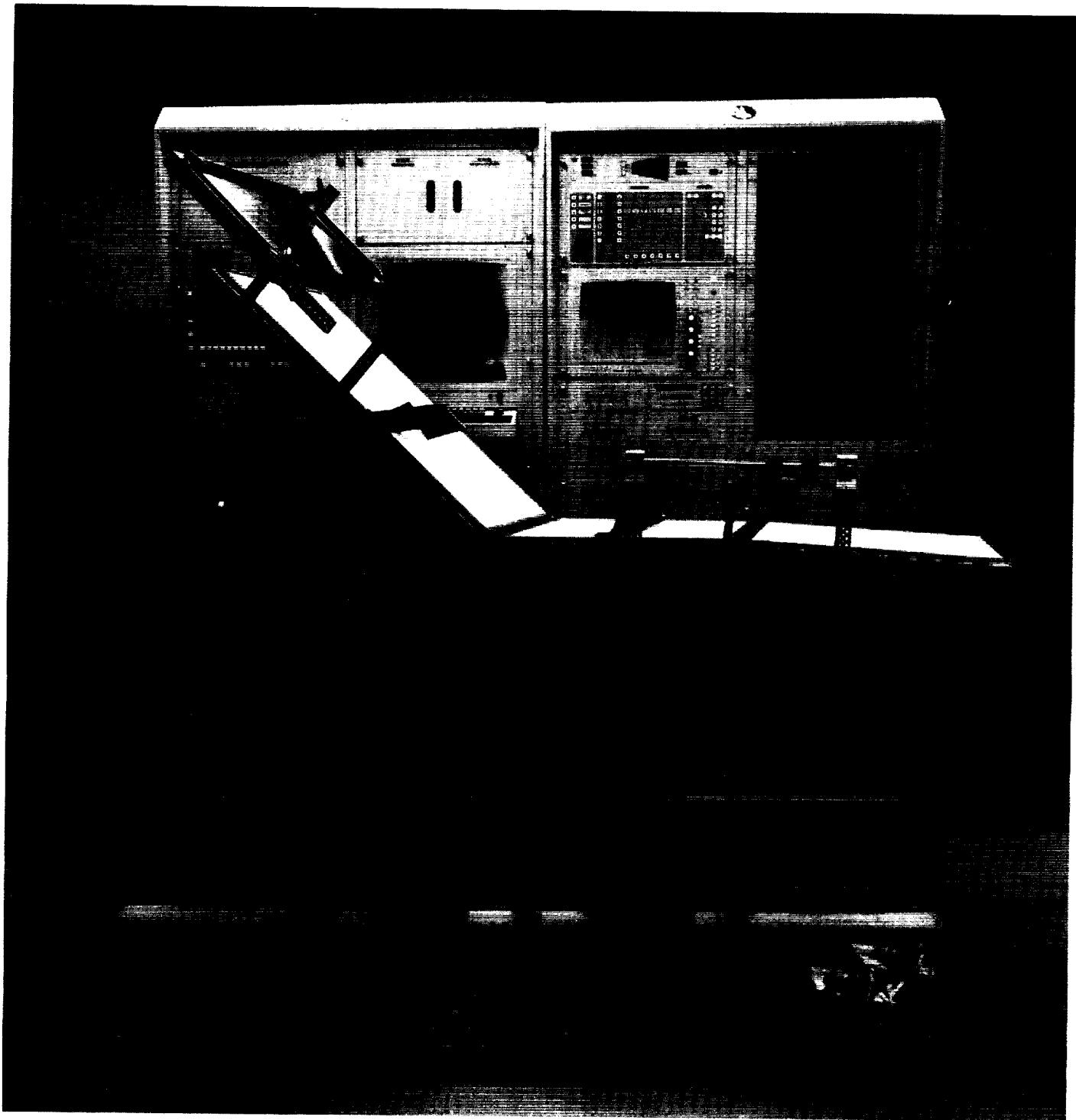
Current design of prototype.

An Empirical Model Describing the Incidence of Aviator Decompression Sickness and Venous Gas Emboli

PI: James M. Waligora/SD5
     David J. Horrigan, Jr./SD5
     John H. Gilbert, Ph.D./SD5
     Johnny Conkin/SD5
     John Stanford, Jr./SD5
     Benjamin F. Edwards,
         Jr., Ph.D./SD5
Reference MS 4

In 1979, NASA began an extensive program of testing various durations of 100 percent oxygen (O_2) prebreathe prior to exposure to a decompression event. From that time to the present, 925 test-subject exposures to altitude have been performed, both at the Johnson Space Center and under NASA contract at Brooks Air Force Base, San Antonio, Texas. The purpose of these tests was to determine the O_2 prebreathe procedure which, in the shortest time, would provide maximum elimination of nitrogen (N_2) from an astronaut's body, thus providing optimal protection from Venous Gas Emboli (VGE) and aviator's Decompression Sickness (DCS) Extravehicular Activity (EVA).

Thirty-six different DCS prevention procedures were performed, with environmental variables including the final test altitude, O_2 prebreathe duration, decompression staging techniques, and/or final breathing gas mixture. Data derived from these ground-based studies were analyzed to determine the relationship between group incidence and severity of VGE and/or DCS and the type of preventative procedures, emphasizing whole body denitrogenation by means of prebreathing 100 percent O_2.

A measure of tissue decompression stress, Tissue Ratio (TR), was devised to allow comparison between test subjects' responses, regardless of environmental parameter alterations.

The final amount of N_2 dissolved in the tissues of the body is dependent upon the partial pressure of N_2 in the prebreathe mixture, the rate of N_2 exchange within the lungs, and the perfusion and N_2 solubility and diffusion rates of the various tissues within the body. The N_2 washout rate which most closely matched the maximum correlation coefficient between TR and the percent incidence of DCS or VGE was calculated. An N_2 half-time of 360 minutes was chosen as corresponding to the washout rate which best described the incidence of VGE and DCS for all the various exposure parameters.

Using an experimentally derived tissue washout half-time of 360 minutes, formulae and curves were generated from 925 tests which described curves for the incidence of VGE and DCS, and resulted either in termination of a test or which showed delayed onset of symptoms. As expected, as the TR of a subject approached that seen at sea level, the incidence of VGE and DCS/ decreased dramatically. Incidence of VGE was much more common than DCS. Indeed, in all cases but two of the 925 tests, VGE was found to be a *necessary, but not a sufficient, condition* for the subsequent onset of DCS symptoms.

These data do demonstrate a correlation between the physiological events of VGE generation/DCS symptoms and the mathematically derived TR at various ambient barometric pressures. These formulae and curves are *descriptive* rather than *predictive*, in that they describe the probable incidence of VGE or the two levels of DCS when a *group* is exposed to a decompression event, rather than predicting the incidence of any of these events occurring to a specific individual. They can, however, be used to quantify the element of risk of experiencing one of these events to which an individual will be subjected when exposed to a particular denitrogenation procedure and atmospheric decompression condition as defined by a particular TR.

Data on DCS and VGE incidence from 49 tests with n = 925
Data on Grade 3 DCS incidence from 42 tests with n = 698
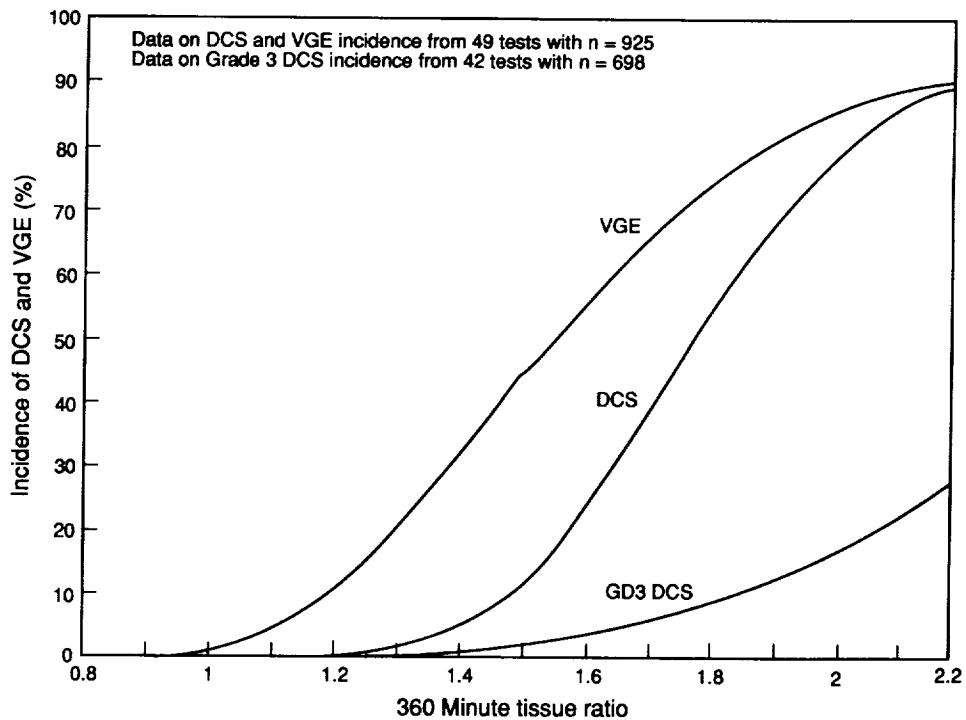
GD3 are Type I DCS symptoms that result in test termination
or symptoms that reoccurred after the test.

DCS and VGE incidence after 6 hours' simulated EVA.

Test subject being monitored with a Doppler bubble detector.

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Selection of a Space Suit Emergency Backup Pressure by Analysis of the Rate-of-Onset of Decompression Sickness

PI: David J. Horrigan/SD5
     Johnny Conkin/SD5
     K. V. Kumar, M.D./SD5
     James. M. Waligora/SD5
Reference MS 5

The possible future use of a space suit with a pressure as high as 8.3 psi prompted an investigation of the issue of backup pressure in the event of a loss of pressure in the suit. Since no prebreathing would pre - cede the Extravehicular Activity (EVA), a series of tests was conducted in an altitude chamber at a candidate backup pressure of 6.5 psi. Fifty-one subject-runs were made with prebreathing, and the subjects exercised with upper-body work for 3 hours. An ultrasonic Doppler instrument with a sensor placed in the precordial position over the pulmonary artery, as described by Spencer, was used every 16 minutes to detect bubbles in the blood as it flowed to the lungs. Although the subjects were asked every hour whether they had any aches or pains in muscles or joints or other symptoms of Decompression Sickness (DCS), they were encouraged to report symptoms the first time they were felt.

The figure below illustrates the cumulative incidence of intravenous gas bubbles in the subject population as a function of time.

The actual incidence during this testing is compared to a predictive curve based on 925 exposures in the Johnson Space Center (JSC) laboratory and United States Air Force (USAF) test results. The following figure shows the results of DCS incidence compared to the predictive model.

Although the Venous Gas Emboli (VGE) incidence was slightly higher than predicted, the DCS incidence was very close to the model curve.

Although this study was done to analyze several parameters of altitude DCS, including exercise effects, it is the first hour of exposure which is particularly relevant to the use of 6.5 psia without prebreathing as a backup pressure to an 8.3 psi suit. Since the first sign of DCS in a subject occurred at 60 minutes, and all of the other DCS was observed later in the exposures, it appears that 6.5 psi would be a safe pressure to use for a period of 1 hour in an emergency situation where the primary pressure level in a space suit was lost.

The method of diagnosing DCS in a test subject involves first completing a control run doing the same exercises at sea level. This enables the test investigator as well as the test subject to acquire an assessment of normal aches which may accompany the exercise. During the altitude phase of the test, intravenous gas bubbles are detected by placing the Doppler sensor over the area of the chest closest to the pulmonary artery that carries blood which has returned from the tissues to the lungs to release carbon dioxide (CO_2) and excess nitrogen. When a subject complains of an ache or pain after flexing a limb and have heavy bubbling was previously detected after flexing this same limb, it is recorded as a possible symptom of DCS. If the discomfort persists and then disappears upon recompression to site pressure, it is considered a confirmed diagnosis of DCS. In the laboratory DCS symptoms are classified into three categories. Grade 1 is an awareness of a pressure or mild ache in a joint area. Grade 2 is a definite pain, but it is not interfering with the exercise or causing the subject to favor a limb. Grade 3 is a pain severe enough to interfere with the exercise or to cause the test subject to favor the limb. In the case of Grade 3, the test is aborted. Grade 1 or 2 is tracked carefully during the test to assess its status. Of the 51 subject runs, there were no cases of DCS in the first hour. Of the 15 cases developing later, 7 were Grade 3 and required a test abort.
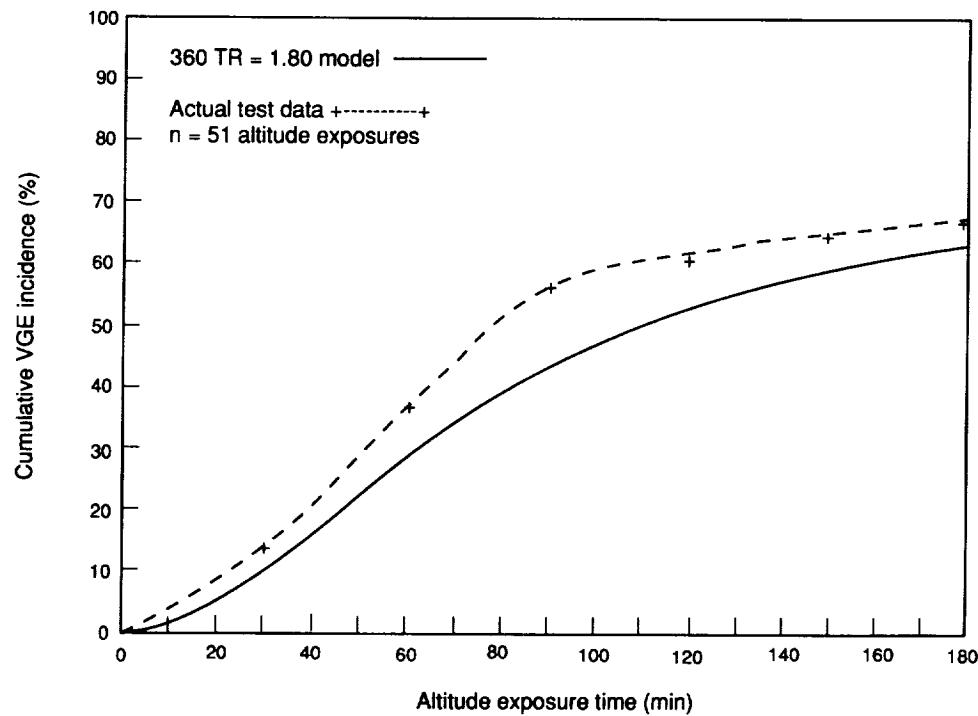
Cumulative incidence of VGE with altitude exposure duration.
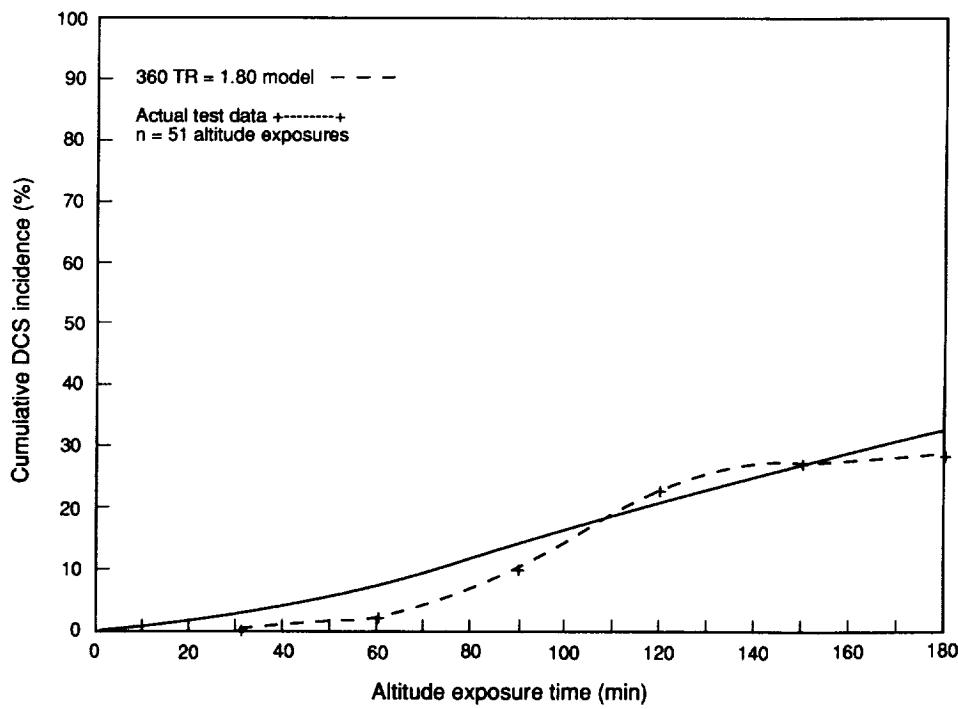
Cumulative incidence of DCS with altitude exposure duration.

18

A Portable Video Imager for High Resolution Digital Analysis of the Retina

PI: Gerry Taylor, Ph.D./SD5
     Richard Meehan, M.D./
         Visiting Professor
     Michael P. Caputo/SD5
     Robert Gibson, O.D./SD5
     Norwood Hunter/SD5
Reference MS 6

When exposed to microgravity, the human body suffers from a headward fluid shift of 1–1.5 liters. This fluid shift is related to the space sickness experienced by 50 percent of all astronauts. Retinal imaging, called funduscopy, is a noninvasive method used to monitor the fluid shift changes in the diameter of the blood vessels in the eye. The conventional method of conducting funduscopic studies requires the use of a large tabletop funduscope using calipers to measure the blood vessel diameters. No system exists for capturing and analyzing retinal images during long duration spaceflights. Current funduscopy systems are limited by their size and dependence on photographic film. The ability to conduct funduscopy during spaceflight and receive real-time data for analysis on the ground requires the technical advancement of the hardware used for retinal imaging.

The solution to conducting real-time funduscopy and analysis of retinal vessels in space requires the development of a video fundus system capable of capturing retinal images and sending them to the ground. The funduscope must be made small, lightweight, portable, and the camera portion must be capable of obtaining real-time images. A quick, objective method of analyzing the vessels must also be devised.

Using these concepts, the Technology Innovation Facility has developed a battery-powered, hand-held funduscope that utilizes a Charge-Coupled Device (CCD) camera to obtain live video of the retina. The live video can be analyzed to give information about the dynamic changes in the retina, or the Inflight Digitizing System can be used to digitize the images. Computer analysis of the digitized images gives the investigators objective information about changes in the retinal vessel diameters, optic disc diameter, and vessel curvature resulting from microgravity fluid shifts.

The portable high resolution digitizing video retinal imaging system has been used at the Johnson Space Center for ground-based studies of retinal changes caused by head-down bed rest. It has also been used as a teaching aid during crew training of astronauts for the Retinal Imaging Detailed Supplemental Objective (DSO) No. 474. The preliminary tests have successfully demonstrated the ability of this portable system to detect changes in vessel diameter and to observe the dynamic changes of the retina.

Future test plans include 0-G flights on the NASA KC-135, a high-altitude expedition, and a head-down bed rest study at the University of Colorado. Plans to evaluate images transmitted from remote locations are also under way.

Aligning the portable video imager for retinal analysis.

A Contact Lens for the Measurement of Eye Movements

PI: M. F. Reschke, Ph.D./SD5
James Zografos
Robert Gibson, O.D.
Reference MS 7

Experiments to be performed during the first International Microgravity Laboratory Investigations (MVI) require that eye movements in response to vestibular stimuli be recorded in three axes. Typically, eye movements are recorded using electro-oculographic techniques based upon the measure of corneal-retinal potential; however, to resolve rotation of the eyes about their z-axis, another approach is required. Of the methods available, the least invasive is to use video to locate the position and rotation state of the eye. The video image analysis techniques being developed to meet this requirement rely on pattern recognition and computer programs to track a defined reference on the eye. Eye color, infrared illumination, and other variables degrade the video signal and make resolution of natural landmarks difficult. The absence of easily identifiable landmarks on the cornea or conjunctiva is compensated for by the application of an opaque indexed scleral contact lens.

Scleral lenses are constructed of methyl methacrylate (PMMA), the same material used in daily wear hard contact lenses. Prior to the advent of keratoplasty, a surgical technique during which the cornea is grafted or modified, scleral (haptic) contact lenses were typically used for the correction of keratoconus and other visual deficits that require an extremely stable lens fit. Since haptic lenses are constructed using a cast impression of the eye to produce a model of the patient's ocular surface, they are inherently stable and conform to the topography of the conjunctiva. It is important from the standpoint of subject or patient safety and comfort, that the contact lens developed for the MVI experiment be slightly vaulted over the cornea and that it not rely upon contact with the cornea to maintain a non-moving fit. These lenses are also fenestrated to provide for tear circulation during blinks, thus reducing the possibility of anoxic stress.

The major advantages of using individually molded scleral contact lenses for the video based measure of eye movements include (1) the elimination of artifacts resulting from variations in iral features in response to parasympathetic activity; (2) the ability to analyze ocular torsion without regard to eye color (patients with light-colored eyes, blue or green, typically do not have iral landmarks of sufficient contrast to allow for reliable identification using automated eye movement analysis techniques); (3) the elimination of the need for other light-occluding devices because the lenses shield the eyes from visible light; (4) extended wear time, up to 4 hours, and improved comfort without undue corneal edema.

Analysis of eye movements recorded with videotape, using the MVI contact lens as a reference, revealed that an opaque scleral lens is an accurate and robust platform from which the video measure of ocular torsion may be accomplished. The calculated precision of approximately 0.1 degrees is certainly competitive with other methods.

A contact lens for the measurement of eye movements.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

A Data Acquisition and Analysis Program for Visual Tracking and Vestibular Research

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Ph.D./SD5
Donald Parker, Ph.D.,
Miami University
William G. Crosier/SD5
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Reference MS 8

A Macintosh program has been developed to perform data acquisition and analysis of eye movements and related signals during vestibular testing at the NASA/Johnson Space Center Neuroscience Research Laboratory. The program is designed for studies of visual tracking and Vestibulo-Ocular Reflex (VOR) function.

The software controls digitization of test data, with interactive calibration and calculation of eye and head velocities from sampled position data. A selection of digital filters and plot scale factors is provided. Saccades, blinks, and artifacts can be removed easily during the interactive data reduction process. Comparison of eye and head movements is performed using non-linear least squares curve fitting of the reduced data, separately for the head (stimulus) and eye (response) movement data, to compute the gain and phase of the VOR transfer function.

The program's standard, interactive user interface, fast response, and modular structure provide significant benefits over earlier programs. The user interface utilizes the mouse with pull-down menus, windows, dialogue boxes, and other standard Macintosh features. One of the major programming goals was to maximize flexibility for the user and take advantage of the user's training and experience, while simplifying and speeding up program operation.

For a typical experiment run, two to four analog channels are sampled at 120 samples per second for 60 seconds. The number of channels, sampling rate, and duration of the data collection are selected or changed through a dialog box. After data collection, the information is plotted and can then be saved (or rejected). Data from more experiment runs can be collected and saved in separate files or in the same file. Between runs or at any time afterward, data may be retrieved, digitally filtered, plotted, and analyzed. After the data are collected or retrieved, the information is first calibrated and then can be analyzed interactively to measure position or velocity values.

Scaled position values can be used in analyzing data from tests involving tracking a visible target. (See figures.) Alternatively, pairs of points can be used to calculate the average slow phase eye velocity for VOR tests.

A scatter plot displays the measured eye and head position data, along with the fitted sine curves. Numerical measures of gain, phase, and propriety of fit are also displayed for the fitted eye and head curves.
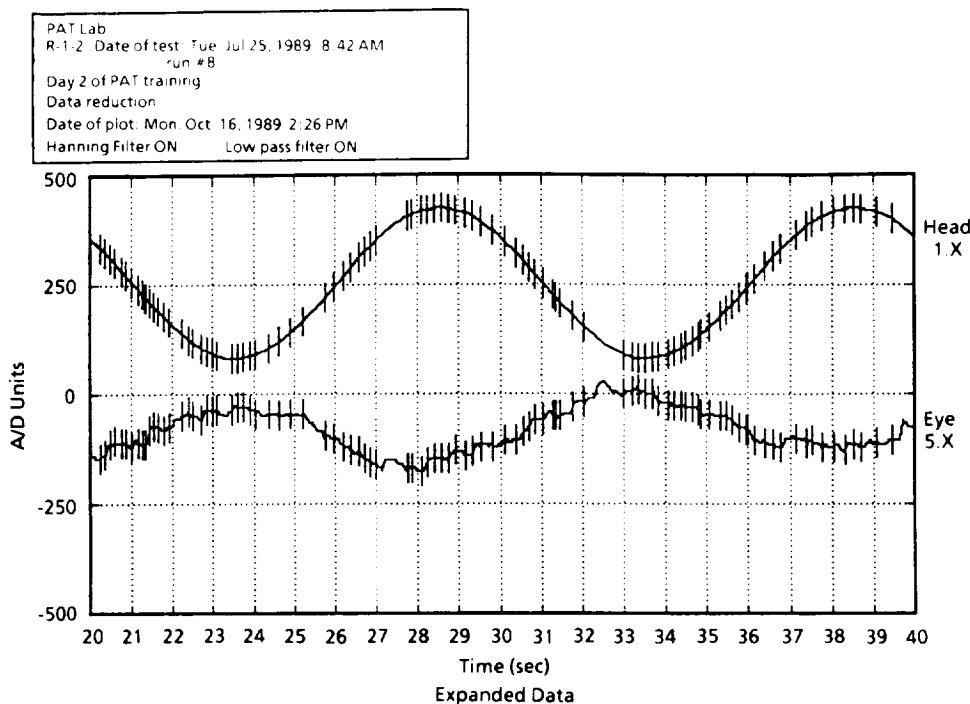

Head and eye position data at 20 sec with operator-chosen points for amplitude measurements marked.

Scatter Plot and Fitted Curve
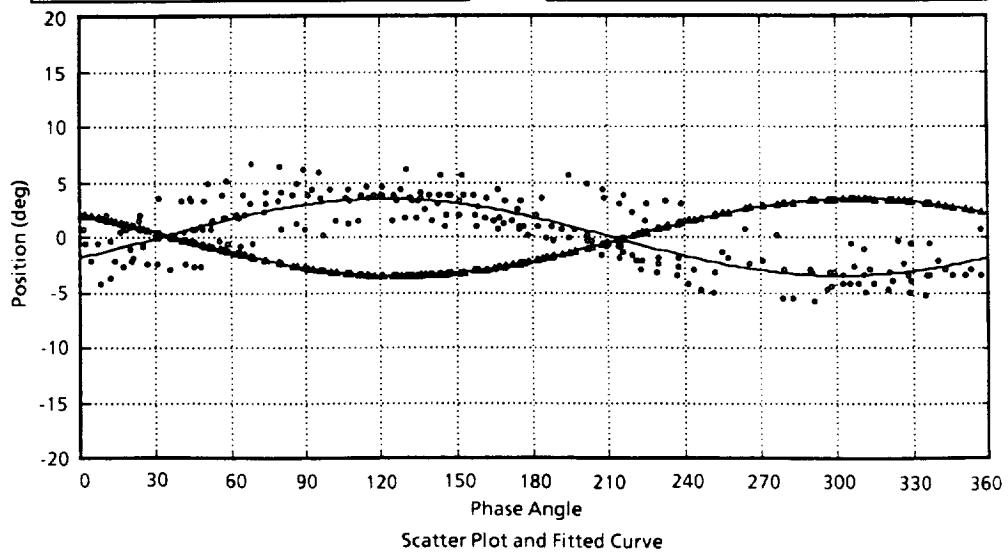
Scatter plots of measured eye and head movement amplitudes, with fitted curves.

Lower Body Negative Pressure and Saline Countermeasure Development

PI: Suzanne M. Fortney,
Ph.D./SD5
Reference MS 9

A major problem during manned spaceflight is that astronauts become hypohydrated. This increases their susceptibility to fainting (orthostasis) after reexposure to gravity. The countermeasure used in the American Space Program to rehydrate astronauts is the ingestion of an isotonic salt solution beginning two hours before landing. This "fluid-loading countermeasure" has significantly reduced the incidence or orthostasis after landing. However, as flight duration increases, the effectiveness of this fluid-loading countermeasure is expected to decline.

Hyatt and West demonstrated that fluid loading is more effective in restoring body fluids and preventing orthostatis when combined with exposure of the Lower Body to Negative Pressure (LBNP). They used bed rest to simulate spaceflight and found that 4 hours of continuous exposure to -30 mm Hg and ingestion of one liter of isotonic saline restored plasma volume and orthostatic responses for up to 18 hours after treatment. This 4-hour LBNP treatment was successfully flown on STS-32 and will be used again during Space Lab J in 1991. (See figure for a schematic of the LBNP device to be flown on Space Lab J.)

The purpose of this project is to reduce the time commitment required for an LBNP + saline countermeasure. The two hypotheses tested are (1) that oscillatory LBNP exposure may be more effective in restoring orthostatic responses than continuous exposure, and (2) addition of glycerol to the drink may enhance fluid retention and orthostatic responses.

There are three phases in this study. Each phase involves a 13-day simulated spaceflight (a 13-day 6-degree head-down bed rest). During each of the bed rests, the cur-rent flight LBNP countermeasure (4 hr LBNP + saline) will be compared to a new experimental protocol.

Phase 1 = compare the flight protocol (4 hr LBNP at -30 mm Hg + 1 liter of saline) to a shortened protocol (2 hr LBNP at -30 mm Hg + 1 liter of saline).

Phase 2 = compare the flight protocol (4 hr LBNP at -30 mm Hg + 1 liter of saline) to a 2-hr oscillatory LBNP exposure (0 to -50 mm Hg cycling in 5-minute cycles for 2 hr + 1 liter of saline).

Phase 3 = compare the flight protocol to a 1-hr oscillatory LBNP protocol + 2 liters of glycerol drink solution.

Phase 1 has been completed. Ten healthy young men (25 – 39 yrs) underwent a 13-day bed rest during which they were exposed to a 4-hr and a 2-hr LBNP + saline exposure. Both LBNP protocols restored plasma volume, but only the 4-hr exposure restored orthostatic responses to pre-bed-rest levels.

The results have shown that the LBNP countermeasure cannot be reduced to 2 hours without modification. During the next 2 years, phases 2 and 3 will be done to determine whether altering the pressure profile or fluid composition will increase the efficiency of this countermeasure.
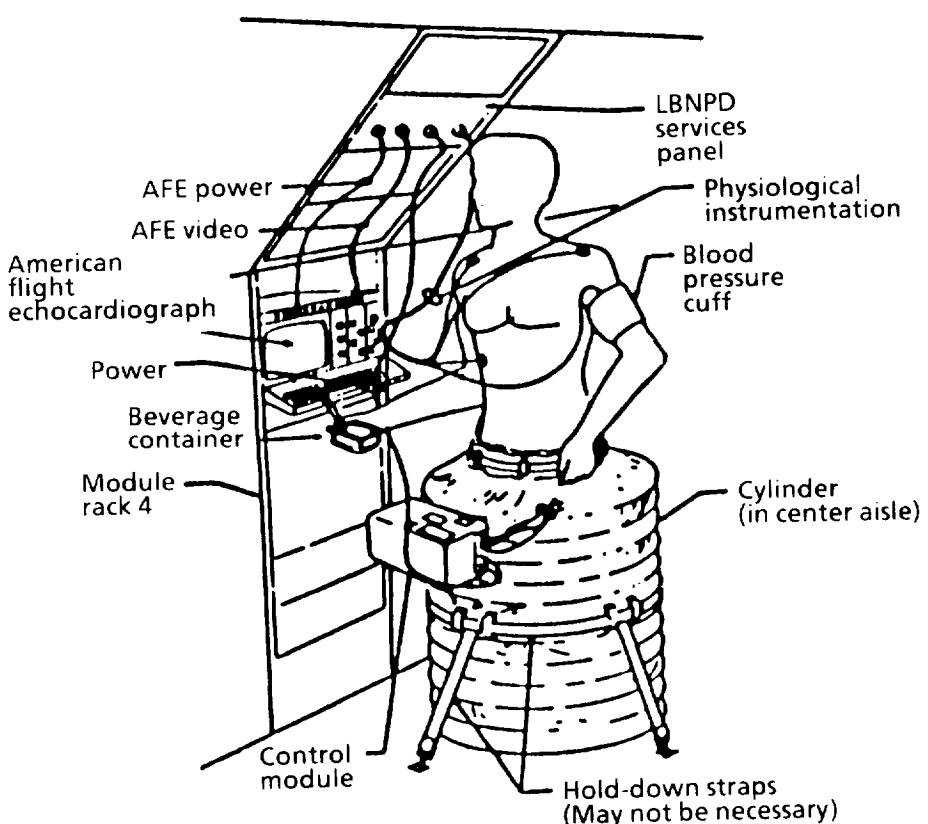
Lower body negative pressure device.

The Biobehavioral Research Laboratory

PI: **Patricia A. Santy, M.D./SD5**
    Albert W. Holland,
        Ph.D./SD5
Reference MS 10

Behavioral research is not entirely new to the space program. Selection criteria for America's first astronauts, those to fly during the Mercury Project, involved extensive psychological testing and psychiatric evaluation. The subsequent flights were monitored intensely to detect any abnormal psychological and psychosocial manifestations during spaceflight that might endanger the crew or the mission. When it became relatively clear that psychological abnormalities were not generally surfacing, and therefore would probably not contribute to a life-threatening or mission-abort situation, emphasis shifted to more operationally concrete issues.

However, with the approach of lengthier missions with more heterogeneous crews, the potential for behavioral issues affecting mission success and crew safety increases. For example, individual coping skills may deteriorate over time, causing manifestations such as stress-induced anxiety (possibly interfering with task performance), crew or crew/ground-control conflict, and/or psychosomatic complaints.

The Biobehavioral Research Laboratory (BRL) at the Johnson Space Center (JSC) was established early in 1989 to identfy psychiatric, psychological, psychosocial, and psychophysiological factors which will have a significant impact on extended-duration space missions and to develop appropriate countermeasures to facilitate adaptation to the space environment. The laboratory represents a multidimensional discipline that interfaces with other medical operations/laboratories at JSC in a cooperative effort to increase flight safety and ensure mission success.

Although there are a number of relevant issues under current investigation in the BRL, primary attention in 1989 has focused on selection and multicultural issues. The 1989 astronaut selection cycle represented the first in-depth evaluation of candidate psychological functioning since the days of the Mercury Project. The objective of the group is to standardize testing and procedures to provide consistent, accurate results for evaluation, research, and future astronaut selection cycles. Noted experts in the fields of psychology and psychiatry were gathered to form the In-House Psychiatric Selection Working Group. National and international participants assisted in selecting a standardized group of psychological, cognitive, and intellectual tests as well as interview procedures for use during astronaut selections. The group will continue to meet for the purposes of refining procedures and monitoring data collection and analysis that pertains to the research segment of selection.

With the advance of long-duration missions involving crewmembers of different nationalities, multicultural group dynamics has not become a pressing issue. A multicultural working group was formed to methodically define and address the questions and potential impact that more heterogeneous crews could have on mission success and crew safety, and to recommend appropriate constructive countermeasures. An example of an early step in this methodical search was the International Crew Debrief, used to gather information concerning experiences during previous Shuttle missions that involved international participation. Astronauts who flew on missions with international crewmember(s) were asked to report anonymously both positive and negative experiences leading up to, during, and following those mission flights. Suggestions and recommendations were also solicited concerning preflight training and orientation, inflight communication and habitation structure, and postflight interaction and debrief.

In addition to the work done in the areas of selection and multicultural interaction, the BRL is increasing its involvement with other in-house and external groups and laboratories. The BRL is working in coordination with the Exercise Countermeasures Project to develop a protocol studying Exercise Motivation; the lab is working in conjunction with other labs to coordinate the Biomedical Monitoring and Countermeasures (BMAC) Project; and the lab is leading the effort to define and compartmentalize the concept of "performance," the bottom-line human component of any successful mission.

As long-duration spaceflight nears and behavioral issues increase in importance, the BRL will continue its effort to identify those psychiatric, psychological, psychosocial, and psychophysiological factors which might adversely affect extended-duration space missions and to develop and implement countermeasures to reduce their operational impact.

Culture of Brain Microvessel Endothelial Cells and Characterization of Atrial Natriuretic Peptide Receptors

PI: Clarence F. Sams, Ph.D./SD4
Peggy A. Whitson,
Ph.D./SD4
M. Helen Huls/SD4
Reference MS 11

A mild cerebral edema has been postulated as a contributing factor in the development of Space Motion Sickness (SMS). The fluid and electrolyte homestasis of the body is significantly altered during microgravity, and these alterations are accompanied by changes in levels of fluid-regulating hormones. Alterations in plasma Atrial Natriuretic Peptide (ANP) levels during spaceflight are consistent with the fluid-regulating role of this hormone. The Blood Brain Barrier (BBB) is a specialized endothelium with structural features, including tight intracellular junctions, minimal pinocytic activity, and the absence of fenestra that functionally control the passage of compounds into the brain. Alterations in the integrity of the BBB can affect the accessibility of water, nutrients, hormones, or drugs into the brain. The ANP has been reported to bind to the BBB endothelium and may play a crucial role in the adaptation to microgravity or in the development of SMS symptomatology. Cyclic guanosine monophosphate (cGMP) is known to alter transendothelial permeability and is a second messenger modulating the biologic activity of ANP. However, there are few studies isolating potential effects of ANP on the brain. Studies of the role of ANP in the BBB *in vivo* are valuable, but the interpretation of these studies is limited by the complex effects that may be observed in the intact organism. An *in vitro* model system offers advantages of decreased complexity and a more experimentally accessible environment that should enable the study of the cellular/molecular mechanisms that regulate barrier homeostasis.

Receptors for ANP have been identified in several cell and tissue types, including Brain Microvessel Endothelial Cells (BMECs) and brain microvessels. However, the characterization of these receptors in BBB-type endothelial cells is not complete. The high-affinity binding sites for ANP consist of at least two distinct receptor subpopulations. One of the receptor subtypes has been copurified with particulate guanylate cyclase activity, and ANP binding to this receptor results in an increase in intracellular cGMP concentrations. Partially truncated ANP molecules do not bind well to this receptor, nor do they stimulate guanylate cyclase activity to the same extent. The second class of ANP receptors that has been characterized differs in that there is little distinction between truncated ANP analogs and ANP for binding, and cGMP levels are unaffected once ligand is bound to the receptor. In addition, data suggest that this receptor exists as a dimer linked by disulfide bonds. Investigators have recently demonstrated that ANP mediates the accumulation of other second messengers, inositol phosphates, through this nonguanylate cyclase-linked receptor.

In order to characterize ANP receptors in the blood brain barrier, BMECs were isolated from bovine brain. The isolation technique involved gentle homogenization of brain tissue, followed by a series of enzymatic digestions. Microvessel endothelial cells were then isolated by density gradient centrifugation. Primary monolayer cultures of the isolated BMECs were used for the binding studies. The ANP binding to primary cultures of BMECs was measured to determine the number of binding sites per cell and the affinity of the ANP for these sites. Between 2 and 10 days after the monolayer was formed, the number of ANP binding sites increased 30-fold, from 9,000 to 260,000 ANP binding sites/cell, and the affinity decreased 7-fold, as calculated from Scatchard analysis of the binding data. These data indicate that brain endothelial cells have a high concentration of binding sites for this fluid-regulating hormone and that the affinity and number of these binding sites are modulated during culture.

To examine the types of ANP receptors present in primary cultures of the brain endothelial cells, two techniques were used. One technique was SDS-gel electrophoresis, which separates proteins based on molecular weight, and the other technique monitors the biological response of ANP binding to the receptor by measuring cGMP levels. The results of SDS-gel electrophoresis are illustrated below.

A single distinct band was observed that corresponded to molecular weight of 64,000. No band was observed in the region that would correspond to a molecular weight of 130,000, the weight of the guanylate cyclase-coupled receptor. However, the modulation of cGMP levels by various concentrations of ANP were noted as shown here.

These data indicate the presence of the guanylate cyclase-coupled receptor in BMECs. The absence of a band corresponding to this receptor using SDS-gel electrophoresis indicates that the guanylate cyclase-coupled receptor is found in much lower proportions that the low MW receptor.

Conclusions from these studies include the following:

1. A large number of ANP binding sites are found in brain microvessel endothelial cells.

2. Both subtypes of ANP receptors were observed in primary cultures of brain endothelial cells.

The physiological significance of either of these receptors in the brain endothelium is not yet clear, but the presence of both ANP receptor subtypes described by these studies indicates potential roles of this hormone in the fluid regulation of the brain.
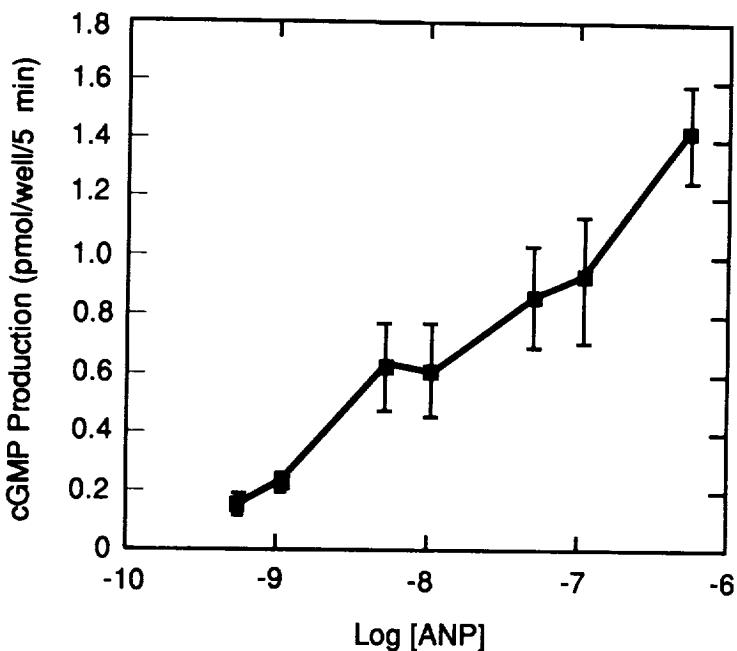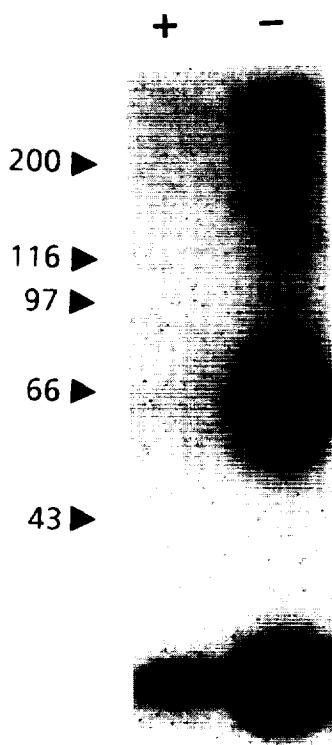
ANP-inducible increase in cGMP levels. A dose-dependent increase in cGMP levels was observed upon addition of the indicated concentration of ANP.

Affinity cross-linking of radio-labeled ANP to intact brain microvessel endothelial cells. A single band corresponding to a molecular weight of 64,000 was observed following affinity cross-linking, SDS gel electrophoresis and autoradiography. The molecular weights in kD are indicated for the standard marker proteins. The specificity of the cross-linking was demonstrated in the control lane (+) in which an excess of unlabeled ANP was equilibrated with the same concentration of radio-labeled ANP.

Iodination of Orbiter Drinking Water

TM: **Richard L. Sauer, P.E./SD4**
PI: **John R. Schultz, Ph.D./SD4**
    Randall E. Gibbons/SD4
    David T. Flanagan/SD4
Reference MS 12

Potable water is produced onboard the Orbiter from the fuel cells as a byproduct of their primary function, the production of electricity. Fuel cell water passes through a Microbial Check Valve (MCV) in route to a storage tank, where it is kept until needed for metabolic or food rehydration purposes.

An iodinated anion-exchange resin within the MCV imparts iodine to the water for microbial control. Crews have reported that the water had a noticeable color and an adverse taste which appeared to have been caused by elevated iodine levels. The Water and Food Analytical Laboratory, in collaboration with other groups, addressed the problem in three stages: (1) verify and quantify elevated iodine levels in flight; (2) determine the cause of the problem; and (3) develop a solution.

Laboratory evaluation of the MCV revealed the device to be temperature sensitive with effluent iodine levels being proportional to influent temperatures. The figure below shows the performance of the MCV with respect to temperature.

The MCV was designed to impart an iodine residual of 2 to 5 ppm with an influent temperature range of 65 to 90 °F. It was known that water leaves the fuel cells at 140 °F; however, the temperature of influent water to the MCV had never been measured.

To determine the temperature of the water entering the MCV, reversible and nonreversible temperature tapes were mounted on the stainless steel MCV inlet line. During STS-29, the crew measured influent temperatures approaching 95 °F with the reversible temperature tapes. Furthermore, nonreversible temperature tape read postflight documented that water of at least 110 °F had reached the MCV. Nonreversible temperature tapes on STS-28 and STS-34 also documented influent temperatures of 110 °F to 120 °F.

As a concurrent effort, a colormetric method was developed to test the iodine concentrations of the water inflight to confirm and quantify elevated iodine levels. Shuttle beverage containers were prepared with a starch-indicator powder that develops a blue color proportional to the amount of iodine in the water over a range of 3 to 13 ppm. Higher concentrations require no indicator, since the yellow color of iodine can be used to directly measure its concentration. After each beverage container (either with or without indicator) was filled with water, it was inserted into a comparator that contained calibrated blue and yellow color chips. The color of the container was then compared with the color chips, and the iodine concentration determined.

Iodine levels of 5 to 13 ppm were found during STS-30 and STS-28.

From these results, in combination with the inflight temperature data and the demonstrated temperature sensitivity of the MCV, it was concluded that increased MCV influent temperatures were causing increased iodine levels in the water.

The solution to this problem is to redesign the MCV resin to deliver 2 to 5 ppm iodine over an influent temperature range of 70 °F to 130 °F. Since this new resin would not be ready for flight for approximately 8 months, an interim solution was developed. Testing showed that the iodine concentration in the MCV effluent is dependent only on the temperature of the inlet water, and, in particular, is not dependent on the influent iodine concentration. This indicated that the MCV could remove iodine from the water if influent temperature were lower. The Microbial Filter Assembly (MFA) was therefore developed and installed at the galley-Orbiter interface as shown in the first figure. The MFA consists of two MCVs. Since these MCVs are further removed from the fuel cells, they operate at lower temperatures and, therefore, remove excess iodine from influent water.

The MFA was flown in combination with the iodine comparator assembly on STS-34. Inflight iodine assays indicated that it operated as predicted. Water drawn from the galley had an iodine content of approximately 3.5 ppm. (See figure above.)

This investigation has resulted in the development of a method to assay iodine concentrations in the potable water inflight, has documented the MCV influent water temperature, has provided the data needed to redesign the resin contained in the MCV, and has developed an interim solution to the problems caused by elevated iodine levels in the water.

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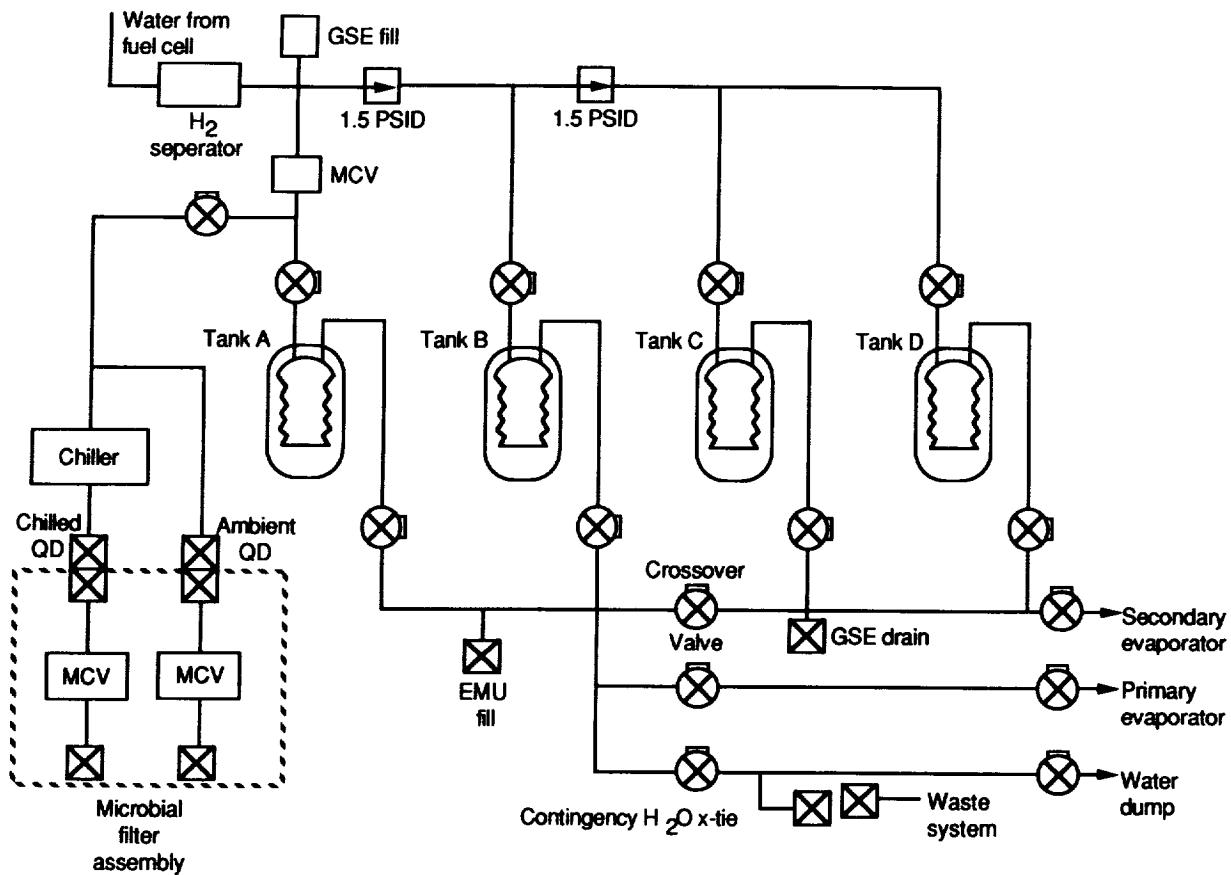
Microbial filter assembly location.
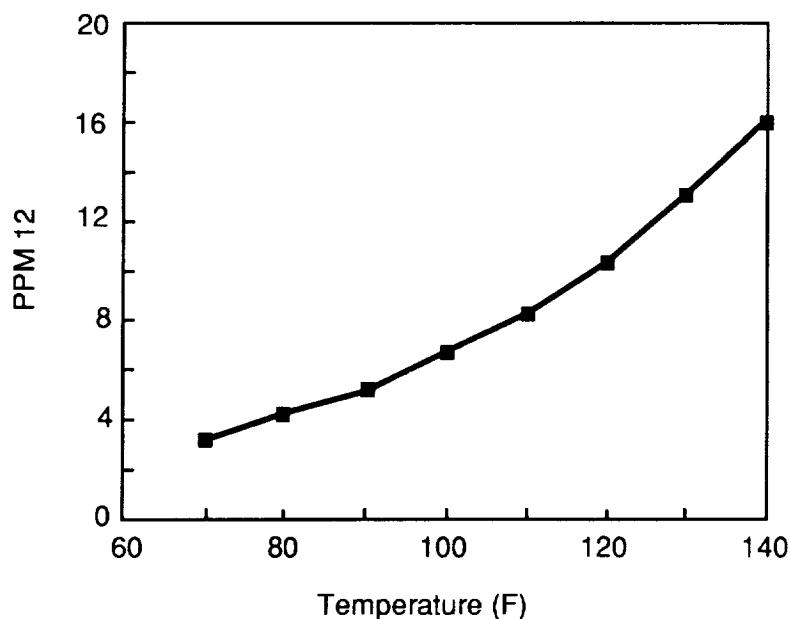
MCV temperature profile.
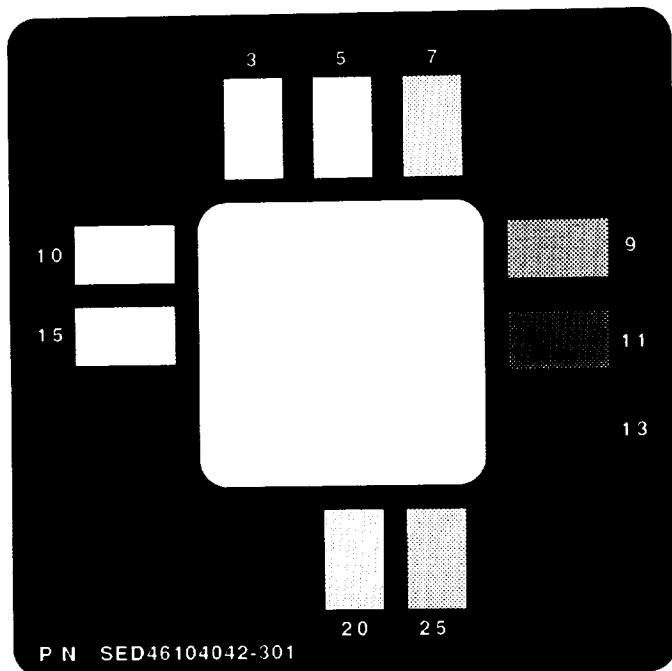
Iodine comparator assembly.

The numbers on the perimeter are mg/l (ppm) iodine represented by the adjacent standard.

The 3, 5, 7, 9, 11, and 13 standards are for the blue starch-iodine color.

The 10, 15, 20, and 25 standards are for the natural color of iodine.
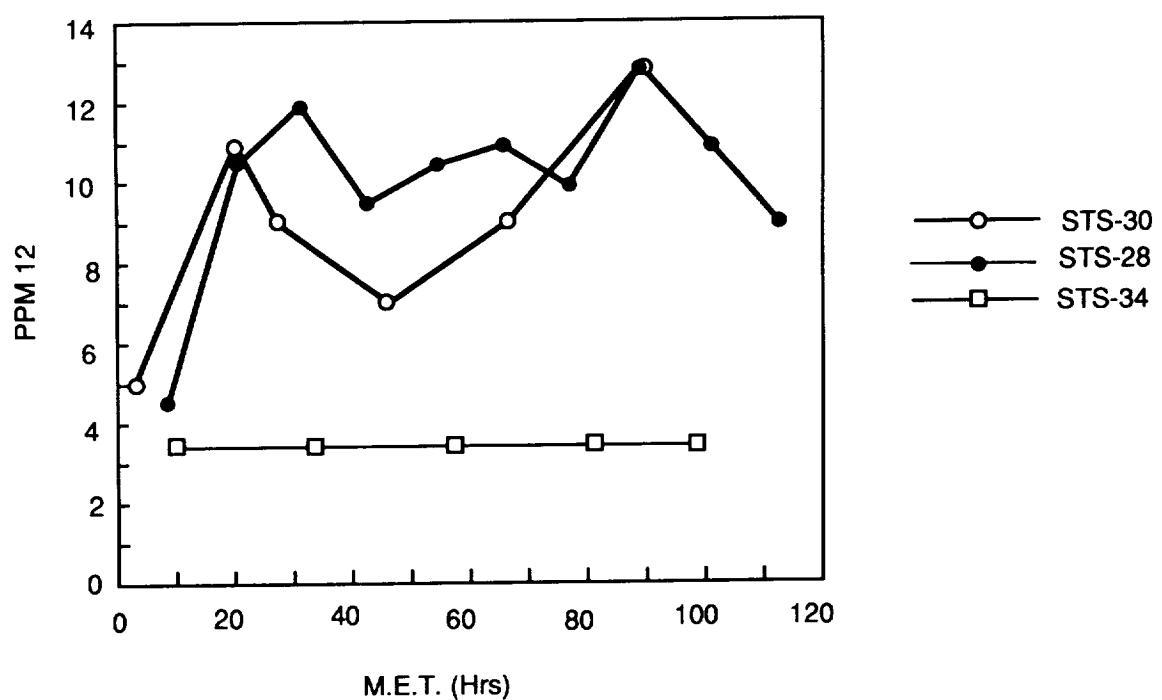
Inflight iodine analysis results (chilled side of galley).

29

Biofilm Formation and Control in a Simulated Spacecraft Water System: Interim Results

TM: Richard L. Sauer, P.E./SD4
PI: John R. Schultz, Ph.D./SD4
      Robert D. Taylor, Ph.D./SD4
      David T. Flanagan/SD4
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      Rebekah J. Bruce/SD4
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      Duane L. Pierson, Ph.D./SD4
Reference MS 13

Spacecraft to be used in long-term manned missions must have a water system capable of delivering potable and hygiene water of acceptable quality over the anticipated lifetime. A major concern from these systems is the control of long-term microbial contamination and biofilm development in the water storage and distribution systems. To investigate this potential problem, a 2-year study is being conducted to evaluate the ability of iodine to control biofilm development in a simulated spacecraft water system. Other objectives include comparing biofilm formation potential on normal and electropolished stainless steel surfaces, characterizing the chemical and microbial quality of delivered water, and developing water sampling and analysis methods for use on Space Station Freedom. This presentation summarizes results from the first 18 months of the 2-year study.

Two parallel stainless steel water subsystems were fabricated to simulate those being planned for Space Station Freedom. Each subsystem has a recirculating loop consisting of a pump, a biofilm coupon manifold, a sampling port, and a 10-L storage tank as illustrated below. One subsystem has an iodine level of about 2.5 mg/L maintained by an iodinated ion-exchange resin contained in a Space Transportation System (STS) Orbiter Microbial Check Valve (MCV). The other subsystem has no iodine added. To simulate actual use by a two-member crew, 2 liters of water are withdrawn three times a day. Make-up water is distilled deionized water that has been polished with a Milli-Q water treatment system, a 0.22 micron filter, and an ultraviolet sanitizer.

Planktonic Microbial Analysis: Plate counts were regularly taken on samples from the influent sample port, the iodinated system draw port, and the noniodinated system draw port. The results of the 7-day counts are shown in the figure below.

The results from the influent sample port (S-3) show the inlet filter and ultraviolet sanitizer were not completely effective in eliminating microbial contamination from the influent water. This resulted in the samples from the noniodinated system draw port (S-8) becoming contaminated by the third week. The bacterial counts at this port exponentially increased to a value of 160,000 CFU/mL at week 10 and then slowly decreased to a value of 5000 CFU/mL at week 71.

The results from the iodinated system show that the iodine was successful in keeping the bacteria levels below 0.1 CFU/mL for the first 50 weeks. After that time, the bacteria levels in the iodinated loop dramatically increased until week 66 when the MCV was replaced. The MCV was replaced because the iodine level imparted to the water had decreased to 1.7 ppm from a beginning value of about 2.5 ppm, as shown in this figure.

Microbial Coupon Analysis: Coupons have been periodically withdrawn from the manifolds and analyzed by culture plate methods, epifluorescence microscopy, and scanning electron microscopy. The results of the culture plate analyses are shown in the table following this article.

For the iodinated system, no bacterial colonies were recovered from the coupons until the 54th week. For the noniodinated system, however, bacterial colonies were recovered from the coupon after 8 weeks of operation. The results from this system show that the number of bacteria recovered from the electropolished side are lower than those recovered from the mechanically polished side of the coupon. This implies electropolishing may aid in controlling biofilm development. These results were confirmed by the epifluorescence and scanning electron microscopy.

In summary, results after 16 months of operation indicate that, although iodine does not completely prevent microbial contamination in a water system, it can limit the number of bacteria recovered in the water obtained from such a system.

BACTERIAL ENUMERATION OF SCRAPINGS OBTAINED
FROM THE MANIFOLD COUPONS

	CFUs/mL							
	Iodinated				Noniodinated			
	Loop		Branch		Loop		Branch	
Week	EP	NEP	EP	NEP	EP	NEP	EP	NEP
2	0	0			0	0		
4	0	0			0	0		
8	0	0			30	512		
15	0	0			40	1400		
31	0	0	0	0	127	TNTC	32	28
54	0	0	0	2	17	88	300	360

EP indicates electropolished side
NEP indicates nonelectropolished side
TNTC indicates too numerous to count

High quality
input water

0.22 uM
filter

UV sanitizer

S-3 port

MCV

Coupon
manifold

Pump

Coupon
manifold

Pump

Coupon
manifolds

Tank

S-6
port

Iodinated
system

S-8
port

Tank

Non iodinated
system
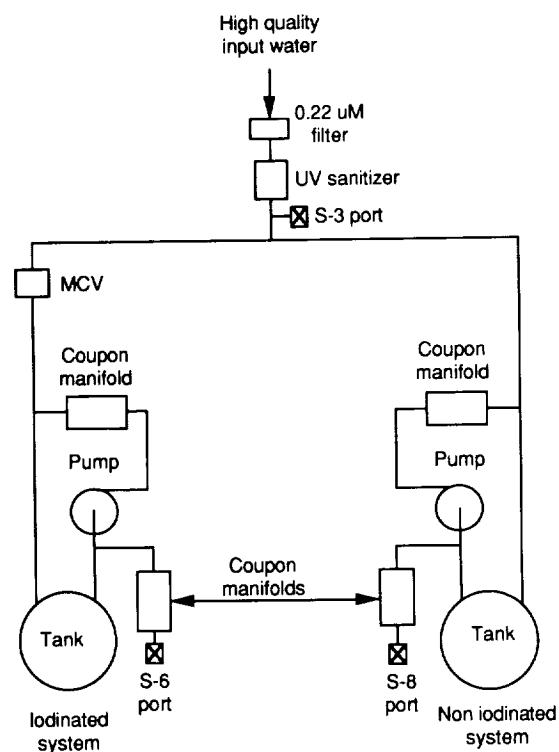
Simplified schematic.
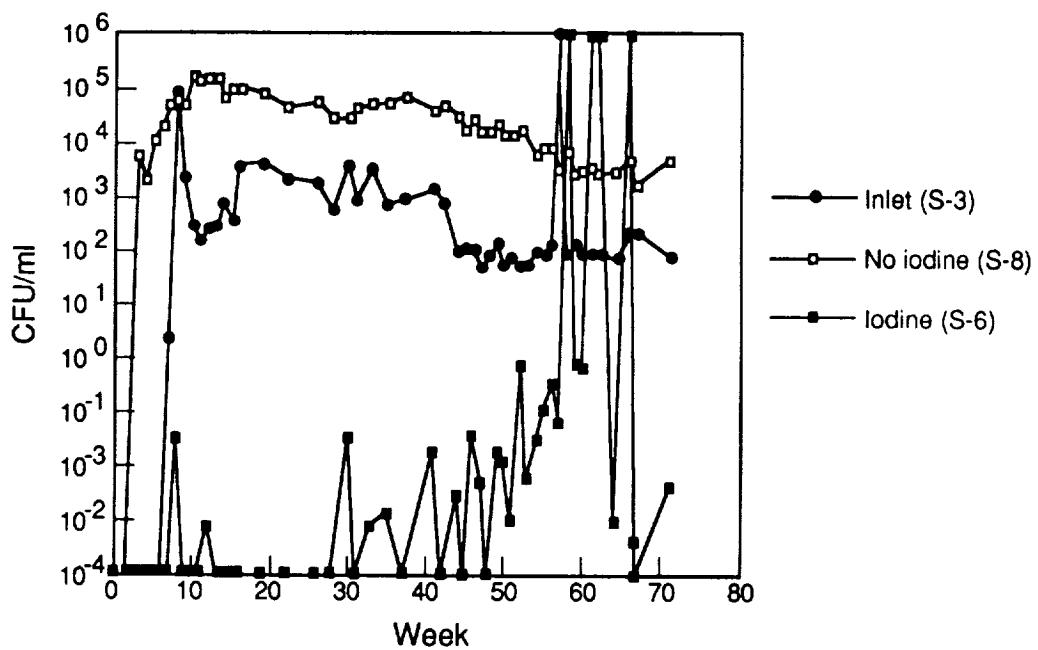
Planktonic microbial results.

Iodine results.

32
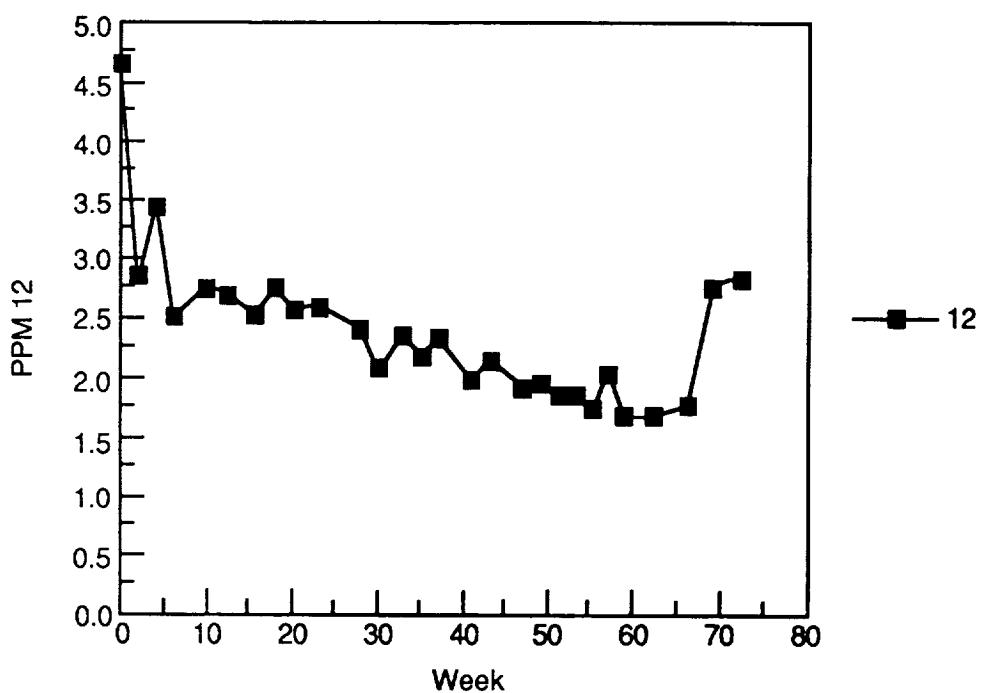
Bioreactor Incubator Tissue Culture System

TM: Steven R. Gonda, Ph.D./SD4
PI: David A. Wolf, M.D./SD4
Ray P. Schwarz/SD4
Clarence F. Sams, Ph.D./SD4
Reference MS 14

A complete tissue culture system which simulates some of the fluid mechanical conditions of microgravity has been shown to achieve superior performance over conventional Earth-based systems. Designed for use in a standard CO_2 incubator, this culture system supports the formation of solid 3-dimensional human tissue from individual cells. The primary components are the rotating tissue culture vessel (A), the external media perfusion loop with associated environmental control effectors (B), and the computer process control system (C). These components, functioning together, achieve the original design criteria of (1) microgravity compatibility, (2) microgravity simulation, and (3) precise control of the culture environment.

These design criteria were chosen for the development of Earth-based instrumentation to support prespaceflight experiments which optimally project the results that may be obtained in microgravity. These ground-based tissue culture systems also serve the purpose of developing key technologies and processes which will be required in microgravity.

Specific analysis of the features, primarily fluid dynamic in nature, which cause the observed high performance indicates that microgravity will offer the optimal environment for further extending the *in vitro* capability to produce large organized tissues that exhibits important features of the corresponding *in vivo* tissue. Such high-fidelity tissue "models" are contributing to the understanding of normal and cancerous tissue function. In addition to cancer research

contributions, this Earth-based spinoff technology offers potential for reducing the dependence on animals for tissue toxicity testing, enhanced pharmaceuticals production techniques, and an improved tool for tissue biology basis research.

It is important that the Earth-based culture systems both simulate microgravity (to the degree possible on Earth) and achieve compatibility with microgravity. This is required to ensure that the large biological data base, accumulated through ground research, provides a valid comparison with future inflight research. These criteria are met by the design of the NASA rotating zero head-space tissue culture vessels (see prior Johnson Space Center (JSC) annual reports). Fundamental changes in the design of the culture instrumentation to obtain reduced gravity compatibility would degrade the validity of such performance comparisons.

Precisely characterized fluid dynamics are required in order to interpret the culture results with respect to the physical environment. Numerical finite element analysis and confirming laser Doppler velocimetry are performed in addition to mathematical calculations to specifically characterize the system's fluid dynamic behavior as a function of gravitational strength. This has allowed identification of gravity-induced limitations of culture vessel performance and identifies promising areas in which microgravity will offer further performance enhancements.

Rotating culture vessel features which simulate some characteristics of microgravity allow limited Earth-based testing of theoretical projections of enhanced microgravity performance. The current level of understanding projects that advantages of microgravity tissue culture include the formation of 3-dimensional tissue structures with a higher level of organization and differentiation than is possible on Earth.

Microgravity will allow maintenance of precise spatial orientations between cells, growth substrates, and assembling tissue in a 3-dimensional aqueous environment. This allows expression of the inductive signals which govern tissue formation, differentiation, and function by greatly reducing mechanical disruption by fluid shear stress, fluid turbulence, and energetic particle collisions. The rotating culture vessels achieve these features to some degree on Earth, but gravity introduces important limitations for the assembly of cells and substrates into organized tissue-like structures. Such structures rapidly sediment as they reach significant sizes, thus limiting the performance of the rotating culture systems in unit gravity. Under these conditions, the Earth-based rotating culture systems are not able to simulate the fluid dynamic conditions of microgravity, and tissue growth and structure is degraded by the resulting physical forces.

The incubator culture systems, incorporating the NASA-developed rotating culture vessel, achieve a highly controlled biochemical and physical environment for the growing cells and tissues. Electrochemical and electro-optical sensors measure the levels of glucose, oxygen, carbon dioxide, and hydrogen ion (pH) in the culture vessel and provide this information to the real-time process control computer.

This computer, implemented as a network of multiple processors, processes this data with intelligent and adaptive algorithms to determine corrective effector actions and maintains hemeostatic culture conditions. Glucose consumption rates are continuously calculated. This, in conjunction with the measured value at a given time and an internal math model of the system response, allows optimal scheduling of glucose concentrate addition to maintain the set level. Similar algorithms are

implemented for other controlled parameters.

A skilled operator is able to interact with the system via a keyboard and graphic displays. Data is logged; caution and warnings are displayed; operator inputs are processed; and system state is displayed graphically on a series of computer menus and displays. The system functions as a testbed for directing the development of a microgravity bioreactor system for use on the Space Shuttle and Space Station Freedom.
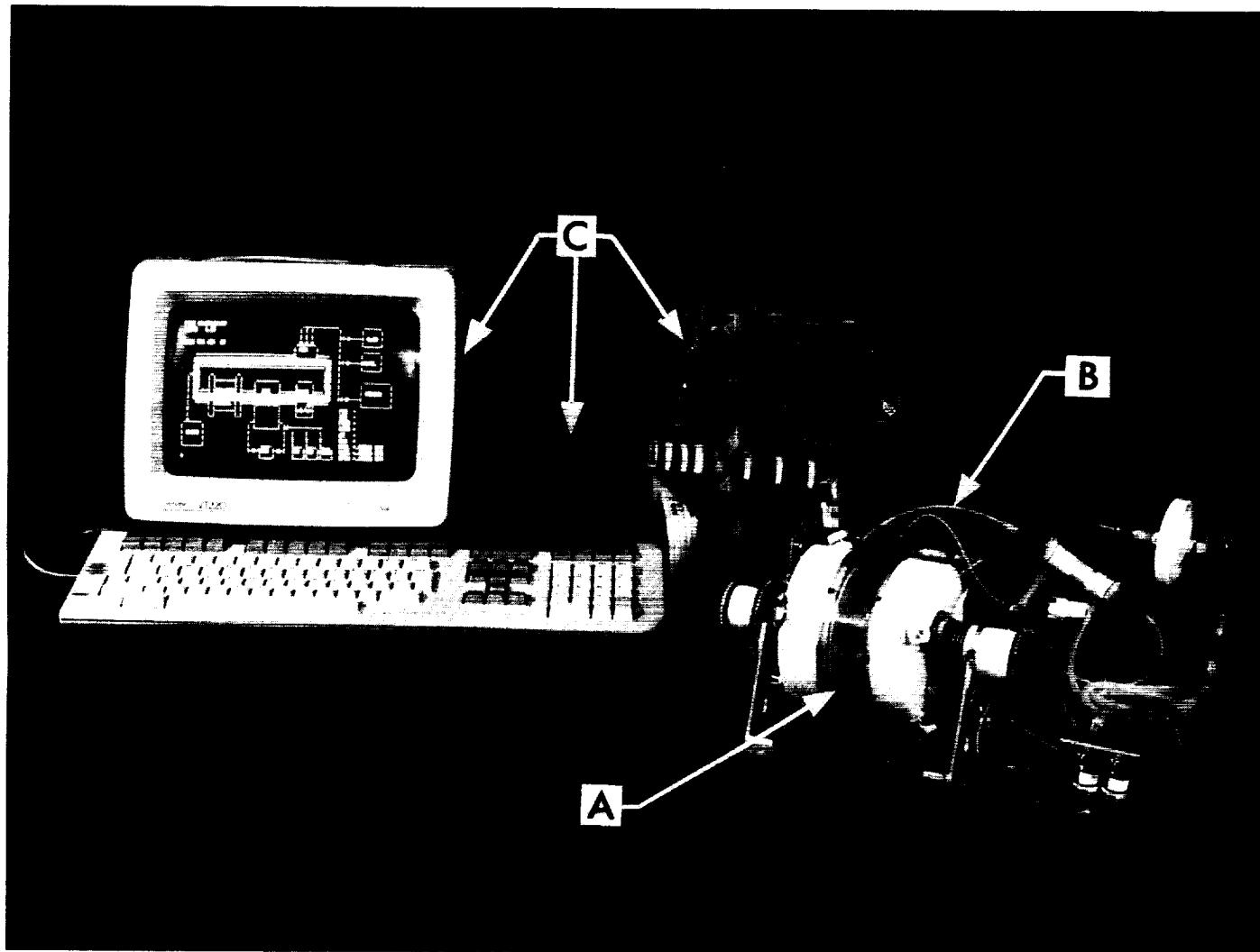
Bioreactor incubator tissue culture system.

Personal Infrared Telemetry System

**PI: Donald J. Stilwell/SE3
Reference MS 15**

Over eons of evolution, human physiology was molded by constant exposure to the Earth's gravitational field. Man's physiological adaptation to space is complex, and our understanding of this process is incomplete. Our ability to guarantee a safe and effective manned presence in space depends on this knowledge and on our ability to devise measures to counteract the adverse physiological effects of zero-gravity. This is particularly important in light of this Nation's commitment to long-duration missions such as a permanently manned space station, a lunar base, and a mission to Mars.

Our understanding of physiological adaptation to spaceflight would be greatly advanced by the development of a nonintrusive infrared telemetry system for acquiring multiple channels of biological data from free-roving astronauts. Such a system must be extremely small and lightweight to permit continuous monitoring without interfering with the daily activities of living and working in space. Additionally, the telemetry system should be adaptable for use in either the Orbiter middeck, the Spacelab, or Space Station Freedom.

An infrared telemetry system has been developed that can monitor and transmit up to 64 channels of biomedical data — typically 8 channels from up to 8 astronauts. The body-worn transmitters measure only 6.5" × 4.0" × 2.0" and may be belt-mounted. Analog signals are digitized with a 12-bit plus sign resolution, and the maximum throughput of each transmitter is 10,000 samples per second. This can be divided equally or unequally between as many channels as the monitoring task requires. Additionally, an independent full-duplex wireless RS-232 link is available between each transmitter and the receiver.

The sampled data from all astronauts is collected by a single rack- or locker-mounted receiver. A line-of-sight path is not required because the infrared carrier readily bounces from wall to wall through multiple reflections.

Additionally, the base unit continuously transmits power control commands to the body-worn transmitters. If the signal from any transmitter falls below threshold, the base unit instantly commands it to increase transmitter power.

The receiver can reconstruct the digitized data for storage on an FM tape recorder, or it can provide the data in digital form for continuous downlink to physicians and medical scientists at a ground station. The system is configured by tiny plug-in memory cartridges. As many as 10 of these cartridges can be carried in a pocket-sized wallet. To change from one experiment or monitoring task to another requires only that one cartridge be plugged into the transmitter and that a like cartridge be inserted into the receiver. All system parameters, including channel sampling rates, channel voltage ranges, and subject identification codes, are stored in the memory cartridges.

Completion and delivery of the engineering model is expected in the first quarter of 1990.
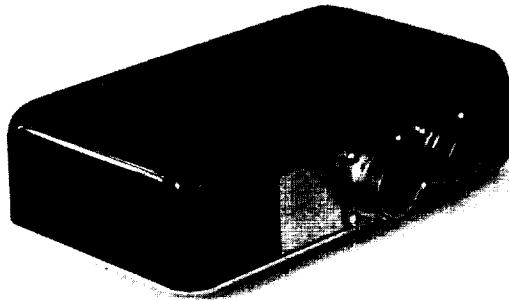
Potable (node) 1R transceiver
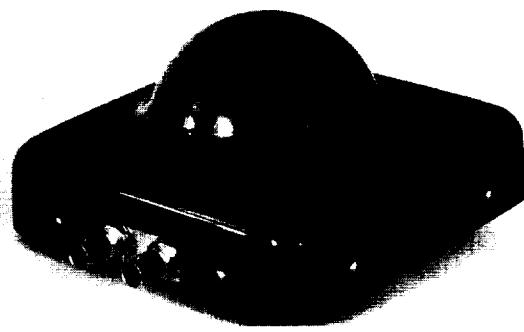
Remote R/T 1R module

The personal Infrared Telemetry system supports up to 8 body-worn transceivers (left). A rack- or locker-mounted receiver (not shown) acquires the carrier signal through two remote receiver/transmitter (R/T) modules (right).

Second-Generation Life Sciences Laboratory Equipment (LSLE) Microcomputer

PI: Donald J. Stilwell/SE3
Reference MS 16

Nearly a decade ago, a Life Sciences Laboratory Equipment (LSLE) microcomputer was designed for use in Spacelab-based medical experiments. The computer supported real-time data acquisition and experiment control in investigations of the human physiological adaptation to zero-gravity. In addition, the LSLE microcomputer formatted experiment data for continuous downlink to a ground station. This important feature allowed medical scientists to monitor experiment progress in detail, to archive data, and to take corrective actions where required.

The past decade, however, has been marked by rapid advances in computer technology. By today's standards, the first-generation microcomputer is a relatively low-performance machine: it acquires only 5,120 analog samples per second; its maximum downlink rate is 32 kilobits per second; and it has no onboard mass storage or graphic data display. The lack of mass storage precludes its use in the middeck where high-speed downlink channels are not available. In addition, the first-generation computer has very little software support and is programmable only in PDP-8 assembly language — now a dead language.

In 1986, we began working on a second-generation microcomputer that would use newer technology and would function not only in the Spacelab but also in the Orbiter middeck. An STD bus architecture was chosen because it is small, low power, commercially well supported, and relatively high performance. The new computer uses multiple processors to increase speed and flexibility. Each processor performs a single Input/Output (I/O) function, and a central exchange processor manages the communications between all I/O processors. Each I/O processor has the approximate computing power of an IBM PC.

The multiple processor approach has several advantages. Because each I/O function is individually controlled by a single processor, driver routines can be written without regard for other computer activities. In a multiprocessor system, modular programming techniques are injected into the structure of the hardware itself. This compartmentalizes software, making maintenance easier, and individual functions may be upgraded with minimal interference with other hardware or software.

A variety of modules are available, and only those modules needed for a given experiment need be included when a computer is configured for flight. The second-generation microcomputer analog input module has 16 single-ended input channels with 12 bits of resolution and a total throughput of 20 kilosamples per second. The Spacelab downlink module provides scientists at a ground station with real-time data at 256 kilobits per second. A mass storage module controls a Write Once Read Many (WORM) optical disk drive with a storage capacity of 400 megabytes per removable cartridge. Other modules include an IEEE-488 interface module, a parallel digital I/O module, an RS-232 serial interface module, etc. Finally, the new microcomputer provides a full keyboard for operator interaction and a high-resolution graphic display for instantaneous inflight data display.

The prototype microcomputer will be delivered in January 1990.
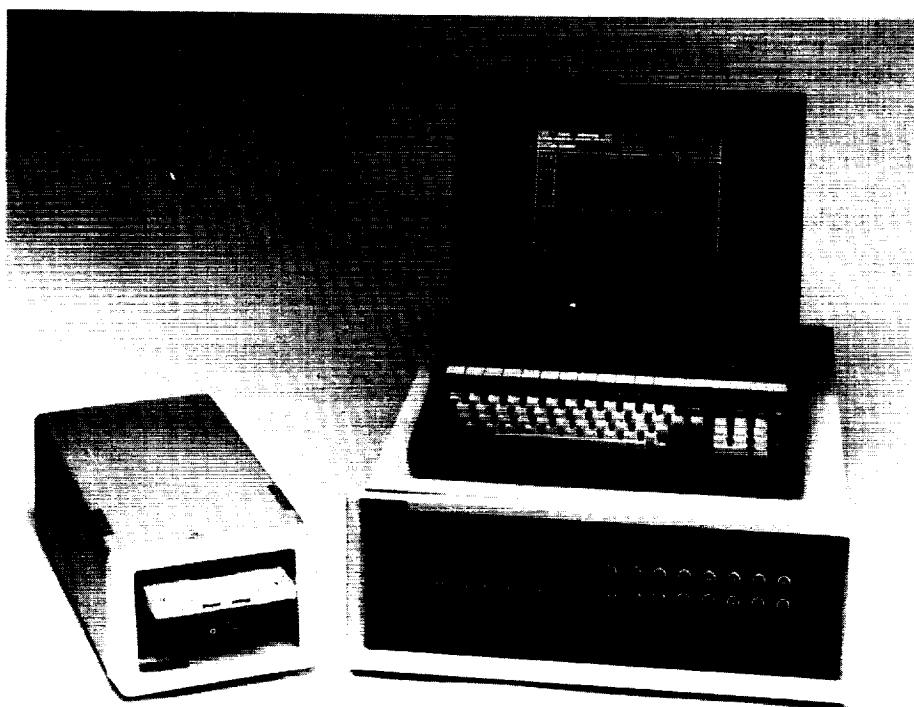
The prototype of the second-generation LSLE microcomputer is composed of an optical disk drive (left), the core computer (right), and a keyboard/display terminal (top).

A Stowable Lower Body Negative Pressure Device

PI: Barry M. Levitan/SE3
John C. Charles, Ph.D./SD5
Reference MS 17

Headward fluid shifts in the body that occur due to microgravity exposure create physiological problems upon reentry into a gravity environment. Orthostatic intolerance, the loss or reduction of the capability to stand upright, occurs in crewmen returning from spaceflight to Earth's gravity due to blood pooling in the lower extremities and reduced cerebral blood flow. This could be critical in the event of an emergency landing or other contingency where the crew needs to stand up quickly and exit the craft. The problem worsens with increased exposure to microgravity. Although some problems have been identified with the 4- to 7-day standard Shuttle mission, Extended Duration Orbiter and Space Station tours of duty will see this deconditioning as a universal problem.

Lower Body Negative Pressure (LBNP) is the procedure of applying a reduced pressure, typically 10 to 50 mm Hg below ambient, from the waist down on a subject. This allows the controlled redistribution of blood and body fluids from the upper torso down to the lower body. Bed rest studies have shown that a large fluid ingestion ameliorates orthostatic deconditioning for several hours, but when performed in conjunction with LBNP, the protection is greater and of much longer duration (past 24 hours), which suggests that this is a good countermeasure that can be performed prior to reentry.

A Skylab LBNP device that was used as a cardiovascular stress was a large aluminum cylinder, which is fine if a generous volume is available. However, to be used in the Space Shuttle, the device would have to be stowed within the small volume of a middeck locker. A collapsible device was designed and fabricated, therefore, that could with stand the relatively large forces generated by the reduced vacuum. This stowable LBNP device consists of four upright segmented struts that are assembled and holds five oval stainless steel rings that are sewn into a nomex bag. After assembling the struts, the top ring sewn in the nomex bag is lifted up and fitted over the top of the struts, which makes the four other rings sewn in the bag automatically positioned. This assembly creates the rigid cylindrical structure that supports an outer vacuum bag — a mylar and/or nylon film bag that seals around the subject's lower body. As regulated vacuum is applied to a feedthrough plate that passes through the vacuum bag and structural bag, the vacuum bag is pulled up against the structural assembly. An outer nomex bag protects that vacuum bag from punctures. A thin neoprene waist seal is bonded to the vacuum bag and seals around the subject's waist. A padded harness is attached to the top oval ring and keeps the subject suspended in the LBNP device without getting pulled down into it.

This device has been tested in the laboratory and onboard the NASA KC-135 zero-g aircraft. It has withstood up to −250 mm Hg from ambient pressure. Assembly in microgravity requires less than 10 minutes. Subject comfort suspended in the harness in 1-g is adequate, but −50 mm Hg will only pull with about 80 lb of force.

The device is scheduled for use in a medical DSO on STS-32 in December 1989. For this flight, the Shuttle vacuum supply (to space) will be the vacuum source through a vacuum regulator. This requires that the system be essentially leakproof to minimize loss of cabin air. Future plans will use an electrical vacuum or blower source that can provide adequate flow for ventilation in the LBNP device. With adequate flow, the waist seal can be eliminated, and the vacuum bag will seal adequately against the subject.

Assembly of LBNP device on the KC-135 0-g aircraft.

Demonstration of LBNPD under vacuum.

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Solar System Sciences

Summary

Solar System Sciences

NASA has established three main initiatives leading to human exploration of the solar system: (1) the establishment of a lunar outpost, (2) Mars rover and sample return mission, and (3) a human mission to Mars. Solar system research at the Johnson Space Center (JSC) supports development of concepts which will play a major role in developing the technology to enable these initiatives to be realized. In the Solar System Exploration Division, research is conducted on the characteristics, origin, and evolution of the terrestrial planets, asteroids, and satellites (the rocky bodies located in the solar system), as well as research into the practical uses of the resources of these planets to support and maintain human expansion into the solar system. This research is conducted by:

- Analyses of planetary materials
- Experimental simulation of planetary conditions and processes
- Remote sensing observations
- Theoretical modeling of analytical, experimental, and observational data

Lunar Sample Studies

The curation and study of extraterrestrial materials, including lunar samples, meteorites, and cosmic dust particles, is heavily emphasized in solar system research at JSC. These extraterrestrial materials are the only samples in-hand with which to study the origin and evolution of the solar system. The lunar samples collected as part of the Apollo program are curated at JSC and distributed to scientists at many institutions for research purposes. Research at JSC on these lunar samples has contributed to an understanding of the accretion of the planetesimals and differentiation processes of other planetary bodies.

Detailed study of the lunar rocks and soils provides insight on the potential for onsite resource extraction. Use of onsite lunar resources has the potential for reducing the cost and increasing the long-term viability of a manned lunar outpost. These studies provide information which aids in the design of unmanned and manned lunar missions, with the goals of establishing a manned lunar outpost and eventually conducting manned Mars missions.

Cosmic Dust Studies

Cosmic dust particles are considered to be very primitive solar system material, possibly the oldest extraterrestrial material that has been obtained. Sources of cosmic dust are thought to include comets and asteroid debris, and interstellar matter. Studies of these particles provide insight into the origin and evolution of the solar system. At JSC, scientists maintain a collection of cosmic dust acquired by NASA aircraft equipped with special cosmic dust collectors during flights through the Earth's stratosphere.

Scientists at JSC are developing new ways of cosmic dust sample collection and preparation to minimize contamination. Such methods enable detailed laboratory analyses of the cosmic dust particles and provide valuable insight with which to develop the cosmic dust collection facility for Space Station Freedom; thus extending cosmic dust research into the next major step of the manned space program.

Life Support System Research

NASA's upcoming space missions to the Moon and then on to Mars are very long-duration missions. In order to minimize costly resupply missions from Earth, all essential consumables must be regenerated from within the life

support system. All water and air will be reused, and food will be produced. Research at JSC has been aimed at developing a solid support substrate for use in growing plants for food and to function in air and water regeneration. A particularly attractive possibility receiving research attention is the use of a zeolite-based "soil" for plant growth. Zeolites have the potential of being pre-loaded with essential plant growth nutrients such that the addition of water will provide the plants with the necessary plant growth nutrients over several growing seasons. Zeolites also have excellent pH buffering capabilities and are very good at retaining moisture for plant growth. It has also been shown that zeolite minerals can be synthesized in the laboratory from simulated lunar glass; thus, it is likely that zeolitic minerals could be synthesized from lunar materials at a lunar outpost.

Studies of Terrestrial Planets and Asteroids

Information about the composition of the surfaces and atmospheres of planets can be acquired by remote-sensing ground-based telescopic observations made of these objects. The spectrum of reflected sunlight from a rocky planetary surface will be affected by the mineralogical composition of the upper thin layer of surface material and by the amount and composition of the atmosphere above the surface. Research at JSC is directed at understanding the atmospheric components of the metals sodium and potassium in the exosphere of Mercury. Variations in the sodium distribution over the planet without a change in the average sodium density seem to indicate that magnetospheric effects could be the cause. The implications are that observations of the sodium exosphere may provide a tool for remote monitoring of the magnetosphere of Mercury.

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Carbonate-phosphate and carbonate-sulfate mineral assemblages of water-based origin imply that, at one time, several biogenic elements (H, C, O, P, S) were assembled together in martian microenvironments. The presence of carbonates on Mars has not been confirmed by either the Viking lander surface experiments or by Earth-based telescopic spectral observations. SNC meteorites have been generally accepted as Martian rocks propelled to Earth by large meteoroid impacts on Mars. Research work conducted at JSC has revealed evidence that Shergottite, Nekhlite, and Chassignite (SNC) meteorites contain carbonates. Such evidence has tremendous implications concerning theories of life and planning for future Mars missions.

Primitive meteorites of types 1 and 2 are assumed to be the result of ice melting and subsequent aqueous alteration of rocky materials comprising their original parent bodies. Research at JSC examined telescopic reflectance spectra of asteroids at varying distances from the Sun. Comparison of laboratory spectra from primitive meteorites and the telescopic spectra from asteroids revealed that D-class asteroids (generally considered to be the most primitive asteroid type) and Trojan asteroids (those farthest from the Sun) exhibit different spectral features, indicating that the aqueous alteration mechanism in the solar system ceased to operate at greater distances from the Sun.

Advanced Planetary Missions

Future planetary exploration missions include an unmanned mission to Mars to explore parts of the planet and to return a suite of samples to Earth for intensive laboratory examination. As with the lunar samples, preparations to accommodate extraterrestrial samples will be necessary. JSC received the lunar samples during the Apollo missions and continues to hold the responsibility of curating the lunar samples.

Work has begun to capitalize on the lunar experience in the early planning and design of a Mars sample receiving facility at JSC. The primary considerations are to provide quarantine of the samples to protect Earth from contamination by possible extant martian organisms and to protect the samples from contamination by terrestrial materials.

Surface landers on remote planetary objects require instrumentation for analysis of surface materials. Analysis provides characterization of the surface materials and, for sample return missions, a basis for selection of representative samples. Iron Mossbauer spectroscopy is specific for iron and is sensitive to its oxidation states and chemical environment; and, for geologic samples, it provides quantitative information on the mineralogy of iron-bearing phases and their proportions. Mossbauer spectroscopy is almost exclusively used in the laboratory in transmission mode (sample between the source and detector). However, backscatter geometry (source and detector on the same side of the sample) is desirable for a remote planetary lander, since sample preparation is minimal or unnecessary. The instrument could be moved by or be part of a robotic arm and placed on the material to be analyzed. Scientists at JSC are developing a backscatter Mossbauer spectrometer for this purpose.

Orbital Debris

With the increasing mission duration of Space Station Freedom and Extended Duration Orbiter flights has come increased attention to the extent of orbital debris. Scientists at JSC are engaged in research to define the orbital debris environment, evaluate its effect on space missions, develop protection and minimization techniques, and raise awareness of the problem among users of space. The space debris environment in the <10 cm range is not well defined. As a

result, more advanced radar systems capable of measuring debris in this size range are being developed so that a statistically valid data base can be assembled. Additional models can then be built to accurately characterize the debris environment.

In addition to accurately describing the orbital debris environment, research efforts at JSC include on-orbit detection of a possible collision event. Efforts are being concentrated on developmental work toward a passive collision warning system. Work is being directed at sensor development and subsequent analysis of acquired data. A Space Shuttle flight experiment has been proposed and is undergoing detailed definition.

Solar System Sciences

Significant Tasks

Analysis of Interplanetary Dust Particles for Volatiles and Simple Molecules

PI: Everett K. Gibson, Jr. SN2
Reference SSS 1

Interplanetary dust particles (IDP's) may contain samples of volatiles which represent materials present at the earliest stages of solar system formation. It is likely that the volatiles associated with the IDP's represent material from comets, meteorites, and asteroids. Regardless of how complex the history of the IDP's has been, the understanding of the nature of volatiles associated with such primitive materials is vital. We have been studying the volatiles associated with IDP's and primitive meteorites. The volatiles in IDP's are being analyzed via mass spectrometry after their release with a laser microprobe.

One of the most critical stages in the analysis of IDP's is sample preparation. Collection of the IDP's usually occurs in the stratosphere on collector plates coated with a 20:1 mixture of silicone oil and freon, respectively. Particles are removed from the collectors, rinsed with hexane, and placed on sample mounts (cleaned with freon). We have examined a variety of sample mount substrates: aluminum, gold, beryllium, indium, tungsten, tantalum, alumina, fused silica, silica aerogel, borosilicate glass, metallized kapton, and Torr Seal. It was found that gold hexane was noted by Reitmeijer and suggests that the JSC Curatorial Office's rinsing techniques are not effective enough. It appears that if the particles are cleaned to remove the silicone oil from the collector plates, some of the oil may be absorbed within the interior of the IDP's carbonaceous matter. It is important to fully understand the interaction of the silicone oil and hexane with the IDP's because any interpretation of the chemical and spectral micro-analyses from carbon-rich chondritic porous and smooth IDP's must consider the presence of silicone oil and hexane.

It also appears that freon, which is present in the silicone oil at a 20:1 ratio, and the hexane rinse also leave residual organic species that appear in the mass spectra for the IDP's. Traces of these contaminants have been observed in all IDP's analyzed to date.

In order to understand the possible contaminants associated with IDP analysis (i.e., silicone oil, hexane rinsing, freon residues, etc.), we have analyzed gold foil blanks (99.999 percent purity) which have been processed in a manner identical to the IDP's. To decrease contamination, the gold foils must be cleaned with commercial detergent, methanol, freon, and distilled water and baked at 900 °C in an oven. The foil is subjected to an oxygen plasma etching prior to placing the IDP's on the gold mount. The gold allows for the particle to be embedded by simply pressing on the IDP with a cleaned glass slide. Embedding the particle in the gold prevents movement of the IDP during volatilization with the laser. This allows complete vaporization of the particle during laser interaction. Prior to the development of this technique, particles were placed on beryllium; and we observed that particles disaggregated during laser interaction, resulting in an incomplete vaporization of the IDP. Analysis of gold foils in which the silicone oil had been rinsed with hexane and freon revealed an abundance of potential contaminants which required removal from the IDP's prior to analysis by any technique searching for components of the CHON family (carbon, hydrogen, oxygen, and nitrogen along with their associated compounds).

Four of the IDP's analyzed (U2015B20, U2015F20, U2022F5 and U2034D1) contained only contaminants from the silicone oil, hexane or freon (large abundance of atomic masses 11, 15, 27, 31, 41, 43, 45, 51, 52, 55 to 57, 69, 70, 72 etc.). The absence of volatiles in some IDP's is not unexpected because selected regions (especially at the 10 to 20 micron size range) of some meteorites do not contain any volatile-bearing phases. IDP U2022G13 gave evidence of the contaminants along with the elemental sulfur and sulfides. The sulfur components are uniquely present as m/z = 32, 34, 48, 60, 64 (i.e., S, H_2S, SO, COS, S_2 or SO_2, respectively). Sulfur is typically present in Type 1 carbonaceous (CI) meteorites as elemental, reduced or oxidized phases. The presence of these components in IDP's is not unexpected. IDP U2017A4 contained sulfides, along with a carbon-bearing phase (graphite-like phase which was released as CO during laser extraction). The particle also showed the silicone oil, hexane, and freon contaminants. IDP U2017A5 contained large quantities of sulfide, along with possible elemental sulfur, in addition to the contaminants resulting from collection, handling, and processing. In some aspects it was similar to IDP U2022G13.

The most unusual IDP studied (U2034D7) was a fluffy porous particle. The particle contained carbonates (m/z = 44 with minor 28, 16), sufides (primarily CS_2 which is the primary sulfur-bearing volatile rleased from sulfides), and m/z = 17, which could be associated with the OH- released from hydrates. In many respects, the volatiles associated with U2034D7 are similar to those seen for the groundmass of CI or CM carbonaceous chondrites.

From our investigations of (Type II) volatiles associated with IDP's it is clear that extreme effort must be made to obtain particles in a contamination-free manner. The collector plates used on the U-2, ER-2, and WR-57 aircraft collect particles using silicone oil. We feel that it is mandatory that the low density aerogel collector material proposed for the Cosmic Dust Collector Facility aboard Space Station Freedom be carefully examined for its contamination levels for the light elements. With proper cleaning techniques, it may be possible to use the existing IDP's to study low molecular-weight species; but care must be employed to avoid the contaminants such as silicone oil, hexane, and freon.

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Laser Microprobe-Mass Spectrometer System used for analysis of interplanetary dust particles. The Nd-glass laser with its optical microscope is shown in the center. The sample chamber with the IDP is shown beneath the microscope objectives. After the laser is pulsed, the extracted volatiles are transferred directly to the source of the quadrupole mass spectrometer (shown on the left). The entire system operates under computer control, and the control keyboard is on the right.
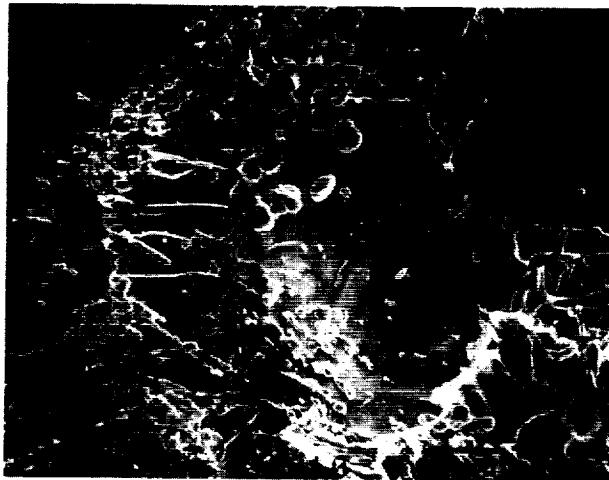
Scanning Electron Microscope photomicrograph of a laser "zap" pit and IDP embedded in gold foil. The 10 micron-sized IDP embedded in gold is shown in the upper right. The crater produced by the 1 kW laser interacting with the gold is approximately 30 to 40 microns in size. The ejected molten gold can be seen surrounding the crater.
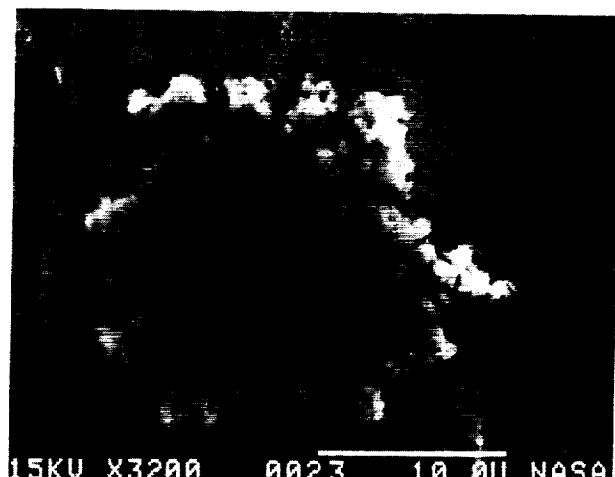
Fluffy interplanetary dust particle U2034D7. The particle is approximately 14 microns in size. Analysis of the volatiles associated with the IDP indicated the presence of carbonate, sulfide, and hydrated mineral phases.

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Carbon-Based Chemistry on Mars: Possible First Evidence from Carbonate Minerals in SNC Meteorites

PI: James L. Gooding/SN21
Reference SSS 2

The chemistry of carbon on Mars has been a subject of extensive conjecture, with few observational constraints. In addition to the obvious connection with possible organic compounds or biochemical processes, the long-term fate of CO_2, the most abundant gas in the martian atmosphere, is viewed as a key component of martian climate change. It is now likely that laboratory analyses of rocks ejected from Mars and delivered to Earth as meteorites have provided the first direct evidence about martian carbon chemistry.

Carbonate minerals have become crucial players in models that purport to explain the decline and fall of an ancient, thick CO_2-rich atmosphere on Mars. Although production of carbonates through chemical weathering on Mars is plausible, Viking lander surface experiments placed no constraints on the existence of carbonates in near-surface materials. Organic compounds were sought in loose sediments by Viking but were not found at the parts-per-million levels of detection; none of the experiments were designed to detect carbonates. Likewise, Earth-based telescopic observations have not yet succeeded in identifying unambiguously the spectrophotometric signatures of carbonates.

Shergottite, Nakhlite, and Chassignite (SNC) meteorites have become accepted by many workers as martian rocks that were propelled to Earth by large meteoroid impacts on Mars. Because they are fundamentally rocks formed by high-temperature volcanic processes, however, SNC meteorites were largely overlooked as possible sources of information about carbonates and other minerals of low-temperature, water-based origin. Nevertheless, at least four of the eight SNCs carry evidence for low-temperature, pre-terrestrial chemical alteration or weathering. The most exciting evidence that is relevant to martian atmospheric evolution, climate change, and organic chemistry consists of the traces of calcium carbonate that occur in the meteorites Nakhla, Egypt (a nakhlite), and Elephant Moraine, Antarctica A79001 (EETA79001, a shergottite). If SNC meteorites are, in fact, martian rocks, then the first direct evidence for martian carbonates is already in hand.

Laboratory work either performed directly at the Johnson Space Center (JSC) or organized under JSC's leadership has been pivotal in uncovering the SNC carbonate story. Although the first evidence for carbonates in an SNC meteorite was reported for Nakhla, based on measurement of carbon gases produced by pyrolysis and combustion of bulk samples, the mineral carriers were first discovered by Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectrometry (EDS) at JSC. Indeed, the first carbonate minerals to be properly identified in SNCs were found in EETA79001 by a JSC team. Stable-isotopic analyses of the carbonates were later performed by other research groups that had been recruited by JSC and provided with samples carefully prepared at JSC.

After substantial work to exclude terrestrial contamination or weathering as possible sources of the carbonates, the preponderance of evidence from mineralogical and stable-isotopic analyses supports interpretation of the carbonates as products of pre-terrestrial, water-based geochemistry. The similarities in the carbon and oxygen isotopic compositions of the Nakhla and EETA79001 carbonates, respectively, reinforce the interpretation that carbonate formation in both meteorites occurred on the same planet. At least one occurrence of carbonate in EETA79001 is unusual with respect to its intimate association of calcium carbonate with a rare magnesium phosphate, a relatively high content of trapped nitrogen, and possible traces of organic carbon. In both Nakhla and EETA79001, calcium carbonate may be volumetrically subordinate to calcium sulfate, which appears to have originated contemporaneously with the carbonate.

The carbonate-phosphate and carbonate-sulfate mineral assemblages of water-based origin imply that, at least in some cases, several biogenic elements (H, C, O, P, S) were assembled together in martian microenvironments. If the salt-mineral assemblages in SNCs are the same ages as their host rocks, then water-based geochemistry was active on Mars as recently as 1300 million years ago and, perhaps as recently as 200 million years ago. Abiotic synthesis of martian organic compounds might have been favored under such conditions, although direct evidence for such compounds remains debatable.

Work in progress at JSC is extending the SEM/EDS search for carbonate minerals to include other SNC meteorites. Understanding the identities and origins of carbon-bearing martian minerals formed by water-based chemistry is important for planning future Mars exploration, especially sample-return missions.
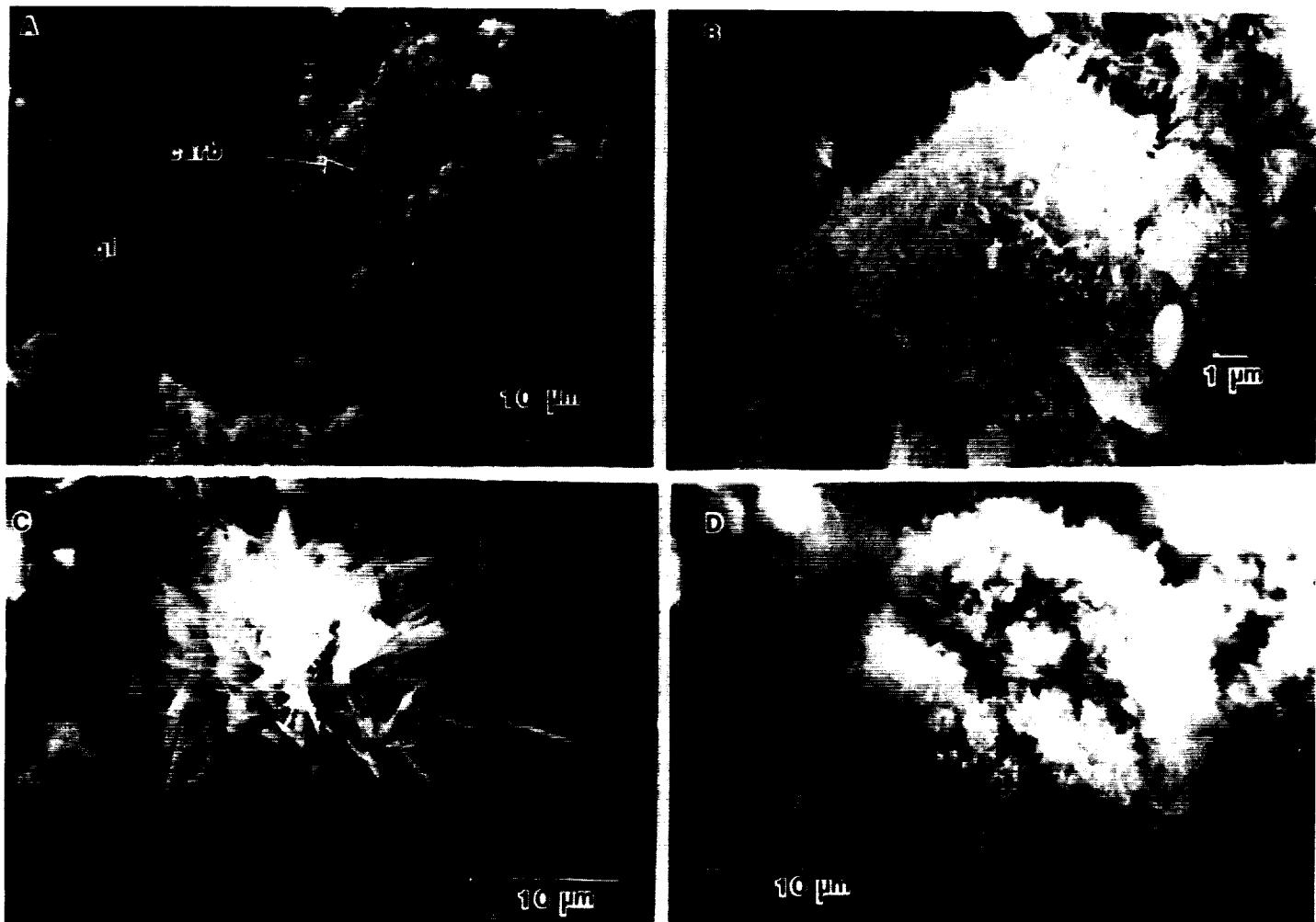
Scanning electron photomicrographs of calcium carbonate ("carb" in (a) and unlabeled in (b) through (d)) associated with rock glass ("gl" in (a)) in shergottite meteorite, EETA79001. The carbonate is believed to have formed through water-based chemistry on Mars.

Orbital Debris Program

PI: Donald Kessler/SN3
    Andrew E. Potter/SN3
    John Stanley/SN3
Reference SSS 3

The objectives of this program are to define the orbital debris environment, evaluate its effect on space missions, develop protection and minimization techniques, and raise awareness of debris problems among users of space.

Significant gaps exist in the data available to characterize the debris environment. The U.S. Space Command sensors are limited to sizes of 6-8 cm diameter at 500 km, and the Space Command catalog does not include any objects smaller than 10 cm diameter. However, model calculations indicate that fragments with sizes below 10 cm probably exist in sufficient numbers to be a significant problem for the Space Station. Shielding against fragments as large as 1 cm is a practical option for protecting critical Space Station systems. Consequently, it is essential that the debris population be measured carefully in the range from 10 cm down to approximately 1 mm in diameter, with particular emphasis on measuring the 1 cm population.

We have used existing sensors in new operational modes to measure as much of the small debris environment as is possible with these sensors. First, we used the U.S. Air Force (USAF) Space Command telescopes on Maui and Diego Garcia to measure debris in low Earth orbit at sizes down to 6 to 8 cm diameter. These measurements and the Space Command catalog agree for sizes of 1 meter and larger, but the measured debris population is larger than the catalog value for all smaller sizes. At 10 cm, the measured population is about twice the Space Command catalog value. Another effort used the Arecibo and Goldstone radars to measure the debris population at sizes below 1 cm. Results from these measurements showed that the debris population was equal to, or somewhat larger than the small debris population predicted from model calculations. However, because of the characteristics and available time, the sensors cannot adequately reduce model uncertainties enough to design Space Station Freedom.

As a consequence, a joint project has been initiated with the USAF to use Haystack and additionally develop a new K-band radar capable of measuring debris in the 1 cm to 10 cm size range. With both radars available to support orbital debris measurements, a statistically meaningful data base can be available by early 1992.

An essential part of the orbital debris program is the model for the debris environment, which is necessary for filling in the gaps in the experimental data and for estimating the future debris environment. The model calculations predict a significant growth in the small debris population in future years unless immediate steps are taken to reduce the number of breakups in space. A series of meetings has been held with European, Japanese, and Russian users of space to explain the potential future hazards of space debris, and to persuade them to adopt operational practices which minimize the possibility of debris generation.
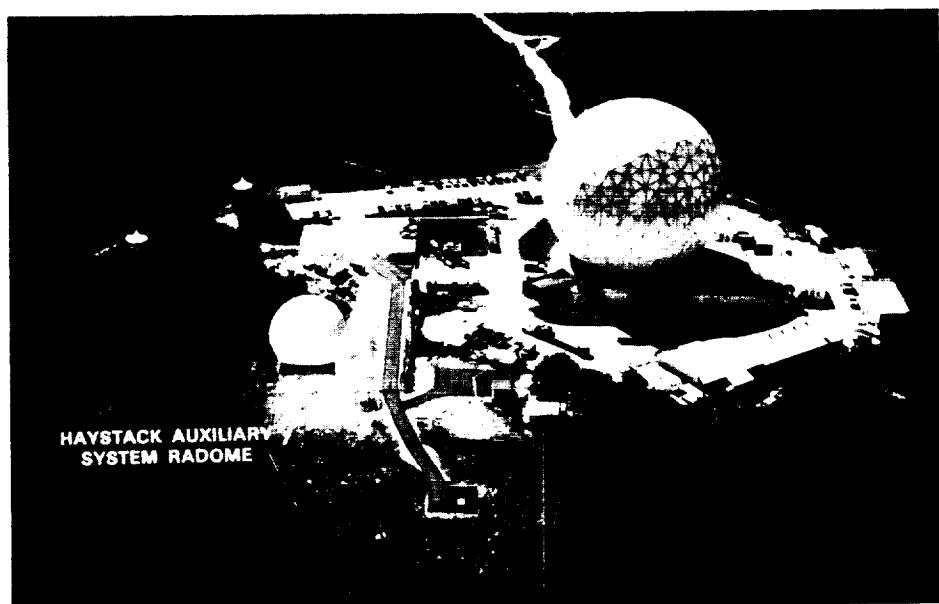
The Haystack radome.

Magnetospheric Effects on the Sodium Atmosphere of Mercury

TI: A. E. Potter /SN31
    T. H. Morgan
Reference SSS 4

The existence of sodium and potassium metal vapors in the atmosphere of Mercury was established several years ago by spectroscopic measurements that showed characteristic emission lines in the spectrum of Mercury. However, the origin of these atmospheric elements and the factors which control their abundance are not well understood. A multitude of processes have been proposed, but it is not clear which of them actually dominates. All of the previous data were one-dimensional, in which a series of sodium emission intensities was measured in a line across the planet. Significant variations were observed, but their interpretation in terms of source and sink processes for sodium vapor was difficult. It was clear that two-dimensional images of sodium emission across the entire planet would be extremely helpful in determining what factors control the sodium atmosphere.

A technique was developed to obtain monochromatic images of Mercury, at the sodium emission lines, by use of the McMath main solar telescope and stellar spectrograph of the National Solar Observatory at Kitt Peak, Arizona.

Images of Mercury in sodium emission lines were obtained on 11 November 1988, 16 through 18 February 1989, and 7 July 1989. Most of these images showed excess sodium vapor in polar regions. The series from 16 to 18 February showed major day-to-day variations of the sodium distribution over the planet, although the average sodium density remained constant. These phenomena cannot be explained by any of the processes proposed so far, and hence point to the existence of previously unsuspected influences on the sodium exosphere. It is suggested that magnetospheric effects could be the cause. Sodium ions, produced by photoionization of sodium atoms, will move along magnetic field lines toward polar regions, and will eventually impact directly on the surface of Mercury, where they will be neutralized, to regenerate neutral sodium atoms in polar regions. Sputtering of surface minerals may also be a significant source of sodium in polar regions during magnetic substorms, when magnetospheric ions directly impact the surface in auroral ovals. Day-to-day variations in planetary sodium distributions could result from changing solar activity, which can change the magnetosphere in time scales of a few hours. It was concluded that observations of the sodium exosphere may provide a tool for remote monitoring of the magnetosphere of Mercury.

Mars Sample Receiving Facility

TM: James E. Townsend/SN
Reference SSS 5

Present NASA exploration plans call for the landing of an unmanned spacecraft on Mars in the year 2001. After landing, a robotic rover will collect samples for return to Earth. Scientists and engineers of NASA are now working on hardware design and definition of sampling equipment. Planning is also underway to provide a preliminary definition of requirements for a facility to receive these samples, procedures to conduct the initial examination of the samples, provide for the distribution of samples for detailed scientific investigations, and for preservation of portions of the sample collection in pristine condition for future studies. The facility is being designed to provide quarantine of the samples to protect Earth from contamination by extant martian organisms, if they should exist, and to protect the samples from contamination by terrestrial materials.

The samples collected for return to Earth will be a diverse suite of martian materials, including uncontaminated atmosphere, soils, sediments, volatile condensates (ices), and both fresh and weathered rocks. The total mass of the returned samples will be approximately 5 to 10 kg per mission.

The martian samples will be considered in quarantine the moment they enter Earth's biosphere. The sample container, and possibly the return vehicle, will be enclosed in a biological isolation container for transfer to the Mars Sample Receiving Facility. Once at the facility, the exterior of the sample container will undergo sterilization to preclude any chance of terrestrial contamination before transferring it into the primary receiving and processing cabinets. The Mars samples will remain inside the containment cabinets until biological testing verifies the presence or absence of harmful martian bioorganisms. The areas of the Mars Sample Receiving Facility in which samples will be located and handled are designed and constructed as biological barrier containment areas, with appropriate sterilization capabilities for protection of personnel inside and outside these areas.

The preservation of the samples in their pristine state during collection, return to Earth, and in handling and processing in the facility depends on a variety of factors that must be controlled by enforced procedures. The protection of martian samples against terrestrial contamination is essential to preclude the misidentification of constituents which may have been introduced into the samples during collection or processing. Procedures will be employed for (1) control of the materials used in construction of the tools, equipment, and containers that come into contact with the martian samples during collection or processing, and (2) ultra cleaning and sterilizing of these items. These procedures will apply to all equipment used in collection of samples on Mars and in the Mars Sample Receiving Facility in handling and processing of the samples. These procedures will be based on those procedures used in the Lunar Sample Program that have proved highly successful over the years.

The Mars Sample Receiving Facility is an integrated scientific facility, designed with unique functional areas to accomplish the critical demands of sample receipt and processing and biological containment and testing. In providing a total design concept to support the mission, the facility is divided into operational areas for receipt of samples, processing and storage of samples, biological testing of samples, and ultra cleaning of tools, containers, and equipment.

The Mars Sample Processing Laboratories (MSPL) and the Biological Testing Complex (BTC) are designed as bio-containment areas. The real-time support areas of the Equipment Sterilization and Preparation Complex, the Ultra Cleaning Laboratory, and the Clean Tool and Equipment Storage are outside the bio-containment area, but are adjacent, to facilitate the transfer of items for use in sample processing in and out of the areas. Other support functions are located outside of the bio-containment area and consist mainly of Sample Documentation and Data Control, the Central Status Station, the Thin Section Laboratory, the Geochemical Analytical Laboratories, Waste Biological Neutralization, and the Maintenance and Administrative Areas. Certain of the Geochemical Analytical Laboratories will be located in the BTC Physical Sciences Section for production of real-time analyses during initial characterization and examination, while quarantine exists.

The MSPL consist of a suite of rooms for (1) processing and storage of samples at minus 40 °C, (2) ambient processing and storage of the samples, and (3) receiving and sterilization of containers. The processing laboratories are provided with stainless steel environmental glove cabinets for processing of the samples in much the same manner as were the lunar samples, and have a simulated martian atmosphere to keep the samples as pristine as possible. The cabinets are provided with integral microscope stations, for optical examination of the Mars samples, as well as stainless steel tools and containers, for processing and repackaging of the samples. Two cabinet lines are provided in this laboratory, since the program calls for a dual-flight, sample collection and return capability.

After sterilization, the sample container will be transferred to a sample processing cabinet line in the minus 40 °C laboratory, where they will be opened, documented, and undergo preliminary examination.

Personnel working in these areas will be free to come and go, but they will be required to shower and change clothes upon entering and leaving.

After microscopic characterization, photography, and assignment of individual sample identification numbers, parts of the samples will be transferred to the BTC for analysis in the Physical Sciences Analysis Section. The remaining samples will be packed for storage in the minus 40 °C storage room and held for shipment to scientific investigators. Samples will not be transferred out of the processing cabinet line until biological analyses prove them to be harmless to Earth's biosphere.
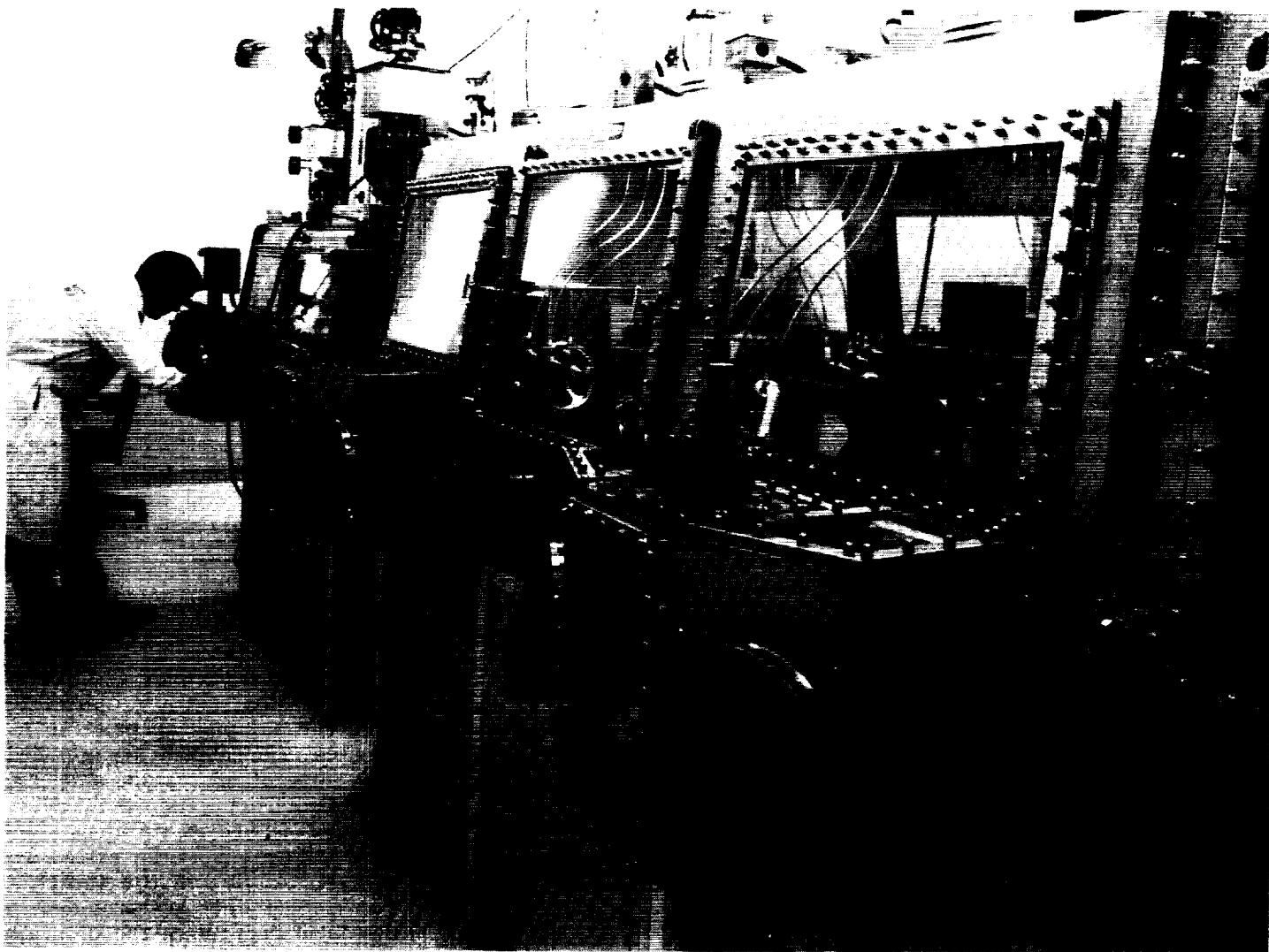
Environmental containment processing cabinets.
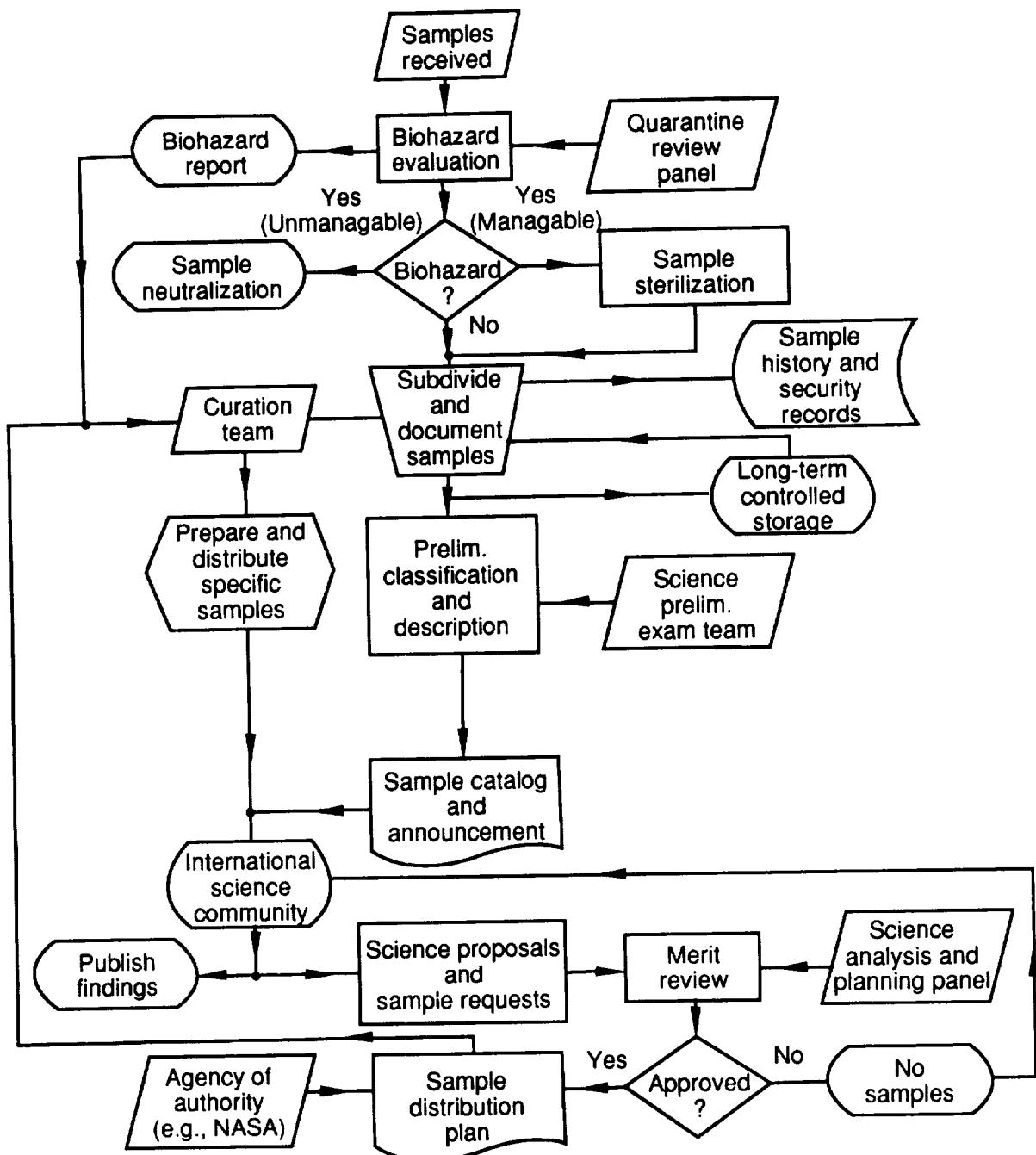
Mars sample flow diagram.

Identification of Phyllosilicate Absorption Features in Primitive Asteroids

**PI: Faith Vilas/SN3**
Reference SSS 6

Primitive meteorites of types 1 and 2 are assumed to be the result of ice melting and subsequent aqueous alteration of rocky materials comprising their original parent bodies. Laboratory reflectance spectra of meteorites that appear to have undergone aqueous alteration and of terrestrial rock samples that are products of aqueous alteration show subtle absorption features in the visible and near-infrared spectral region. However, telescopic reflectance spectra of asteroids labeled "primitive" have been considered featureless in the same spectral regions. In this study, 26 high-quality spectra of primitive (C-, P-, D-, F-, G-class) asteroids, primarily located in the outer belt and defined as the area between the outer edge of the main asteroid belt (mean distance from the Sun, a = 3.2 astronomical units) and Jupiter's orbit, were searched for weak features in the visible and near-infrared spectral region. Each spectrum was treated as a continuum with discrete absorption features superimposed

upon it. For each object, a linear least squares fit to the spectral data points defined a simple linear continuum, which was then divided into each individual spectrum, thus removing the sloped continuum and allowing the intercomparison of residual spectral features. The residual features for some of the various asteroids are shown in the figures below and are intercompared with residual features from laboratory spectra of carbonaceous chondrite meteorites.

The CI1 through CM2 meteorites exhibit a suite of spectral features generally similar to those seen in these dark asteroids. The strongest of the residual features (shown in the second figure) has a maximum absorption intensity of approximately 5 percent. The asteroid features are generally 2 to 3 times weaker than those seen in the meteorites. Although all of these features appear to be relatively weak, they must represent intense absorptions to be present in spectra of objects having such low albedos (amount of visible light reflected by the surface material) and therefore certainly arise from strongly featured mineral species. Only a relatively limited suite of viable candidate species meets these criteria. The strongest asteroidal features, seen in main-belt asteroid 102 Miriam (see the first figure) and outer-belt asteroid

1467 Mashona (see the second figure), are similar both in shape and intensity to features seen in spectra of CM2 (carbonaceous) chondrites Murchison, Mighei, and Nogoya. The features in 102 Miriam and 1467 Mashona as well as those in the meteorites are consistent with the absorption features in iron-bearing serpentines (antigorite) and chlorites.

In addition to the main-belt asteroids, 14 Cybele (a = 3.4 astronomical units), 4 Hilda (a = 4.0 astronomical units), and 4 Trojan (a = 5.2 astronomical units) asteroids were included in this study. Ten of these asteroids (Cybele asteroids 76, 87, 566, 643, 733, and 1167, and Trojan asteroids 884, 1172, 2357, and 2674) have spectra with no absorption features that passed an acceptance criterion of depth greater than 1 percent. This suggests that the asteroids have not undergone any aqueous alteration. All of the measured D-class asteroids (generally considered to be the most primitive asteroid type) and all measured Trojan asteroids (the asteroids sampled which are farthest from the Sun) show no phyllosilicate absorption features. This suggests that the aqueous alteration mechanism in the solar system ceased to operate at these distances from the Sun.
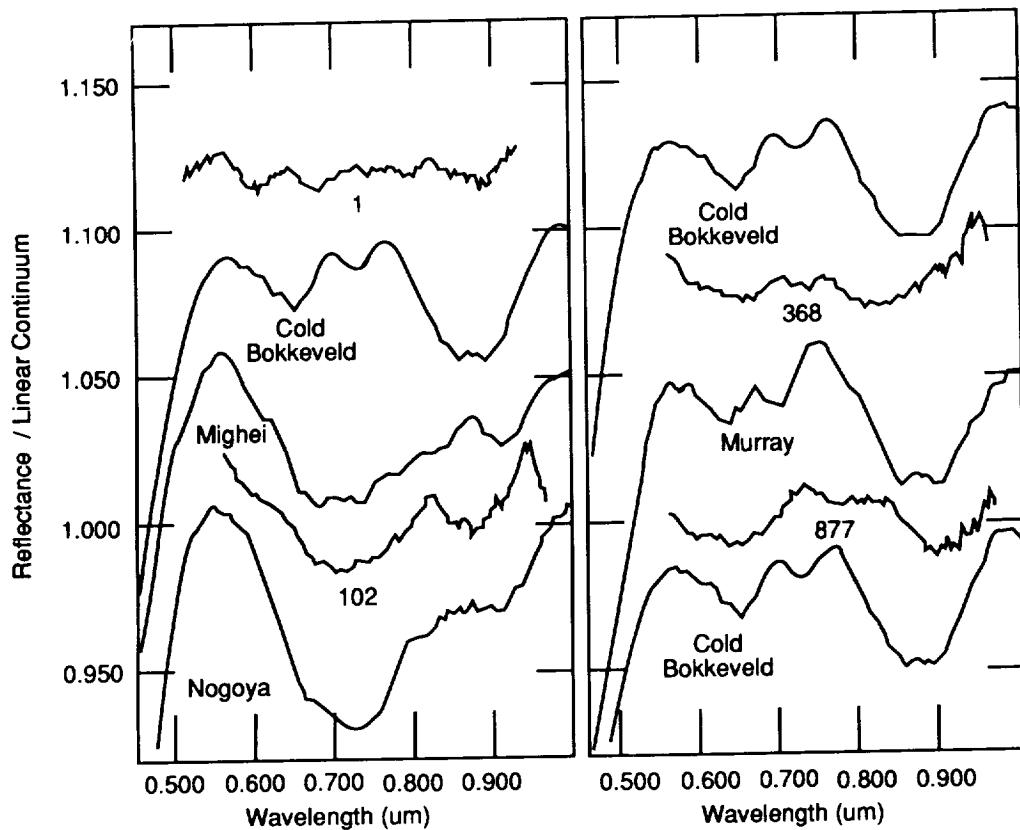
Residual spectra of main-belt asteroids, 1 Ceres, 102 Miriam, 368 Haidea, and 877 Walkure, compared to residual spectra of the CM2 carbonaceous chondrites, Cold Bokkeveld, Murray, Nogoya, and Mighei. (Spectra are linearly offset by reflectance increments of 0.05 for the purpose of display).
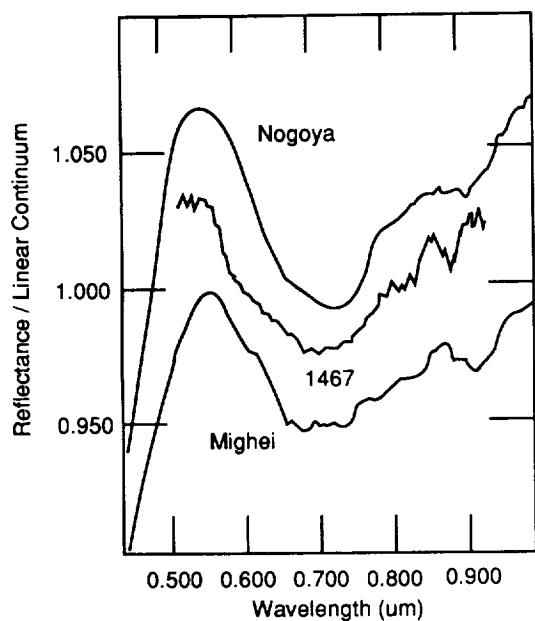
Residual spectrum of (outer belt) Cubele asteroid, 1467 Mashona, compared to spectra of CM2 carbonaceous chondrites Nogoya and Mighei. (Spectra are linearly offset by reflectance increments of 0.05 for the purpose of display.)

55

A Shuttle-Based Flight Experiment for Developing Orbital Debris Collision Warning Sensors

PI: Faith Vilas/SN3
David L. Talent and
Robert C. Reynolds/
Lockheed Engineering &
Sciences Co./C23
Reference SSS 7

The increasing hazard of man-made debris in Low Earth Orbit (LEO) has focused attention on the idea that collision warning systems should be developed to warn both manned and unmanned spacecraft of impending impact by a debris piece. Hypervelocity impact by an object could result in a destructive-to-catastrophic collision. The most significant hazard exists for Space Station Freedom, and protection of the station from collision with orbital debris has been directed toward three different problems, defined by three different size regimes of debris. Current design guidelines require that the habitation modules of Freedom be shielded to withstand the impact of particles having diameters up to 1.0 cm at speeds of 10 km/s (Christiansen, 1987). The existing USSPACECOM ground-based tracking network can follow objects with sizes down to 10 cm diameter at the Space Station altitude of 500 km. A plan to use these data to provide timely and adequate warning for Freedom to move in orbit is under development. However, this leaves a size gap between the particle size for which Freedom may be shielded and the size which can be detected from the ground. With the number of debris pieces expected to be increasing exponentially with time, the impact hazard will be increasing. On-orbit detection of a possible collision becomes important, but requires scientific technique and technology development. In addition, the amount and quality of data on orbital debris are worst in the size range (1 to 10 cm) and spectral locations (0.56 μm, 5 μm) where information is most critical to collision warning system design. No data exist for particles having sizes of 1 mm to 10 mm. Existing sources of debris data are shown in the first figure.

An on-orbit collision warning system can be developed using either passive or active sensors. Passive detection involves using reflected sunlight and earthlight in the visible spectral range or emitted thermal radiation in the infrared spectral range as a means of detecting an object. Active detection requires the use of radar or lidar or some other means of irradiating debris pieces, thereby requiring a considerable power source in space, especially for continuous operation. Active collision warning systems must also work in tandem with another means of initial debris detection. This experiment is developmental toward a passive collision warning system.

Detector technology covering the visible spectral range has developed to the greatest extent and, if the station were in perpetual sunlight, would be spectrally optimal for observing debris. The Earth can, however, occult a debris piece for up to one-third of its orbit. The infrared radiation from a debris piece should potentially be visible during the part of the orbit in darkness. Thus, both the visible and thermal infrared spectral ranges will be investigated as part of this flight experiment.

In-space observations are necessary to test detector techniques which could be used in collision warning systems and identify possible problems such as noise sources or false signals, which could be caused by small debris pieces or other unknown effects. Size distribution measurements of small (1 to 10 mm) debris pieces will contribute to modeling these effects. Ground-based observations of small debris pieces are hampered by the presence of the Earth's atmosphere and the large distances between ground-based telescopes and LEO debris. Information about the mean albedo or albedos of debris is necessary for calculating the size of fragments observed with visible or thermal infrared spectral measurements and requires in-space observations for both the visible and thermal Infrared (IR) measurements necessary to calculate mean debris values with object size. The albedo and thermal heating information which will be obtained by this experiment are necessary to optimize the selection of detectors for a debris collision warning system, and can only be obtained through space-based observations for the smaller debris sizes.

The objectives of the Debris Collision Warning Sensor experiment are threefold. First, the experiment should sample the size distribution of LEO debris pieces with altitude above the Earth. In particular, a statistically significant sample of debris in the 1 to 10 mm size range should be obtained. Second, the experiment should measure the signal at both visible (0.56 μm) and thermal IR (5 μm) wavelengths to obtain albedo and diameter information about a large sample of debris and to determine where the strongest spectral signal would be obtained. Third, detector technique can be developed to maximize the effectiveness of spacecraft collision warning sensors. Finally, these objectives should be met during a reasonable time interval for a Space Shuttle flight, which has been defined to be 1 working day for the experiment operation. The experiment can be reflown to monitor the LEO debris population temporally (for example, after an individual breakup or a change in the solar cycle), and to test IR detectors to optimize the response in the spectral range having the highest thermal emission. Operating the experiment onboard the Space Shuttle rather than a free-flying satellite eliminates problems of downlinking high-speed, high-density data and allows flexibility in the detector testing operations.

The proposed flight experiment consists of one 60-in., f/1.2, all-reflecting optics telescope, which

would be mounted on a pallet in the orbiter payload bay. A Tektronix 2048-by-2048 pixel Charge-Coupled Device (CCD) detector, operating in the visible spectral range (0.56 µm) and surrounded by single-element 5-µm InSb thermal IR detectors, would be mounted in the nominal focal plane. The CCD is clocked at a readout rate of 1/10 sec per frame; the IR detectors are clocked at a rate of 1/10 sec or faster. Data are recorded onboard the orbiter and are retrieved after the orbiter's return to Earth. The primary objective of the experiment is a blind search for debris of sizes equal to or greater than 1 mm. To optimize this search, the orbiter should be launched into a 57-deg inclination orbit near either the June 21 or December 21 solstices. Other experiment options include observing targets of opportunity taken from the USSPACECOM catalog of debris, and observing objects which have known spectral and physical characteristics, such as those ejected from the orbiter payload bay.

Central to the argument for different aspects of this experiment is the need to minimize the noise affecting the signal and the need to retain every possible incident photon – that is, to obtain the best possible Signal-to-Noise (SNR) ratio. In order to detect signals from the maximum number of small-sized particles, the signal must be optimized in all possible ways. This experiment does not require high spatial resolution in the CCD as long as the area covered by the detectors is large enough to provide directional information about the debris piece passing through the field of view. Thus, the proposed telescope is designed to be 60 in. in diameter, with a fast focal ratio of f/1.2, and having a geometric throughput of 70 percent, thus increasing the light-gathering power of the experiment. The design produces a 3.7-deg Field of View (FOV) and a physical nominal focal plane 4.6 in. in diameter. To remove the problem of chromatic aberration and allow the proposed detectors responsive to different wavelengths

to be located in the same focal plane without focus change problems, the design uses all-reflecting optics. The 3.7-deg FOV provides a large detection cone through which LEO debris can pass and possibly be detected. A silver coating on the mirrors will increase the amount of light transmitted through the reflective optics to 91 percent of the light incident on the primary mirror. This represents a significant increase over the percentage transmitted by a standard aluminum coating; however, the telescope would need to be handled carefully on the ground to avoid oxidation of the silver surface. All-reflecting optics also permits the telescope to be fitted with detectors covering different spectral ranges (e.g., 10 to 20 µm), if it is determined in the future that these wavelengths should be tested for collision warning systems.

The nominal focal plane is large enough to contain the Tektronix 2048 by 2048 CCD, surrounded by the IR detectors. The combination of these detectors responsive to different wavelengths can be accomplished for a variety of reasons. The objects being observed will pass through the conical FOV, unlike the situation surrounding most astronomical observations where the object is centered in the telescope. From this signal, the experiment will obtain visible photometry, thermal IR radiometry, and relative angular velocity data. The large focal plane provided by the 60-in. primary mirror permits the Tektronix CCD and the IR detectors to fit within an area which avoids vignetting, causing signal loss. The space-based operation of this telescope also eliminates additional problems of large background signal encountered with ground-based IR observations.

The telescope is designed to point to a given location within a circle defined by ±15 deg from the perpendicular (+Z) axis of the orbiter. The telescope will not be required to track any object. The pointing allows an operator to point

the telescope toward a dark sky background.

The Tektronix 2048 by 2048 CCD, now under development for the second generation of Hubble Space Telescope (HST) instruments, should be an available space-qualified detector in time for this experiment. Individual pixels in this CCD have dimensions of 27 µm by 27 µm, producing a total active chip size of 2.18 in by 2.18 in. The HST CCD has a quantum efficiency of ~70 percent at 0.7 µm and the capability of on-chip pixel summing and segmented readout, which permit the readout of the chip during the required short time interval. Binning 16 pixels together to form 1 "macropixel" will optimize the signal-gathering power of the CCD while not increasing the readout noise, thus increasing the SNR. This, combined with selecting the orientation of the orbiter so that the debris stream passes the telescope's FOV, optimizes the detection of debris.

A signal received by the detectors is stored onboard the orbiter, using a high-speed high-density tape recorder located on the middeck or at a crew station. The commercially available Datatape DDR-100 has been identified as capable of storing data at the 1/10 sec readout rate necessary for the CCD, with sufficient storage capability to require only one tape change during a 7-hour observing period. One tape should cover 3.67 revolutions of the orbiter around the Earth. Data storage onboard the shuttle is preferable to data downlinking, which requires data compression techniques that degrade the SNR within the data. Some capability to downlink a frame periodically has been retained by the experiment in order for a ground support team to maintain a constant check on the data quality.

Selection of launch date, time of day, and orientation of the orbiter strongly affects the total minutes in which the necessary lighting conditions exist during a revolution. Launch near either the June or December solstice ensures a launch

near the dates when the Sun will be at declination ±23 deg. An inclination of 57 deg will put the orbiter near the terminator angle of 66.5 deg, as shown in the second figure. The launch date (and therefore the observation date) can be used to select a dark sky background, avoiding, for example, the center of the Milky Way.

A sample "ideal" mission would launch the Space Shuttle into a configuration on January 5, 1994 at 7:25 a.m. EST to an altitude of 500 km at an inclination of 57 deg and would allow the orbiter to ride the terminator of the Earth's shadow for a full revolution, putting the orbiter into an orientation where the payload bay would face darkness while the belly of the orbiter would face the Sun. This physical configuration of the orbiter is feasible for long time intervals. The experiment would view Sun-illuminated debris at phase angles of 0 deg to 15 deg, while the telescope would remain shielded from the Sun by the orbiter and would be pointed toward a dark sky. With this selection of experiment orbital configuration, the orbiter is able to maintain an orientation facing dark sky throughout an entire 7-hour observing period. The orientation of the detector relative to the orbital velocity vector will also affect the results, including the frequency of observation opportunity, the direction of motion of thedebris pieces, and the dwell times in the telescope FOV.

Estimated counts in different size ranges, shown in the table, are designated for the visible spectral region. These counts are derived using the model of the debris environment in LEO, developed at the Johnson Space Center (Kessler, Reynolds and Anz-Meador, 1989) for the date of the nominal flight. The criterion for a successful experiment is the number of counts in the visible spectral region obtained for the 1 to 10 mm size range. Fewer counts are expected for the thermal IR observations in this small size range. The experiment conducted with the same design but having a smaller primary mirror diameter will suffer from a number of problems. The nominal focal plane will be physically smaller, and thus will be able to hold either most of the large Tektronix CCD and no IR detectors or IR detectors surrounding a smaller CCD. The amount of angular velocity data will be reduced, and vignetting becomes an increased problem. More importantly, the reduced number of object counts occurs completely in the 1 mm to 3 cm size range, the range of greatest interest to the experiment and critical for collision warning system operation. The large diameter of the primary mirror in the telescope is key to the success of the project.

DEBRIS PIECE DETECTION DURING 7-HOUR NOMINAL OBSERVING PERIOD

Size Range	Number of Pieces
1 mm to 1 cm	47
1 cm to 3 cm	3144
3 cm to 10 cm	424
Greater than 10 cm	23
Total	3638
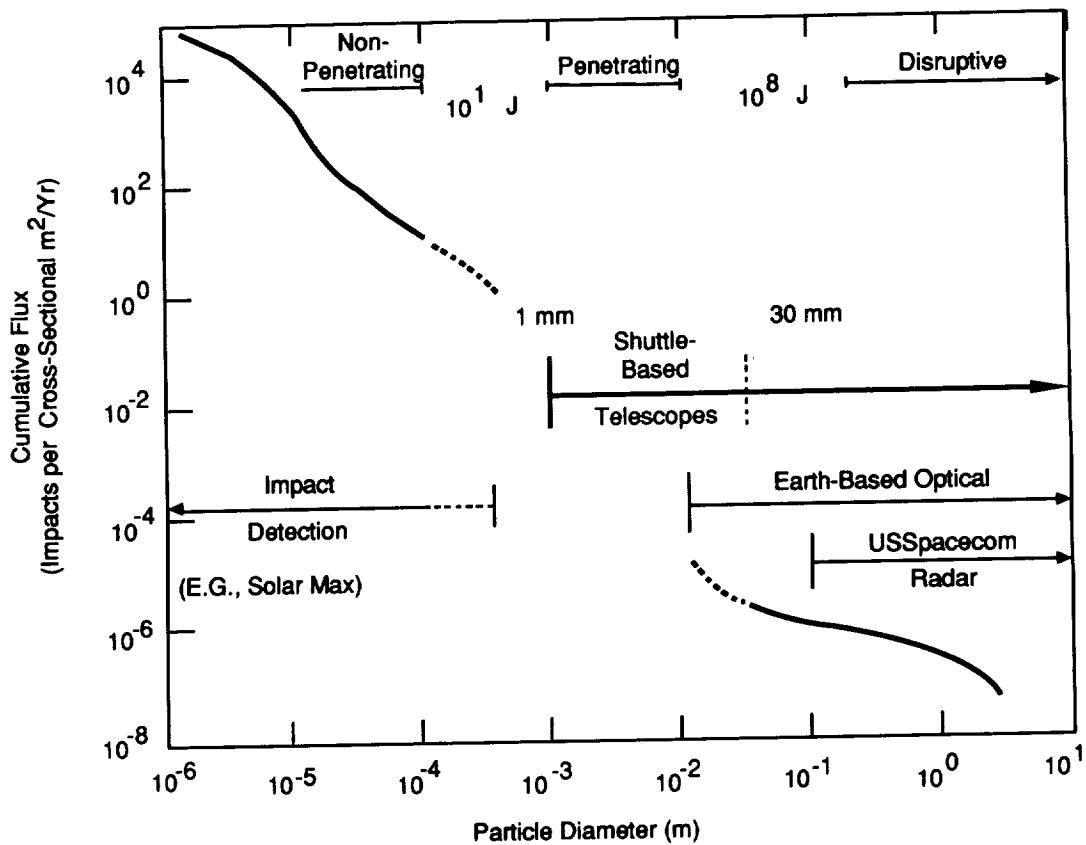
Plot of cumulative flux vs. diameter of LEO debris. Different methods of debris detection for different size regimes are also shown.

Ø = Phase Angle
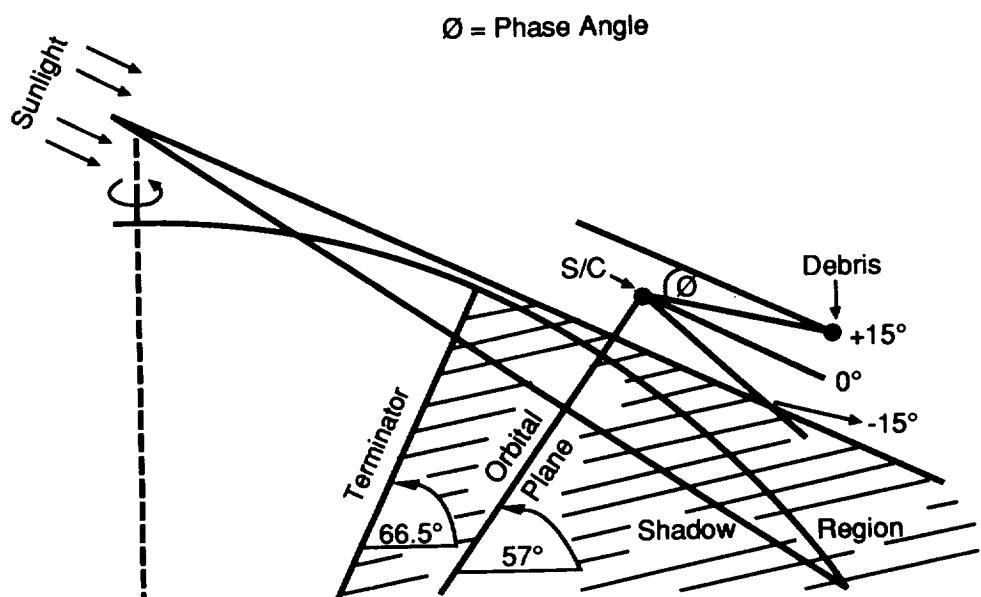
Sun-spacecraft-debris geometry under nominal observing conditions.

Backscatter Mossbauer Spectroscopy for Remote Analysis of Planetary Materials

PI: Richard V. Morris
Reference SSS 8

Surface landers on remote planetary objects, such as the Moon, Mars, and asteroids, require instrumentation for analysis of surface materials. Analysis provides characterization of the surface materials and, for sample return missions, a basis for selection of representative samples. Iron Mossbauer spectroscopy is specific for the element and is sensitive to its oxidation states and chemical environment. For geologic samples, Mossbauer spectroscopy provides quantitative information on the mineralogy of iron-bearing phases and on the relative proportions of those phases. Because of this high selectivity to mineralogy and because of the inherent simplicity of the instrumentation and no requirements for sample preparation, a Mossbauer spectrometer operating in backscatter geometry is a highly viable candidate for inclusion on a surface lander.

Basically, a Mossbauer spectrometer consists of a multichannel analyzer, a ^{57}Co source attached to vibrating rod, and a detector. Transmission geometry (sample between source and detector) is most widely used in laboratory instruments. However, backscatter geometry (source and detector on the same side of the sample) is desirable for an extraterrestrial field system because sample preparation is minimal or unnecessary. If the instrument is configured so that the source and detector are next to the outer skin of the lander (with a suitable window material), a sample need only be placed on the window for analysis. The instrument could be part of or moved by a robotic arm and placed on soil or rock surfaces for analysis thereof. Transmission and backscatter Mossbauer spectra of metallic iron are shown in the first figure.

A schematic representation of a backscatter Mossbauer spectrometer is shown in the second figure. A lightweight, piezoelectric-based system would replace the bulky electromechanical transducer commonly used in laboratory instruments. Velocity calibration could be done by a small diode-laser interferometer or by analyzing a known material (e.g., Fe metal, which could be part of the robotic arm). Recent advances in detector technology have made available solid-state detectors that are more suitable than the gas-filled proportional counters used in many laboratory instruments. With an annular array of small solid-state detectors, the source-detector distance may be decreased, allowing a good Mossbauer spectrum to be recorded in a fraction of the time currently required in the laboratory (typically 1 to 24 hours, depending on source strength, sample Fe content, and precision required). During data collection, spectra will be stored internally, placing no burden on the main computer of the lander. Based on the halflife of ^{57}Co, the estimated useful instrument lifetime is a minimum of 3 years. The estimated size for the instrument is less than 700 cm^3.

Transmission (Adsorption of gamma rays by Fe metal)

Backscatter (Emission of X-rays by Fe metal)

Velocity (mm/s)
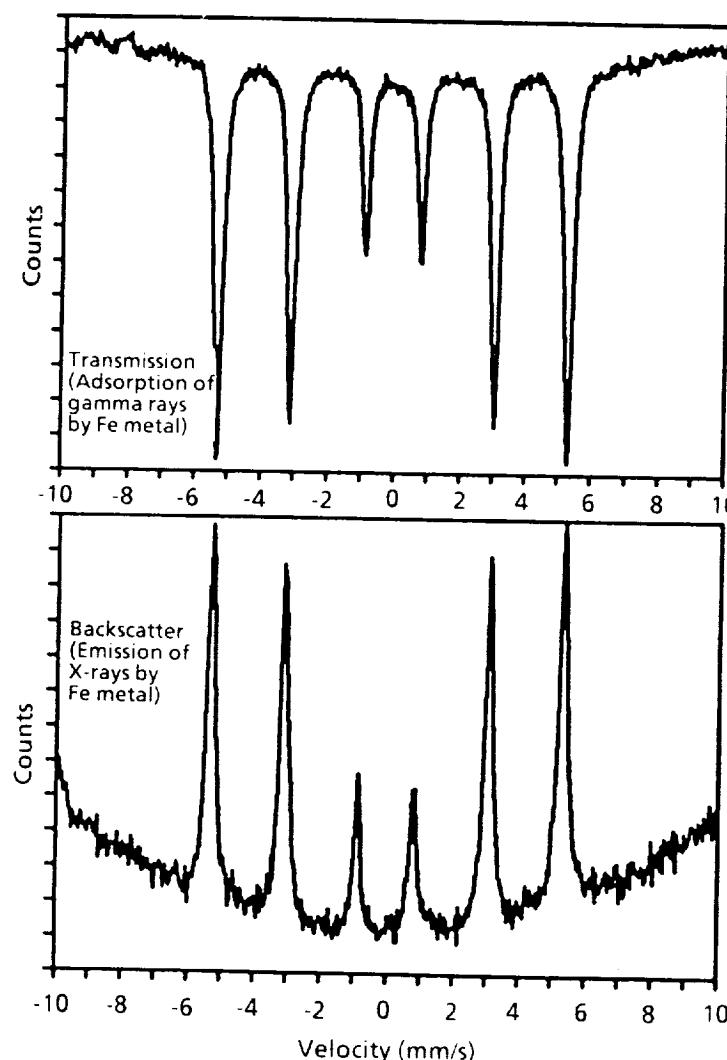
Transmission and backscatter Mossbauer spectra of Fe metal.
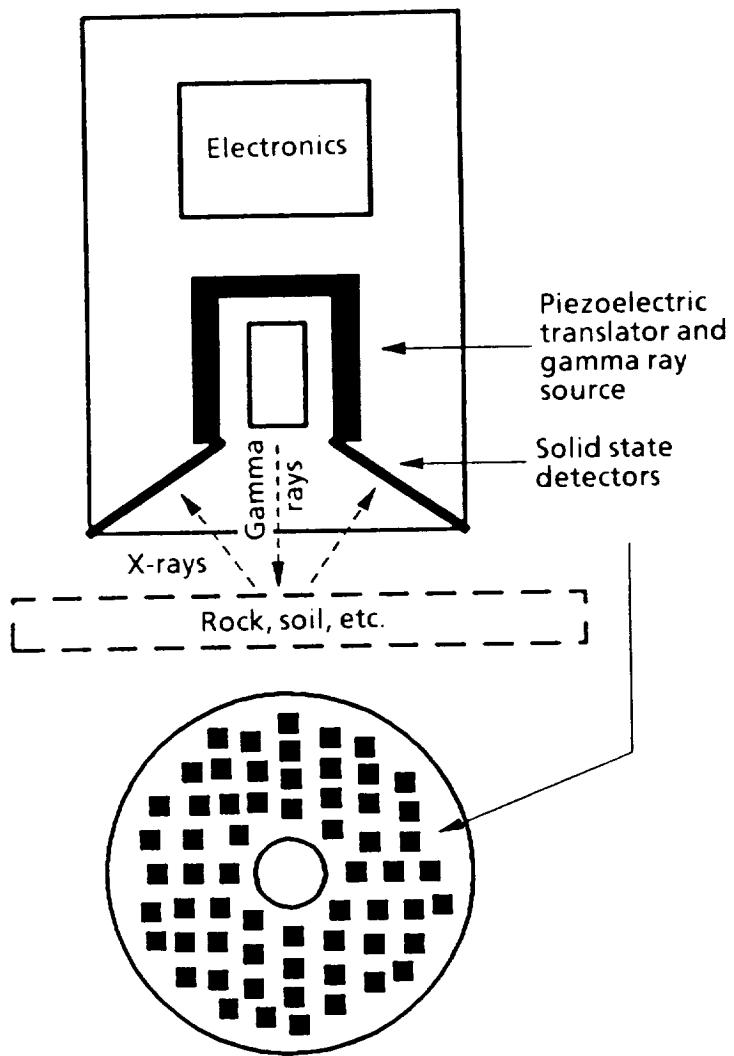
Backscatter Mossbauer spectrometer.

Solid-Support Substrates for Plant Growth at a Lunar Outpost

PI: Donald L. Henninger/SN14
Douglas W. Ming/ SN14
Reference SSS 9

A regenerative life support system for long-duration space missions is one in which all essential consumables are regenerated from within the system. All water and air are reused; and food is produced within the system, rather than being resupplied from Earth. Photosynthetic organisms (green plants) consume carbon dioxide (CO_2), the major metabolic waste product of human respiration, and combine it with water, converting these materials into food as well as producing the essential gas, oxygen. A regenerative life support system is needed to reduce costly resupply from Earth and to permit a lunar outpost to become a self-sufficient, and even potentially expanding, facility.

The growth of plants at a lunar outpost has other attractive features beyond the supply of food to lunar crews. Instead of resupplying food to Space Station Freedom (and future space stations) from Earth, resupplying through lunar outpost agricultural production could reduce the transportation costs. Furthermore, industrial and human wastes from Freedom could be transported to the lunar surface, where they could be recycled; thus, they would become a resource available to lunar outpost expansion rather than a liability for Space Shuttle to return to Earth. Interplanetary spacecraft will be extremely large vehicles, requiring on-orbit assembly and supply, due to their long-duration missions. Initial supplies of food could be provided from lunar agricultural production. Waste products from the returning interplanetary spacecraft could be sent to the lunar surface for renovation and use.

A self-sufficient lunar outpost will require the utilization of onsite resources for construction materials, propellants, life-support systems,

etc. The growth of plants at a lunar outpost will be essential to sustain a self-sufficient human colony; and there are several systems in which to grow plants, e.g., hydroponics (plants grown in water) and solid support substrates (soils). Most of the plant growth research in regenerative life support has been aimed at hydroponic systems. Lunar-derived soils may also be viable plant growth systems. However, the knowledge of how lunar materials will react as a soil is limited.

The ultimate goal of this research is development of a lunar-derived soil for the growth of plants at a human-occupied lunar outpost: a soil very much like those of Earth – highly productive, stable, resilient, and psychologically pleasing. Such a lunar agricultural soil would then become a central component in the life support system at a lunar outpost, functioning in food production and most likely in air and waste renovation as well. The objectives of this research are as follows:

- To examine unaltered lunar regolith as a soil (dissolution experimentation)
- To investigate the synthesis of a highly productive solid-support substrate for plant growth
- To prepare and characterize lunar simulants that may be used for plant growth experiments
- To conduct plant growth experiments in various prepared solid-support substrates

A 1-gram sample of each of three size fractions ($> 150 \mu$, 150 to 38 μ, and $< 38 \mu$) of a simulated lunar glass was subjected to 250 ml each of water an 0.05 M HCl at 25 °C and shaken continuously. Aliquots taken at periodic intervals (1, 10, 90, and 120 days) were analyzed for the elements Na, Mg, Al, Si, K, Ca, Ti, Cr, Mn, and Fe, using an atomic absorption spectrophotometer. The simulated lunar glass consisted of the six major elements and five minor elements, as shown in the table.

The concentrations of the elements as a function of time for one of the two solvents (H_2O) is shown in the first figure. The concentration of all the elements increased with time. After 90 days, the $< 38 \mu$ fraction with water as the solvent had highest concentrations of Si, Ca, and Mg. After 90 days, the $< 38 \mu$ fraction with HCl as the solvent had highest concentrations of Fe, Ca, Al, Mg, and Si. High Fe, and to some extent Cr, concentrations pose potential problems for plant growth; however, Ca, Mg, Mn, and Fe concentrations will also be beneficial to plant growth.

The lunar samples returned during the Apollo program represent an extremely valuable resource and are made available to researchers only in very small quantities. Even then, researchers are usually required to fully verify their experimental procedures with some substitute material before using actual lunar material. Typical allocations of lunar sample are in the tens of milligram quantities. Thus, experiments requiring sample material of greater than 1 gram are forced to resort to the use of some sort of simulated material.

Lunar "soil" simulants have been prepared from synthetically-produced glass (see the table) and terrestrial lithic fragments that are similar in chemical composition and mineralogy to Apollo 11 mare "soils." The lunar simulant starting materials have been ground to selected particle size distribution (one matching an actual measured lunar "soil" size distribution). Several properties of lunar materials are unique to the lunar surface and are very difficult to simulate on Earth (e.g., solar radiation damage); however, studies are being conducted to simulate these complex features. The mixture of glass and mineral phases described above will represent a "baseline simulant" for current and future research and will allow for comparability of results between experiments.

Several systems exist in which to grow plants; e.g., hydroponics,

aeroponics, and solid-support substrates. Most of the plant growth research in Controlled Ecological Life Support Systems (CELSS) has been aimed toward hydroponic systems. Solid support substrates that slowly release essential growth elements to the plant may also be viable plant-growth systems. Zeoponics is such a potentially viable solid substrate for plant growth. In this work, zeoponics has been defined as the cultivation of plants in zeolite substrates that (1) contain essential, plant-growth cations on their exchange sites, and (2) have minor amounts of mineral phases

(e.g., apatite) and/or anion-exchange resins (e.g., activated aluminum resins) that supply essential, plant-growth anions (e.g., H_2PO_4). It has been shown that zeolite minerals can be synthesized in the laboratory from simulated lunar glass. Thus, it is likely that zeolitic minerals couldbe synthesized from lunar material at a lunar outpost.

Wheat plants are being grown in a controlled environment plant-growth chamber. The zeoponics system used for these plant-growth experiments consists of varying amounts of a zeolite/apatite and

inert quartz sand mixture. Wheat-plants showed favorable response in zeoponics systems consisting of 25 to 75 percent zeolite/apatite compared to other zeolite/apatite treatments and controls of commercial potting soil, as shown in the second figure.

The goal is to develop a zeoponics system wherein all plant growth nutrients are supplied by the plant growth medium with only water being added.. A further goal is that such a system for plant growth, where water is the only thing added, will function in that mode for long periods of time (many growing seasons).

CONCENTRATION OF ELEMENTS IN SIMULATED LUNAR GLASS

Element	Concentration (% by weight)
Si	45.6
Fe	22.8
Al	10.2
Ca	8.6
Mg	5.8
Ti	5.4
Cr	0.2
Mn	0.2
P	0.1
Na	0.04
K	0.03

Concentration (ppm) of Al, Ti and Si
38 - 150 micron fraction
H_2O

Concentration (ppm) of Ca, Mg, and K
38 - 150 micron fraction
H_2O

Concentration (ppm) of Cr
38 - 150 micron fraction
H_2O

Concentration (ppm) of Mn, Fe and Na
38 - 150 micron fraction
H_2O
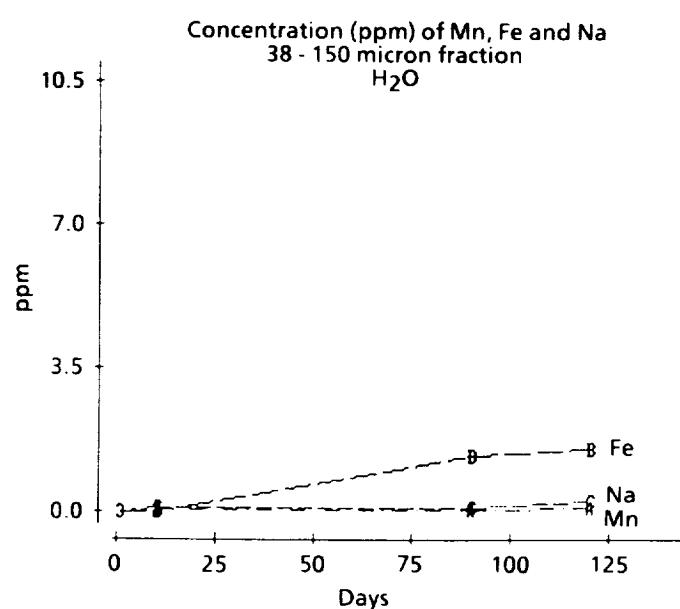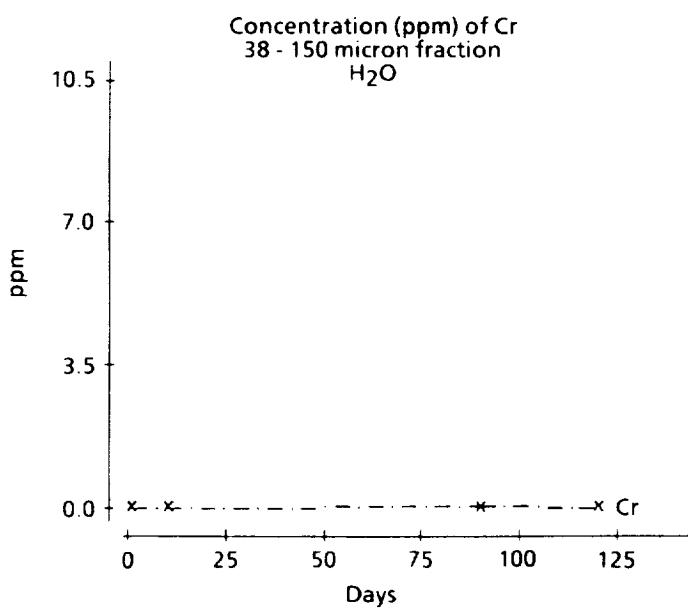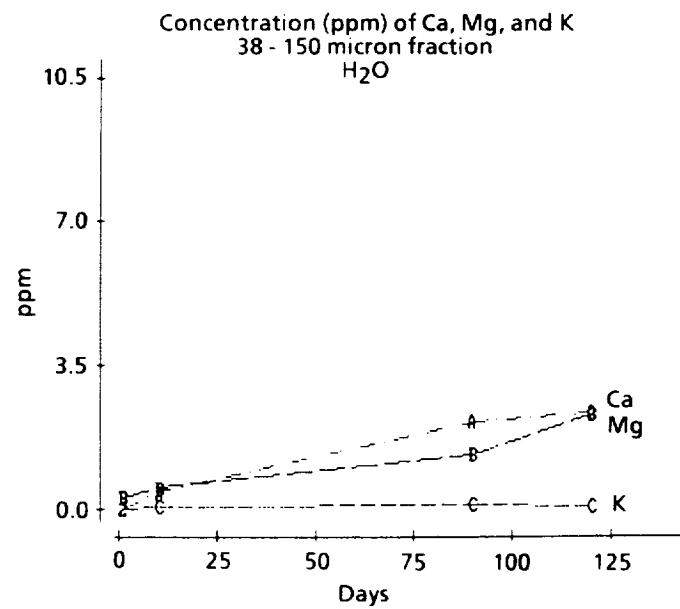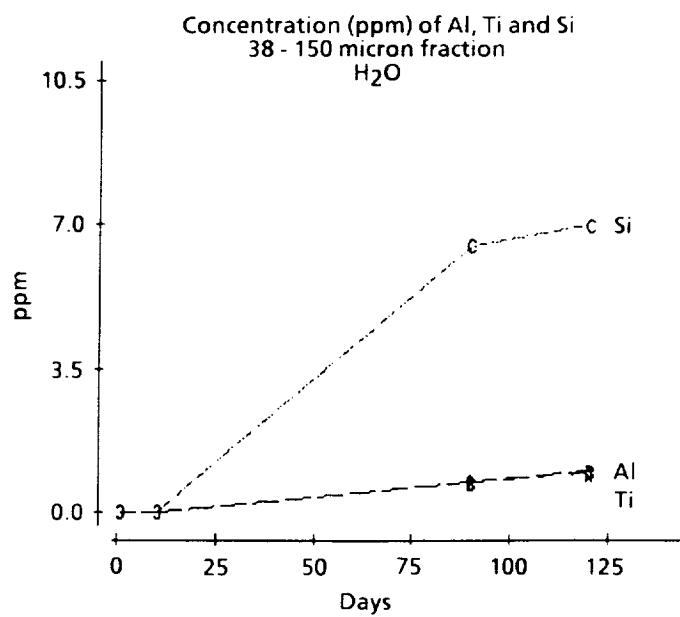
Elemental concentration of simulated lunar glass in water as a function of particle size and time.
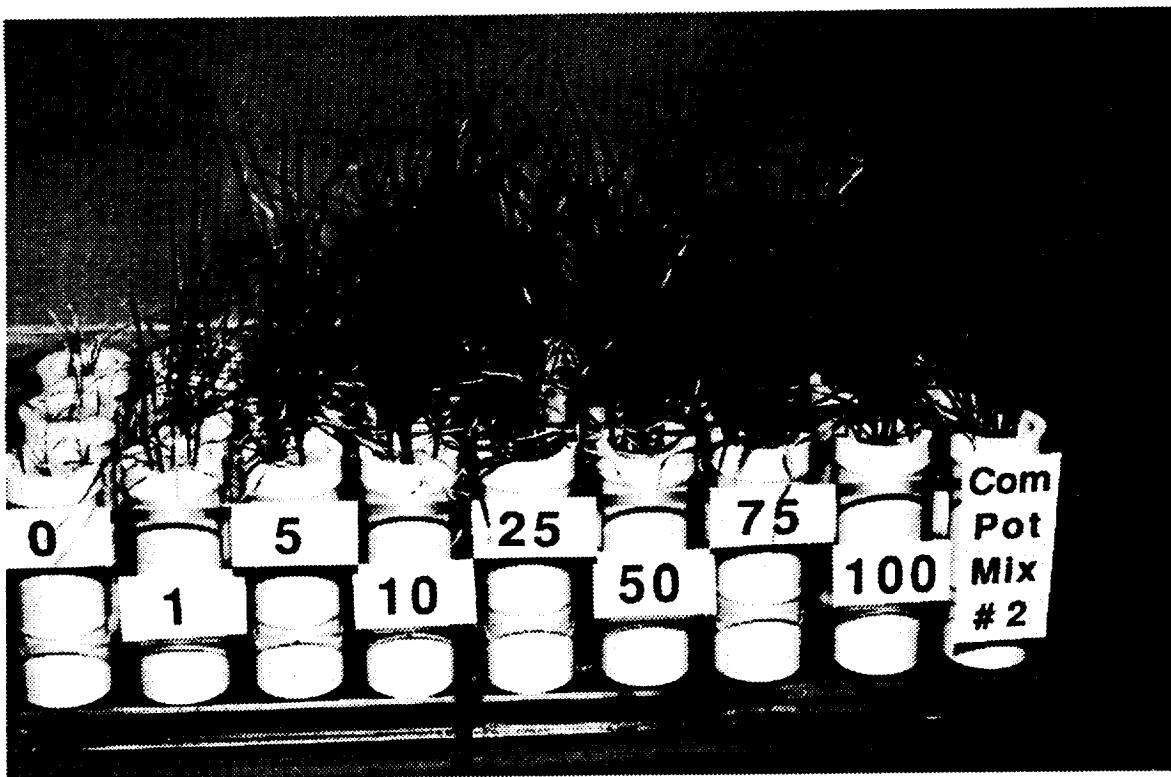
Plant growth in zeoponics systems with varying amounts of zeolite (percent content indicated by the numbers) and quartz-sand mixtures. After 45 days, wheat plants (soft, red winter wheat, Coker 68-15) showed favorable response in 25 to 75 percent zeolite, compared to other zeolite treatments and a commercial potting soil (Com Pot Mix #2).

Space Transportation Technology

Summary

Space Transportation Technology

Space Transportation Technology related studies at JSC are primarily supported by Office of Space Flight Advanced Program Development funding. These activities are primarily directed toward enhancing and expanding the National Space Transportation System (NSTS), increasing its capabilities to meet new requirements, and developing an architecture and technical basis for future transportation systems to be used in the human exploration of the solar system.

The resumption of regular NSTS missions and the explicit national goal of establishing a lunar base and conducting the manned exploration of Mars have helped focus the JSC studies and technology investigations on specific future needs, while continuing to support and enhance the NSTS, which will have a vital role in manned activities into the 21st century. Studies selected to review in this report are those continuing studies which provide direction for other efforts or those special activities which have significant accomplishments to report and which illustrate the broad range of interests being investigated.

Advanced Transportation

The advanced transportation systems work at JSC during 1989 continued the course charted previously and ranges from Shuttle technology enhancements, following the Shuttle Evolution Study-developed strategy, to new transportation elements required for lunar and Mars exploration and for the operation of Space Station Freedom.

The Space Shuttle Evolution Study furnishes the direction and strategy for ensuring that the NSTS remains a reliable, effective, primary Earth-to-low-Earth orbit and return transportation system into the next century. Plans for evolving or modifying the Space Shuttle on a systematic basis to increase safety, reduce costs, and increase capability have been developed for both hardware and operations. Previous work established the Space Shuttle Enhancement Data Base and Shuttle Evolution technical working groups; and it identified near-, interim-, and long-term goals. In 1989, the data base was made available for personal computer access, a user's guide was issued, and a "Top 20" list of enhancements and a Block II upgrade were proposed.

Work to increase the Space Shuttle Orbiter performance by an uprated Orbital Maneuvering System (OMS) engine is continuing, and a complete engine was successfully hot-fired in ground level environmental conditions. This engine, which is an uprated pump-fed version of the current pressure-fed OMS engine, has the potential to not only increase the Shuttle Orbiter payload and altitude capability, but also to serve as the main engine for future space transfer vehicles and upper stages, in which storable propellants (nitrogen tetroxide and monomethylhydrazine) are desirable.

Work has begun on a Personnel Launch System (PLS), which is intended to investigate a low lift-to-drag ratio concept, whose primary purpose is to transport human crews, with little or no cargo. Uses being considered for such a vehicle are Space Station crew rotation, lunar and planetary crew delivery to low Earth orbit (LEO), Earth orbit sorties, rescue missions, and orbital servicing missions.

The human exploration of the solar system continues to provide a focus for advanced transportation tasks. Work continues on the Lunar Based Systems Study, which outlines a lunar outpost, to be established in 2005, and the associated space transportation system. The study has identified required transportation elements, with reference missions and operational scenarios; and it has also developed a series of orbital trajectory programs for use in future studies. One study of interest investigates the use of lunar material as propellant for lunar orbit/surface operations. If feasible, the payload required from Earth could be greatly reduced for large scale operations.

Advanced Operations

Operating the NSTS is a primary function of NASA and is a major expenditure. Operations requirements and complexity will be greatly increased with the advent of Space Station Freedom. JSC is preparing for this by working on means to increase efficiency in several areas which have the greatest potential for savings.

Software development is a schedule driver in the construction of complex systems. Increasing the reuse of software designs and components is a way to relieve this bottleneck. One approach to achieving software reusability is through the development and use of software parts composition systems. JSC is continuing to work on the Advanced Software Development Workstation (ASDW) Project to investigate ways to use knowledge representation and to use retrieval and acquisition techniques to reduce the amount of manual effort spent in the creation of similar systems. Field testing was begun in 1989 and will continue to be a major activity in 1990.

Training is a major effort at all NASA operational centers and has high direct and indirect costs. In addition, most critical training is obtained in an on-the-job setting. Such training depends on the availability of experienced personnel and is generally inefficient. Studies at JSC have investigated the application of artificial intelligence technology to the development of autonomous intelligent training systems. The first product of this effort, completed last year, was an Intelligent Computer-Aided Training (ICAT) system for the Space Shuttle flight controllers who guide the development of satellites. In 1989, a prototype ICAT system for Spacelab training was completed. The

Vacuum/Vent Line (VVL)/ICAT system was designed to acquaint trainees with operation and fault detection, isolation, and reconfiguration of Spacelab"s VVL system.

The monitoring and management of spacecraft systems will become a costly job in the next decade, in terms of human resources. The number and complexity of spacecraft will increase, and so will the operational lifetimes. Expert system technology is being developed to aid in the autonomous management of spacecraft subsystems, and it has been applied as a prototype to a Shuttle-like elective power system, composed of three fuel cells, plus power distribution and fuel handling subsystems. The expert system can isolate faults, take corrective action, and conduct tests to assure that faults are correctly identified before taking corrective action.

The efficient operation of the NSTS, especially with the construction and operation of Space Station Freedom, requires careful scheduling of facilities and resources. Since normal automated scheduling systems have been found unsatisfactory in many instances, JSC has developed an interactive system that allows human controllers to directly control the scheduling process and edit the resulting schedule, while the computer performs the computations required to develop a feasible, optimal schedule plan. This system, the Computer-Aided Scheduling System (COMPASS), is written in Ada using standard X-windows interfaces and is easily ported between machines that support these standards. In 1990, COMPASS will be applied to support the planning for Shuttle flight STS-39 and to demonstrate the feasibility of hosting this software on flight-certified hardware, by producing a version for a GRID/386 laptop computer.

The development of the Autonomous Space Vehicle Operations Simulation Test Bed (AUTOPS), mentioned in last years report, is continuing according to the phased

planning schedule. The proof-of-concept prototype was demonstrated in 1989, and initial operational capability will be demonstrated in 1990. The test best uses a variety of technologies and techniques to implement mission planning and monitoring functions; fault detection and recovery activities; sensor and subsystem data processing; and guidance, navigation, and control functions. AUTOPS will support a wide variety of spacecraft and robotic manipulators. The test bed will permit evaluation of various control systems, including expert systems and fuzzy logic controllers, and their interactions with simulated vehicle components. The products of such evaluations are sets of rules, fuzzy set definitions, and procedural programs that would be incorporated into autonomous vehicle systems. A final goal of the test bed is real-time operation. This will allow a user to observe the effect of decision-making time on the quality of automation that can be obtained, to evaluate the interactions between coordinated or cooperating intelligent systems, and to determine any anomalous effects due to sensor sampling times or delays in system interactions with a simulated space environment.

Satellite Servicing

Although satellite servicing as a separate technology is in its infancy, satellite servicing functions and operations have played a major role in manned space activities for many years. Apollo 13; Skylab; Westar/Palapa; Solar Max; and, most recently, the Long Duration Exposure Facility (LDEF) recovery are examples of the importance of on-orbit servicing activities.

Satellite servicing on-orbit has historically been limited to those activities that can be performed by humans during extravehicular activities (EVA) and intervehicular activities (IVA), since humans are dexterous, adaptable, and innovative. Development of an auton-

omous servicing capability, however, is vital to the widespread and cost effective application of space-based servicing. Autonomous servicing will

- Permit servicing in locations not readily accessible by man

- Permit servicing deemed too hazardous for man

- Reduce dependency on the National Space Transportation System (NSTS)

- Become increasingly cost effective as satellites increase in cost, complexity, and size

Programs to develop systems which can be used to service complex future spacecraft are currently in development, e.g., the Orbital Maneuvering Vehicle (OMV) and the Flight Telerobotic Servicer (FTS). The OMV is a free-flying transfer vehicle; and the FTS is an advanced, evolutionary manipulator system, presently under development, which includes two 7-degree-of-freedom manipulator arms, cameras and lighting systems, workstations and hand controllers, and necessary computers and software. JSC has been named lead center to implement a program to utilize these existing technologies in a flight demonstration of autonomous rendezvous and docking, and supervised autonomous orbital replacement unit (ORU) exchange and fluid transfer.

The development of satellite servicing capabilities is directly dependent upon the required technologies, including space transfer systems; tracking, rendezvous, and docking sensor systems; robotic manipulators; vision systems; electrical connectors and fluid couplings; and advanced computers and software. These technologies are not independent. For example, in order to duplicate human functions, robotic manipulator systems require sophisticated vision systems which can

identify targets and determine their position and orientation. Vision system technology is being developed at JSC in the areas of video cameras, millimeter-wave radar, infrared detectors, three-dimensional ladar, and the imaging technologies required for object recognition and obstacle avoidance.

Many of the required technologies for satellite servicing are demonstrated in JSC's ground demonstration project to develop an autonomous free-flying robot for the development of techniques necessary to retrieve objects (tools, or astronauts) which accidentally separate from the main vehicle. This Extravehicular Activity Retriever (EVAR) consists of a manned maneuvering unit (MMU) attached to a two-armed robotic body. The system has a target recognition and obstacle avoidance system and responds to voice command.

Another area of satellite servicing technology development at JSC is on-orbit fluid management, including refueling of both Earth-storable and cryogenic propellants. JSC is developing concepts for tankers which can transfer both types of propellants, as well as the required couplings. Efforts are also proceeding on the development of a super-fluid helium (SFHe) coupling, to be used on-orbit in a flight experiment to simulate a satellite reservicing operation.

Space Transportation Technology

Significant Tasks

Application of Expert Systems to Onboard Systems Management

PI: C. J. Culbert/FR5
Reference STT 1

The number and complexity of spacecraft in operation will increase significantly over the next decade. Some of these spacecraft will be operating for much longer contiguous time periods. If autonomous systems are not used effectively, the monitoring and management of spacecraft systems in the next decade will become a costly job in terms of human resource consumption.

One technology available to support the autonomous management of subsystems is expert system technology. Significant experience has been gained in the use of expert systems to manage one system or subsystem. However, spacecraft are composed of multiple subsystems and dependent payloads that are developed somewhat independently of each other while having significant interrelated functionality and interdependences. To manage the complexity of developing monitoring and management expert systems for spacecraft and their dependent payloads, techniques to cooperate or coordinate among separately developed and possibly distributed expert systems need to be established.

This applications of expert systems to onboard systems management project approached this need by first designing two prototype expert systems to provide management of operational activities of individual subsystems that were judged typical of those encountered on advanced spacecraft. These expert systems focused on planning activities associated with monitoring and controlling resource availability and usage from a Shuttle-like electric power generation and distribution system and a Shuttle-like propulsion system. A System Manager expert system is being developed to coordinate the recommendations of the subsystem monitors.

An expert system that monitors a Shuttle-like electric power system consisting of three fuel cells, power distribution, and fuel handling subsystems was developed in 1989. The expert system can detect and isolate faults and take corrective action. The expert system also conducts tests to assure that the cause of the fault is correctly identified before reconfiguring the system to correct the fault. The architecture is a hierarchy of experts that passes diagnoses and recommendations to a higher level for processing. A similar system to monitor and control a propulsion system like that of the Shuttle Reaction Control System was constructed and demonstrated. Rudimentary simulations of the electric power and propulsion subsystems were developed to allow testing of the expert systems. Both of these expert systems were displayed at the Space Operations Automation and Robotics (SOAR) '89 conference.

The system monitor expert system coordinates the activities of the other two expert systems. For instance, it might direct the electric power subsystem expert system to delay a test that could interrupt engine firings being commanded by that subsystem's expert system. The architecture remains hierarchical.

The development and demonstration of the expert systems takes advantage of the capabilities of the Autonomous Space Vehicle Operations Simulation Test Bed, which is being developed as a separate research topic and is providing a system to test and demonstrate the test bed. A Code R task also is starting to extend the architecture for cooperation between experts rather than simple hierarchical coordination.

The following figure shows the coordination between a propulsion monitor and an expert system (EPSYS).
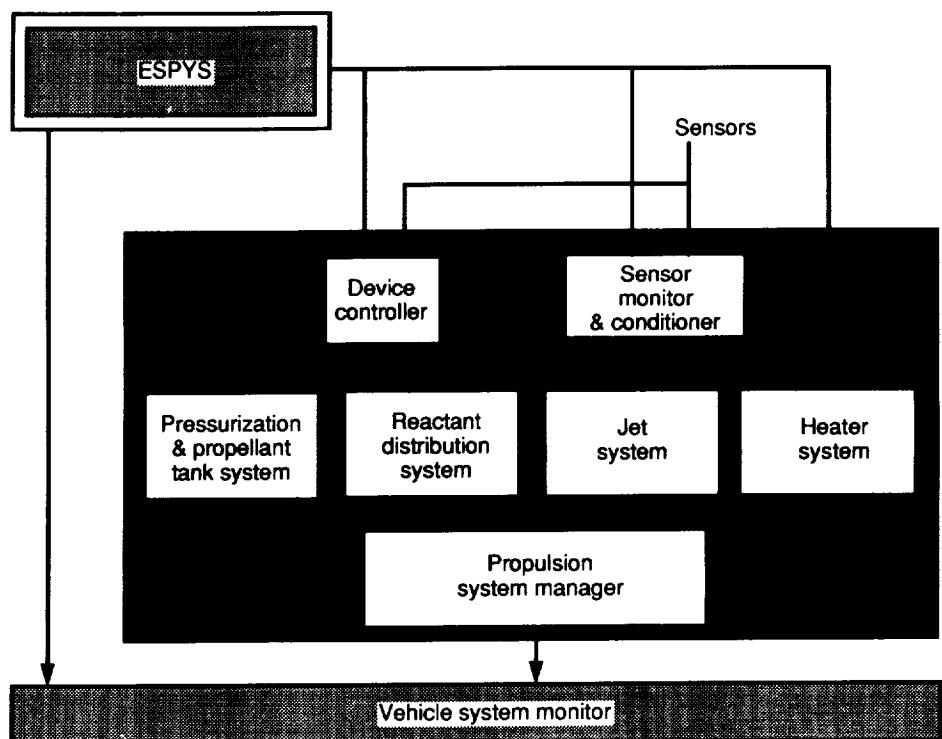
Coordination of propulsion monitor and EPSYS.

Automation and Expert Systems Application to Spaceflight Operations

PI: Robert T. Savely/FR5
Reference STT 2

Effective use of the Space Transportation System (STS) and the future Space Station Freedom requires careful scheduling of all facilities. Scheduling is a difficult, error-prone process, and unexpected events necessitate frequent rescheduling. Although manual scheduling methods are very costly and time-consuming, automated scheduling systems rarely produce schedules of acceptable quality.

The solution to these scheduling problems is to produce interactive scheduling systems that allow human schedulers to directly control the scheduling process and to edit and modify the resulting schedule while the computer performs those detailed computations that guarantee the production of feasible, high-quality schedules. To meet these requirements, the Computer-Aided Scheduling System (COMPASS) is being developed. It provides the ability to interactively schedule critical activities while providing a full spectrum of automatic scheduling and editing capabilities.

COMPASS is written in Ada using standard X-Windows interfaces. It is easily ported between machines that support these standards. Currently, COMPASS runs on Sun workstations with Sun OS 3.5 or 4.0, ×11.3, and the Verdix Ada compiler. In the near future, it will be installed on other machine machines including VAX and Apollo workstations.

COMPASS is an interactive planning and scheduling system with a mouse-driven, X-Windows user interface based on requirements that were generated at a NASA workshop on planning and scheduling held at the Jet Propulsion Laboratory (JPL) in 1986. COMPASS acts much like a spreadsheet to create and revise activity schedules. In a typical scenario, the user loads activity and resource data from a data file, creates a schedule by invoking a series of high-level scheduling and editing commands, and saves the resulting schedule in a data file where it can be retrieved for later publication or modification and revision.

Using COMPASS, the user can control the sequence of the scheduling process and the general placement of activities on the time line. At the same time, the user can rely upon the system to place activities only at feasible times, taking into account all of the constraints imposed upon an activity and the resources that it requires. The user can schedule activities one at a time to control the resulting product or can command the computer to schedule everything automatically without human intervention. COMPASS is suitable for a wide range of problems including both activity and project scheduling. It has the capabilities necessary for plan creation in advance of execution time, plan revision prior to execution time, and plan revision at execution time in response to failures and delays. It can be used to manage activities subject to timing constraints, ordering con-straints, and the availability of resources. It can also be used to manage a wide range of resources, including tools, equipment, crew, electricity, and water. Resources such as tools may be used and then returned by an activity. Resources such as propellant may be consumed by an activity. Or resources such as water may be produced or resupplied by an activity.

The system is being developed by a phased approach. Version 1.0 was released in Fiscal Year 1989 (FY 1989). FY 1990 accomplishments will be the specific application of COMPASS to support the efforts of the Johnson Space Center (JSC) Mission Operations Directorate Payload Support Integration Section to plan and replan for flight STS-39, and to demonstrate the feasibility of hosting this software on flight-certified hardware by producing a version for a GRID/386 laptop computer.

A COMPASS screen layout is shown in the following figure.
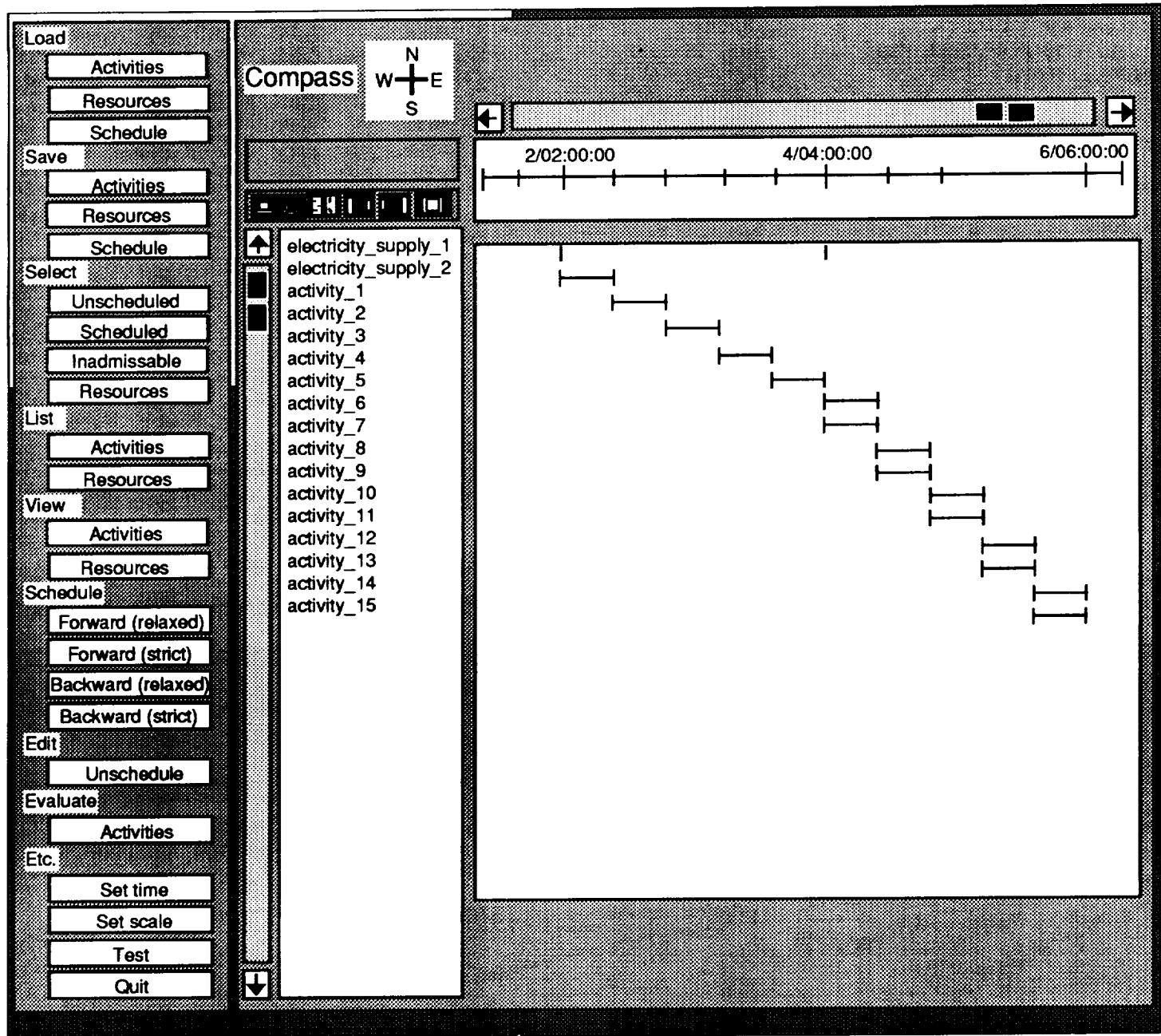
COMPASS screen layout.

Integrated Flight Operations Functional Simulation

PI: C. J. Culbert/FR5
Reference STT 3

Orbital operations of space vehicles in the 1990s and beyond will involve rendezvous, proximity operations, docking, grappling, and station keeping of unmanned, manned, and robotic vehicles. These vehicles and robots will require varying degrees of autonomy to achieve efficient use of consumable and human resources and safe, reliable, and timely operations. Effective autonomous operations will depend on the appropriate use of software technologies such as expert systems and fuzzy logic that are well integrated with conventional software and appropriate hardware.

A capable test environment must exist to define operational requirements, select and integrate software technologies and hardware sensors, and investigate mission design and analysis alternatives to support autonomous vehicles. This test environment must support the ready incorporation of hardware and software system models, real-time simulation of multiple diverse space vehicles, substitution of some actual hardware for hardware models, and tools for building subsystem simulations and intelligent software.

An Autonomous Space Vehicle Operations Simulation Test Bed (AUTOPS) is being developed to meet these requirements. The system is being distributed on a local area network to provide flexibility and real-time capability. System components are being designed for portability and are being coded in Ada. Standard off-the-shelf components (e.g., the X-Windows system) are being used where available to reduce development and maintenance costs and to retain portability. The test bed uses various processors on the network for special functionality – such as fast, high-resolution

graphics – or speed to maintain real-time performance with multiple-vehicle simulations and complex environment models running. To provide flexibility in vehicle and subsystem configuration, the test bed system is object oriented for "plug in" operation.

A phased approach is used for test bed development. A proof-of-concept prototype was demonstrated in January 1989. This prototype system demonstrated expert system and fuzzy logic control of proximity operations for a Shuttle-like vehicle rendezvousing with an Orbiter Maneuvering Vehicle (OMV)-like vehicle. Development then proceeded toward initial operational capability to be demonstrated in early calendar year 1990. The baseline test bed configuration was defined in Fiscal Year 1989 (FY 1989). The test bed "backbone" and the data manager to provide the multiple process and

networked multiple processor capability were also developed. This work will continue toward a full operational capability in FY 1990.

Two preexistent rendezvous and proximity operations simulations were installed in the system. These will be linked with expert systems and fuzzy controllers for testing and demonstration of the test bed. Two expert systems that monitor and control Shuttle-like power and propulsion systems, respectively, along with rudimentary simulations of the power and propulsion systems have also been built by a separate related project and are being used for test bed demonstration. The test bed will be used in 1990 for a new Code-R-funded task investigating cooperation among expert systems.

The AUTOPS architecture is shown in the following figure.
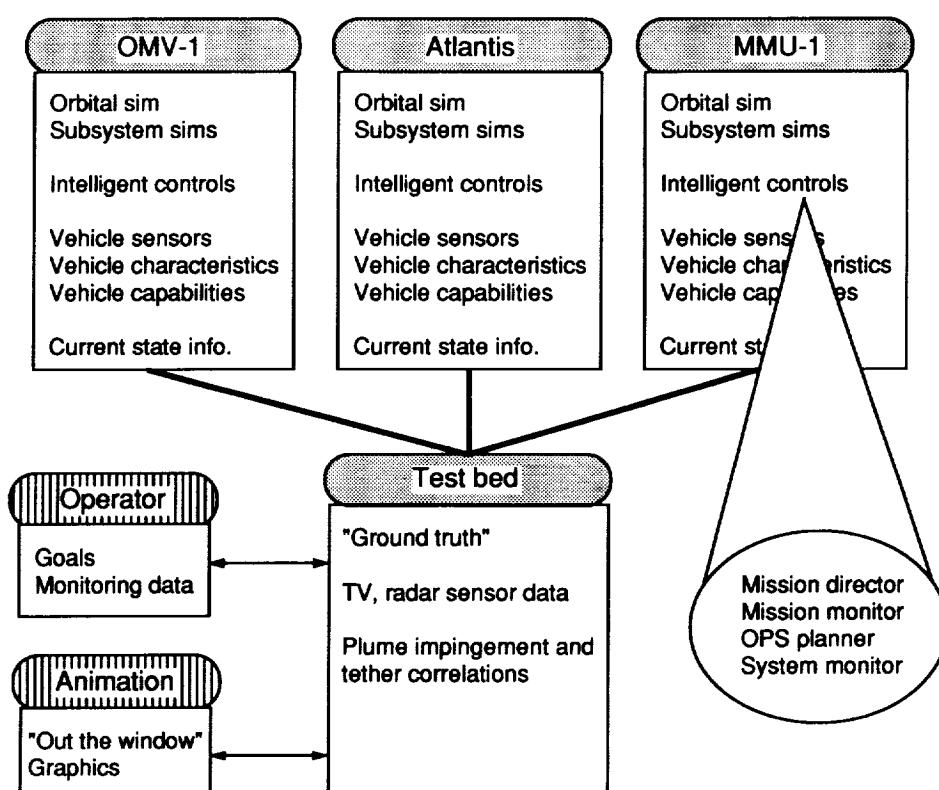
AUTOPS architecture.

Advanced Software Development Workstation

PI: **Ernest M. Fridge III/FR5**
Reference STT 4

The Advanced Software Development Workstation (ASDW) task is to research and develop technologies that are necessary to support Computer-Aided Software Engineering (CASE). Emphasis is placed on advanced methods, tools, and processes that will benefit all of NASA. An immediate goal is to supply research and prototype tools that are needed to provide near-term productivity increases in projects including the Software Support Environment (SSE), the Space Station Control Center (SSCC), and the Flight Analysis and Design System (FADS) used to support the Space Transportation System (STS). Future goals include providing technology for SSE and operational systems by adding knowledge-based system support to all phases of information systems development, evolution, maintenance, and operation.

Software development seriously impacts the construction of complex information systems during system evolution. Related development and maintenance costs can be high. The heaviest costs tend to occur in the earliest stage of the life cycle during requirements generation and analysis, design, and application development. Maintenance costs that sustain the proposed information system are even higher. An increased reuse of any of the software "parts" used in these activities has been viewed as a way to alleviate the impact. One approach to software reusability is to develop and use software parts composition systems.

A software parts composition system is a software development environment that consists of a parts description language for modeling parts and their interfaces, a catalog of existing parts, a composition editor that aids a user in specifying a new application from existing parts, and a code generator that takes a specification and produces an implementation of a new application in a target language.

The current ASDW is an expert system shell that provides the capability to develop and manipulate these software parts composition systems. The ASDW is now in Beta testing at the Johnson Space Center (JSC). Further work centers on responding to user feedback for capability and usability enhancement, expanding the scope of the support for collecting, representing, and manipulating knowledge during the early phases of the information system life cycle, and providing solutions for handling very large libraries of reusable components.

ASDW is the basic shell to support the reuse of stored information, whether the information concerns software artifacts or any other design artifact. It contains object management and rule-based constraint handling and a sophisticated "point and click" textual user interface (the Specification-by-Reformulation interface) that models the way people communicate among themselves. A neural network approach has been implemented to handle the large number of information objects that can be stored, and a capability to automatically generate the taxonomy of objects has been incorporated. The "Help" system uses hypermedia technology.

Field testing by users in JSC's mission planning community began in Fiscal Year 1989 (FY 1989) and will be a major thrust in FY 1990. The capability to directly define applications from a block diagram point of view will make the user interface more graphical. The total number of objects will be increased to handle about 100,000 items. The capability to model, generate, and reuse early life cycle artifacts will be added, as will the capability to use integrated methodologies and a common representation of their information content so they can share common information.

In FY 1991, a "Management Framework" will be developed to guide the knowledge acquisition and modeling process, the proper use of modeling tools, and the selection of proper methodologies to be used as a function of the information system characteristics. This Framework will be supported by a platform of integrated services and a knowledge representation language that will integrate modeling tools used to define information systems. These modeling tools will enforce the correct use of the methodologies. Also in FY 1991, field testing support will define techniques to assist users in acquiring knowledge necessary to operate the developed information system and will provide the capability to aid users in setting up operational data input with knowledge base expert assistance.

Intelligent Computer-Aided Training

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     Dr. R. Bowen Loftin/
     FR5/FTS525-8070
Reference STT 5

The training of NASA astronauts, flight controllers, ground support personnel, and test engineers has historically required extensive exposure to the task environment for trainees to acquire the knowledge and skills necessary for acceptable performance and/or certification. Current flight rates and the retirement and transfer of experienced personnel severely reduce the ability of traditional training approaches to produce an adequate number of trained personnel. Workstation-based Intelligent Computer-Aided Training (ICAT) systems can deliver intensive training to large numbers of trainees independent of integrated simulations.

As the figure illustrates, ICAT systems bring artificial intelligence, training technology, simulation, and other software technologies to bear on the problem of training. The role of artificial intelligence in ICAT systems is to model the behavior of experts and novices in performing a complex task. The expertise of a trainer also is modeled and used to determine the feedback given in response to trainee errors and to design increasingly challenging simulations to meet training goals. Thus, the efforts of both an expert in a task and an expert trainer are simultaneously applied to each trainee. Such systems offer increased efficiency and reduced training cost and provide uniform and verifiable training, enhanced safety, and the probability of mission success.

The Payload-Assist Module (PAM) Deploys/ICAT system is the first ICAT application in the NASA training environment. This system was designed to train novice Flight Dynamics Officers (FDOs) in the complex task of deploying a P AM

satellite from the Shuttle. The PAM Deploy (PD)/ICAT system is operational and has been used by both experienced and novice FDOs. During Fiscal Year 1989 (FY 1989), the PD/ICAT system was tested in training novices. The data shown below was obtained from three FDO Trainees who used PD/ICAT to learn the nominal PD process. Despite varying expertise levels, all three trainees rapidly approached the same level of performance on the task. These results demonstrate the rapid and effective training that can be achieved through the use of ICAT systems as an adjunct to existing techniques.

A prototype ICAT system for mission and payload specialists assigned to Spacelab missions was completed during FY 1989. The Vacuum Vent Line (VVL)/ICAT system was designed to acquaint trainees with operation and fault detection, isolation, and reconfiguration of the VVL system on the Spacelab. VVL/ICAT required 3 man-months to build, used CLIPS (a NASA-developed expert system language) and off-the-shelf graphics applications, and was delivered on 386-compatible computers. VVL/ICAT demonstrates the ability of CLIPS to

be directly linked with a graphics interface.

The design of a general architecture for ICAT systems was also completed in FY 1989. This general architecture is now being applied to other training tasks at the Johnson Space Center (JSC), the Kennedy Space Center (KSC), the Marshall Space Flight Center (MSFC), and the Goddard Space Flight Center (GSFC). To facilitate the production of ICAT systems for a wide spectrum of NASA tasks, work recently began on a suite of software tools that will aid the ICAT developer in building a new application with the general ICAT architecture.

During this year, significant progress in the areas of knowledge acquisition, interface development in X-Windows, and object-oriented data bases has been made. The goal of this project is an integrated, workstation-based software environment for the development of specific ICAT applications. Such an environment would significantly reduce the time required to build new applications and serve to transfer ICAT technology to other NASA centers and into the military, commercial, and educational sectors of the Nation.
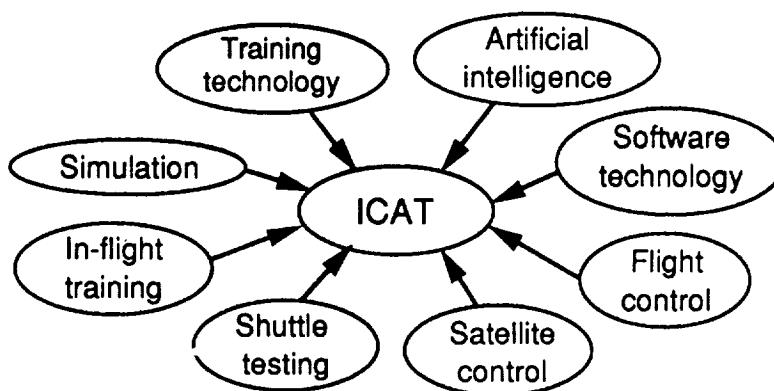
ICAT systems integrate diverse technology, providing effective and efficient training to many NASA operations.
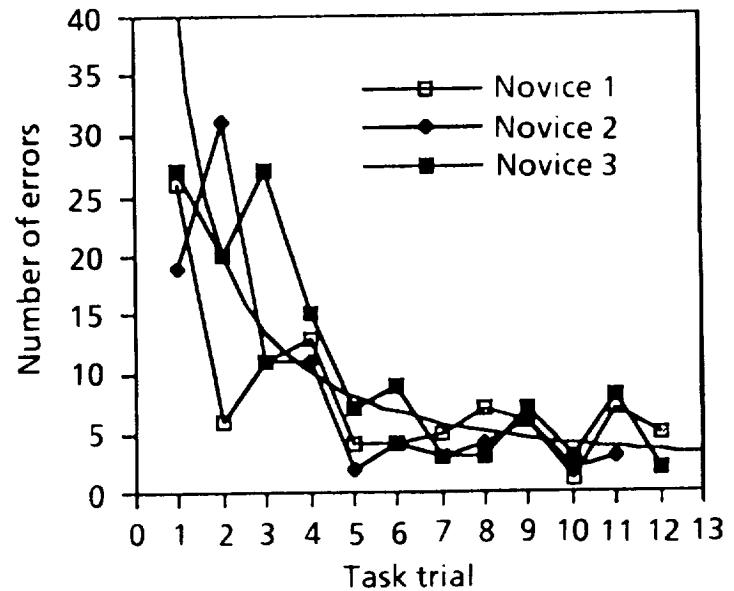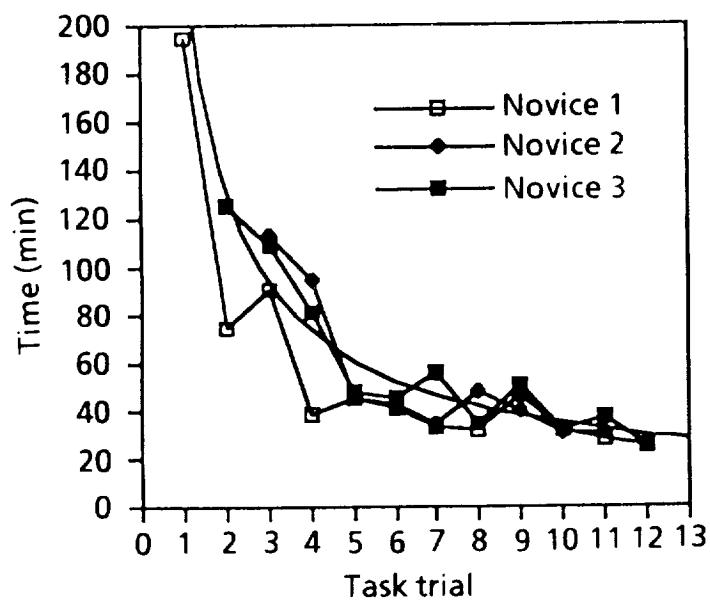
The PD/ICAT system greatly enhances the training of novices in the performance of complex, critical tasks.

Fuzzy Logic for Adaptive Control and Operational Decision Making

PI: Robert N. Lea/FR5
Reference STT 6

Developing more efficient systems for adaptive control and decision making for future flight operations is crucial to the operational efficiency and success of autonomous spacecraft control systems. Process control and sensor data fusion, the utilization of sensor data in decision making, and vehicle and robotic arm control will also be vital to future flight operations. Many quantities in life support systems – e.g., pressures, oxygen levels, temperatures, etc. – must be monitored and controlled. Problems will need to be detected and diagnosed, and solutions will have to be found and implemented. Fuzzy diagnostic systems and fuzzy control systems may solve at least some of these problems.

In work at the Johnson Space Center (JSC), several of these problems were addressed using this new technology. In particular, fuzzy sets were applied to space vehicle control and control of sensor data processing with good results. Solutions were achieved through a rule-based approach where rules, as developed by human experts for certain control problems, were modeled by the use of fuzzy sets. However, many more problems remain unsolved, and this new technology has much potential that has not been studied yet. The ongoing examination of fuzzy logic for adaptive control and operation decision making endeavors to push fuzzy set technology further toward achieving its full effectiveness. JSC has set two objectives – (1) to develop fuzzy logic applications to control space vehicles and remote manipulator systems, and (2) to develop an adaptive logic design to create more robust fuzzy controllers. A prototype system will serve as a test environment in which to evaluate the effectiveness of new methodologies in automation and robotic control and to study the feasibility and desirability of building an adaptive fuzzy controller microprocessor.

To achieve these objectives, in Fiscal Year 1989 (FY 1989) a fuzzy attitude controller for space vehicle applications was developed. This attitude controller was implemented into a previously developed proximity operations simulation for Shuttle and Orbital Maneuvering Vehicle (OMV) control that utilizes fuzzy sets for transitional control and position maintenance. The attitude controller's performance was evaluated against the Shuttle's Digital Autopilot (DAP). Preliminary results showed the fuzzy controller saved 33 percent to 50 percent fuel over the conventional controller. An investigation using fuzzy methods for the gimbal angle control of a Closed Circuit Television (CCTV) camera was also initiated. This will be used in a camera tracking system that will be developed using the Togai Infralogic system purchased in FY 1989.

Although fuzzy controllers work well under highly variable conditions, no set of decision-making functions suffices to cover all situations. Control functions depend on variables such as time, relative states, type of scenario, etc. Adaptive techniques are vital to space-related problems such as control of sensor data processing, and to robotics applications such as grappling objects with the proper force, avoiding collisions within the workspace, and diagnostic systems. Various candidate control techniques will be studied and alternative methods developed for evaluation which are likely to involve an integration of adaptive filters with fuzzy controllers. Two approaches to developing adaptive controllers which will be investigated are the use of neural network algorithms and fuzzy associative memory architectures.

The following figure provides an example of how fuzzy logic for adaptive control and operational decision making might be applied to Shuttle operations.
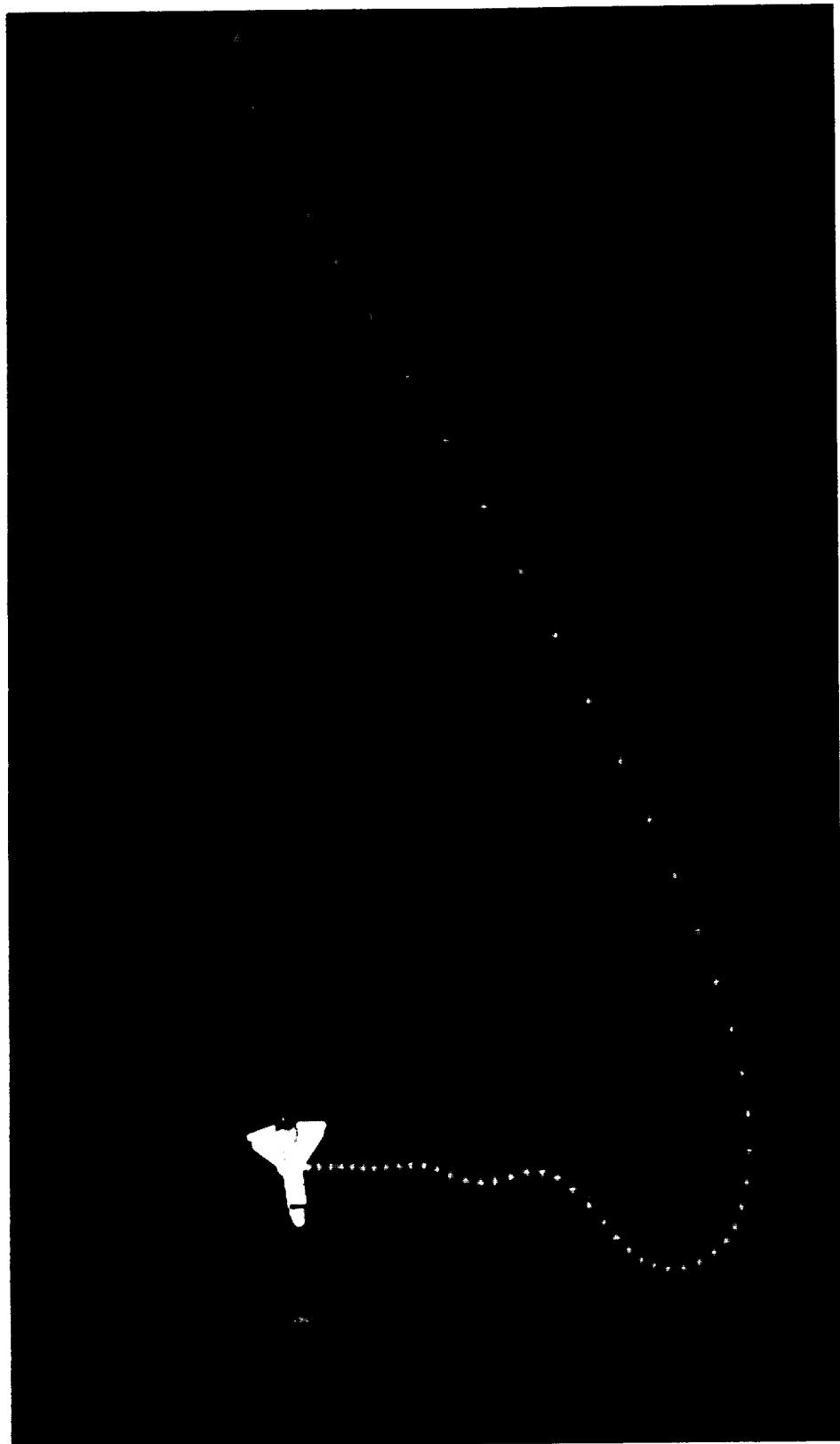
Computer simulation of the Space Shuttle under fuzzy logic control.

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Photonics for Navigation, Hazard Detection, and Avoidance

PI: Richard D. Juday/EE6
Reference STT 7

Hazardous unmodeled terrain features might be encountered during automated planetary landings. This is especially true if the landing occurs on an "interesting" site, and even truer if the landing site has not been mapped with sufficiently fine resolution or if descent navigation is incapable of bringing the lander to the desired location.

Two image-processing techniques originally devised for optical image processing were developed that can apply to both this problem and to digital computations. They are distortion invariant pattern recognition and estimation filtration.

Digital or optical image correlation is sensitive to distortions such as scale, rotation, or differing perspective. Ordinarily, this would necessitate a large bank of reference images to accommodate all expected deviations from the nominal appearance of the reference. Using convolutional blurring and shift invariant coordinate transformations (filtering techniques developed in the Tracking Techniques Branch), the scope of a given filter's applicability should be widened so that fewer filters are needed to achieve a given accuracy.

When a target point is identified, another Tracking Techniques Branch method (the Synthetic Estimation Filter (SEF) can come into play. With a site's identity established, the image of the known site can have variation suppressed in it that corresponds to the identification but that is not useful for the next stage of the problem. That is, information that contributed to the site's identification can become confusing or useless to fine estimation of the location from which the now-known site is viewed.

The SEF technique expressly extracts information from an image that yields an estimate. A ratiometric method – in which ratios of correlation strengths resulting from bracketing filters bear the information about perspective, etc. – the SEF is relatively robust against illumination variation, dust obscuration, and the like. As a whole-image correlation operation – done in either digital or optical Fourier transformation – it is fast and robust when compared with conventional digital feature extraction methods.

Photonics for Autonomous Rendezvous and Docking

PI: Richard D. Juday/EE6
Reference STT 8

Several technologies are being developed with partial support from this funding code. One technology is the alternative docking targets for manned spaceflight, which is being realized in laboratory hardware for demonstration and evaluation. One of four methods in work, the moiré target, is most relevant to machine vision for the approach phase of an autonomous rendezvous and docking. Since ordinary receptors for machine vision—i.e., solid-state television cameras—are strongly patterned, they will periodically sample the image of a moiré target without the intervention of a focal plane reticle. The image plane reticle is necessary for human perception of the interference pattern that contains finely accurate relative position information.

Optical correlation has been advanced as a rendezvous and docking technology during Fiscal Year 1989 (FY 1989). Several points can be mentioned.

The project utilizes the Defense Advanced Research Project Agency's (DARPA's) development of battlefield correlators. The intent is to modify these small, lightweight correlators into a configuration that is amenable to space application. For the battlefield correlator, an optical filtering theory is being advanced under NASA auspices. This filtering theory will be applied to reducing the potential effect of noise on pattern recognition for autonomous rendezvous and docking. It will also apply to reducing the storage requirements for sheer numbers of filters necessary to maintain object recognition under a complicated rendezvous/docking scenario. The quality of spatial light modulators is also being advanced at Texas Instruments with autonomous planetary landings and rendezvous and docking motivating participation. The properties being optimized are speed, light efficiency, low power, and high-space bandwidth product per volume.

A comparative study among a suite of correlation pattern recognition techniques has been initiated. It covers both digital and optical means of correlation pattern recognition. Binarized and gray scale digital correlation is being considered, and the digital regime is being adapted to some techniques previously developed for increasing optical correlation's robustness against perspective point motion, obscuration, and other confounding factors.

The arena of cooperation with other Government technology sources is being enlarged by bringing in people who work with vision-guided atmospheric reentry vehicles. Presently, these individuals are advancing an image correlation means fundamentally different from the one being pursued at JSC. Image correlation is being worked on a whole frame basis; those individuals brought in have been working on shift-and-add, line-at-a-time correlation. These methods have interesting relative strengths and weaknesses that must be investigated.

Mars Rover Sample Return Communications Subsystem

PI: Elaine M. Stephens/EE8
Reference STT 9

The Mars Rover Sample Return (MRSR) mission consists of four segments: (1) the Imaging Orbiter, (2) the Communications Orbiter, (3) the Rover Flight System, and (4) the Sample Return Flight System. The Imaging Orbiter will be in Mars orbit and will map portions of the martian surface. The Communications Orbiter will be in Mars orbit and will act as a relay satellite for Mars vicinity and surface operations to/from the Deep Space Network (DSN). The Rover Flight System will deliver the rover to the martian surface where it will collect samples. The Rover Flight System consists of the aeroshell and rover lander, which are Johnson Space Center (JSC) responsibilities, and the rover, which is the responsibility of the Jet Propulsion Laboratory (JPL). The Sample Return Flight System will land on the surface, receive the samples from the rover, and return them to Earth orbit. The Sample Return Flight System consists of the aeroshell, lander, Mars Ascent Vehicle (MAV), rendezvous and docking module, Earth Return Vehicle (ERV), and Sample Return Canister; the responsibility for these is JSC's.

All direct links to the DSN are X-band using a 1.5-m dish antenna, except where specified. All S-band links utilize three omni antennae. Both aeroshells have a direct link to the DSN until just prior to Mars aerocapture where the links switch to S-band through the Communications Orbiter. The rover lander and the MAV lander have an S-band link to the Communications Orbiter. The MAV lander also has an X-band

Slink to the DSN. The MAV has an X-band link to the Communications Orbiter using three omni antennae. The ERV has a direct link to the DSN. The Sample Return Canister has an S-band link to the DSN and to the Tracking and Data Relay Satellite System (TDRSS). The DSN link begins 4 hours before aerocapture through retrieval by the Shuttle. The TDRSS link is for Earth orbit until retrieval. Electronics consist of an encoder, modulator, up converter, high-power amplifier, diplexer, low-noise amplifier, down converter, demodulator, bit sync generator, decoder, and command decoder.

The primary goal of the Phase A Iteration 1 for the communications subsystem at JSC was to design a functional-level communications system. All links were designed to satisfy a $1.E^{-5}$ or a $1.E^{-6}$ Bit Error Rate (BER) with a minimum 3 dB link margin. A set of trades was conducted for each vehicle. These trades included the type, number, and size of antennae; antennae placement; the antenna mounting method; and electronic component placement. Necessary functional electronics were determined for each vehicle. Weight was estimated for each vehicle, and power estimates were computed for each vehicle for each phase of the mission timeline. Circuit margins for each communications link were calculated.

The results of the trades and analyses were published as a final report to be used as a Phase A baseline.

Shuttle Evolution

PI: C. Teixeira/C. Mallini/ED2
Reference STT 10

The Shuttle provides unique payload delivery, servicing, onorbit operations, and payload return capabilities. To ensure that it remains a viable, cost-effective transportation system past the turn of the century, a comprehensive long-term evolution strategy is required. The Shuttle Evolution assessment – initiated in Fiscal Year 1988 (FY 1988) and continued in FY 1989 – is addressing such a long-term strategy.

During FY 1989, several milestones were achieved. Prioritized goals/objectives were established and a Shuttle Mission Needs Statement was drafted for National Space Transportation System (NSTS) concurrence. A Personal Computer (PC)-based enhancement data base was completed, and a user's guide was issued. Finally, a "Top 20" list of enhancements was proposed with a Block-II upgrade in the 2000 time period.

Some FY 1989 funding was utilized as seed money to better define a few of the Top 20 enhancements. Studies defining a candidate electromechanical actuator system and onboard checkout and verification as well as a crew escape module study were initiated. These studies are scheduled for completion in late FY 1989 or early FY 1990.

A key to strategy development is defining the technology and advanced development requirements summarized in the table below. To support this, a technology readiness review was held at Langley Research Center on April 17, 1989. Discussions and data exchanges occurred on many topics – focusing on an advanced Thermal Protection System (TPS) and on Electromechanical Actuators (EMAs) – with representatives from the Ames Research Center and Lewis Research Center attending. An annual technology readiness review for Shuttle Evolution was also planned at that time.

The following figure illustrates some vehicle enhancements.

	Basic Technology Development	Advanced Development Demonstration
● Electromechanical Actuator System		X
● Advanced Electrical Power for EMA (HPD FC)	X	X
● Advanced (Durable) Thermal Protection System	X	X
● Quad Global Positioning System Navigation		X
● Integrated Thermal Control System		X
● Advanced Cockpit		X
● Integrated Orbital Maneuvering System/ Reaction Control System		
● Lightweight Structures (Aluminum, Lithium, etc.)	X	X

Simplified
manufacturing
techniques

External heat
exchanger

Block II
controller

Turbopump redesign
- Reduced welds
(297 to 4)

Phase II +
powerhead

- Increased
- Performance
- Reduced weight

Increased system
design and
operations margins

Main combustion
Chamber redesign

- Producibility
  - Precision casting
    methods

- Improved safety and
  reliability

- Quality control
  - Reduced inspections

Streamline
cargo interface

Automatic checkout
using integrated
on board/LPS

Electromechanical
actuators

Glass cockpit

Common
propellants
(No hypergolics)

Composite
materials

Subsystems
reconfigured
for access

Lightweight
durable TPS

- Advanced technology
  utilization
  - Avionics
  - Propulsion
  - Materials

- Safety and reliability

Vehicle enhancements.

Personnel Launch System

PI: A. Petro/ED2
Reference STT 11

Studies of the next-generation manned transportation system are focused on three potential paths – a Shuttle-derived system (e.g., Block-II vehicle); an Advanced Manned Launch System (AMLS) which typically is a lifting, winged concept; and a low lift-to-drag ballistic vehicle, a Personnel Launch System (PLS).

The objective of the PLS study initiated in late Fiscal Year 1989 (FY 1989) was to develop a launch system concept with the primary objective of transporting human crews with little or no cargo. The premise is that a dedicated people carrier can be a small, relatively simple system.

Using high-level guidelines as a basis, a set of ground rules was established for the PLS study. A mission model for passenger traffic was also defined from 1996 to 2020.

Six reference missions were considered including Space Station crew rotation, lunar and planetary crew delivery, Earth orbit sorties, rescue missions, and orbital servicing missions. These missions served as the basis for conceptual design and system analyses.

In addition to the in-house concept definition, a contracted effort was initiated in October 1989.

The following illustrates a PLS.

Front View

Side View

Entry hatch — SS docking ring/hatch — EPS tanks — Avionics — Storage volume — ECLS tanks — Propulsion Tanks

PLS configuration - Biconic A

Dry weight	15 337
Inert weight	18 628
Gross weight	23 023 lb
Surface area	666 ft^2
Volume	1 295 ft^3

2 crew, 8 passengers

19.5 ft

12.0 ft

Plan View
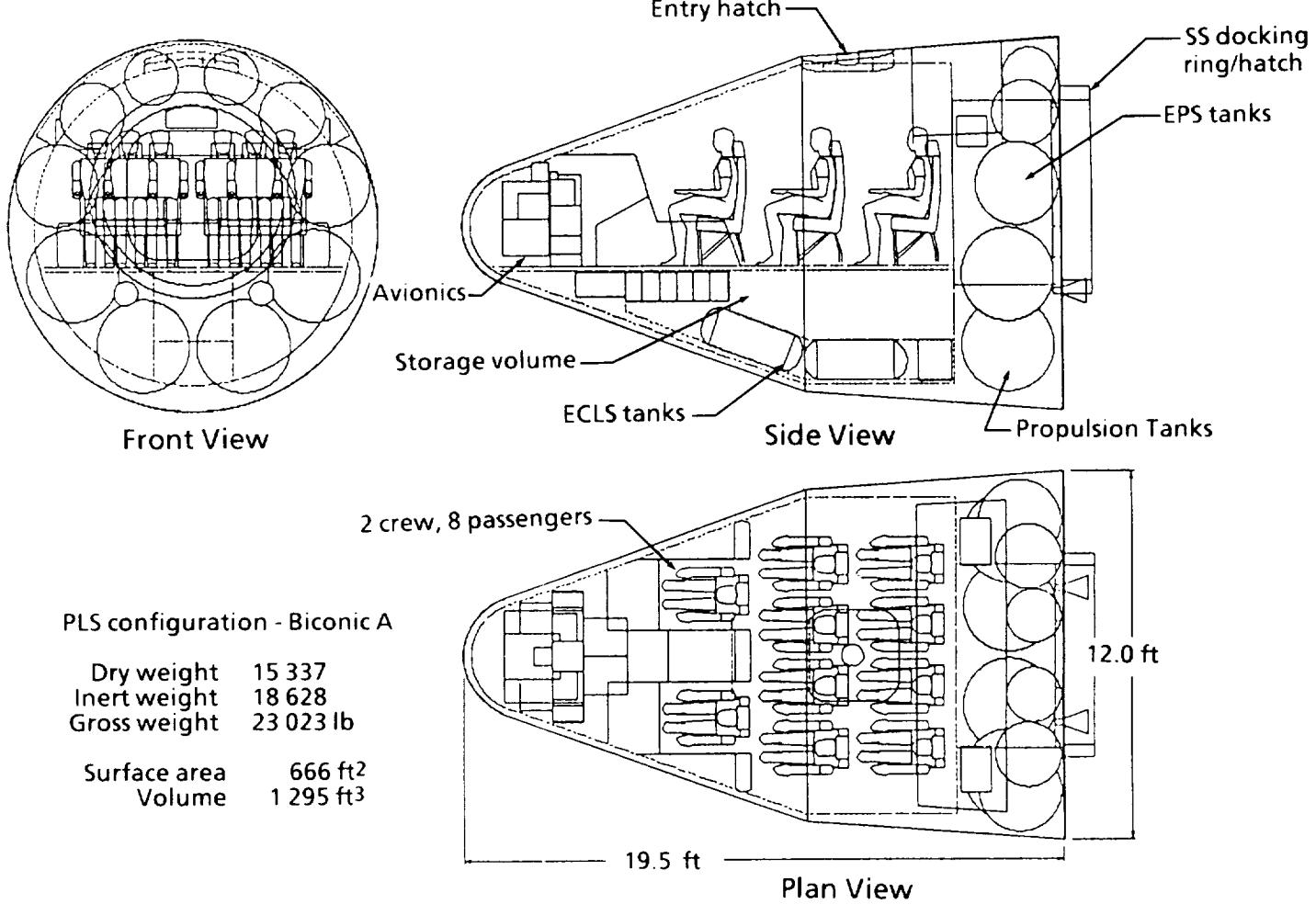
Personnel launch system.

Integrated Flight Control and Training Process

PI: Marilyn W. Kimball/DC46
Reference STT 12

The Shuttle Mission Training Facility is the main facility used to train crewmembers and flight controllers. The redesign and upgrade of this facility is being considered. Thus, the current consoles and displays for the Shuttle Mission Simulator (SMS) operators and instructors will probably be replaced with distributed engineering workstations. Changing from a mainframe system to distributed engineering workstations would necessitate a complete change in training facility operations and an entirely new set of user requirements.

User requirements and associated human/computer interfaces often lack precise definition. This results in delivered systems which fail to meet desired objectives or user expectations. Imprecise requirement definitions result in numerous modifications and upgrades to operational systems. This is inefficient and costly. Applying a "requirements prototyping" process to define user requirements can significantly improve the current process. Requirements traditionally are derived through paper-intensive brainstorming sessions. With the prototyping process, however, the quality of the delivered system should be improved (i.e., more fully meet the needs of the user community) and total life cycle costs should be reduced.

The Mission Operations and Mission Support Directorates have joined forces to sponsor this new process – requirements prototyping – to define user requirements. Requirements prototyping involves in-depth task analyses, system modeling, iterative sessions of rapid prototyping combined with user evaluations, and a team approach involving users and developers.

The near-term (Fiscal Year 1989/1990) (FY 1989/1990)) goal is to define the requirements for a workstation-based instructor/operator environment. Defining users' functional requirements and related human computer interfaces will be emphasized. Functional requirements will be the first product derived from this process. The prototype will be delivered later to the development community along with detailed requirements which have been tested and validated by the users.

The long-term goal (FY 1990/1991) is to make some of the displays functional, using real-time data. This would provide proof-of-concept for a workstation-operated SMS facility.

Thus far, contacts with all elements of the user community have been established, and these elements have worked together to analyze the various components of their tasks. Based on this analysis, the prototyping team created multiple displays for the users to evaluate. The displays were refined and enhanced according to user comments. A second round of analyses, prototype building, evaluation, and enhancement has taken place. This process will be repeated until a comprehensive set of user (human/computer interface) requirements is defined.

Some issues addressed in the prototype are: logging into the system, system headers, window management, menus, menu editor, message system, graphical displays, malfunction entry using several formats, and crew cockpit displays. Efforts are now underway to port applications developed for the flight controllers into the prototype. This will show the training community what can be done in distributed workstations and what types of applications will be available to them.

The figure represents one type of display which is being evaluated for the workstation-based instructor/operator training environment. Schematics can be used to view component interfaces and induce failures into the trainers.

?

Generic Graphics Panels Malfunctions

LT: 276/14: 20: 00

SMET: 000/00: 02: 00
SGMT: 276/19: 20: 00

Timer
01:00

? GPC 1 DPS Overview-ADP 1   Fire   Prev   IS05   Next   X

GPC 1

■ Fail to halt
■ Activate
☒ ICC 1
■ ICC 2
☒ ICC 3
■ ICC 4
■ ICC 5

DEU1 DEU2 DEU3 DEU4   MMU1 MMU2
DK1   DK2   DK3   DK4   MM1   MM2

DK1
DK2   MM1
DK3   MM2
DK4

Status
MMU1 BSY
MMU2 BSY

FF   M A L   FA   M A L   DDU   M A L

FC1 — PRI ☐   — Sec ☐   Port1 ☐   1
FC5 — Sec ☐   1   — PRI ☐   Port2 ☐
                                              Port3 ☐
                                              Port4 ☐

FC2 — PRI ☐   — Sec ☐
FC6 — Sec ☐   2   — PRI ☐   M A L
                                              Port1 ☐
                                              Port2 ☐   2
                                              Port3 ☐
                                              Port4 ☐

FC3 — PRI ☐   — Sec ☐
FC7 — Sec ☐   3   — PRI ☐

                                              M A L

FC4 — PRI ☐   — Sec ☐   Port1 ☐
FC8 — Sec ☐   4   — PRI ☐   Port2 ☐   3
                                              Port3 ☐
                                              Port4 ☐

PCMMU M A L

Port1 ☐
Port2 ☐   1
Port3 ☐
Port4 ☐
Port5 ☐

M A L

Port1 ☐
Port2 ☐
Port3 ☐   2
Port4 ☐
Port5 ☐
IP

PL1 — PRI ☐   — Sec ☐
PL2 — Sec ☐   PF1   — PRI ☐   PF2

SMS instructor menu.

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Surface Insulation Materials Studies

PI: G. D. Arndt/EE3
Reference STT 13

A Time-Domain Reflectivity (TDR) technique has been developed and applied to problem areas involving surface-insulating materials on the Orbiter and External Tank (ET). Problem areas include debonding of insulation material isolated areas on the ET, measurement of ice thickness or buildup on the ET's surface just prior to launch, and thermal tile debonding on the Orbiter's surface. The TDR technique, while not able to solve all of these problems due to their unique conditions, is an excellent tool for investigating irregularities or defects within insulation materials.

A TDR measurement sends a voltage step function down a transmission line and measures the reflected voltage waves from changes in the transmission line impedance or from a load. Discontinuities on the transmission path can be located and intuitively identified since the time measurement to an impedance discontinuity can be interpreted as a distance measurement. A diagram of the test setup is shown in the following figure.

The load impedance is the metal surface of the ET or the Orbiter. Discontinuities on the transmission line are the interfaces (layers) and/or defects in the insulation materials or tiles. The TDR method is inexpensive in that off-the-shelf laboratory equipment can be used to generate the sharp rise-time pulses required to resolve small imperfections. A 10 peco-second pulse was sufficient to resolve 1/16-in. defects. To minimize reflections from the test equipment, silver-plated copper rods with a specially designed balun were used.

Electromagnetic TDR rather than sound TDR was selected for use in the studies since microwaves are easily transmitted through insulation materials while sound waves are highly attenuated. However, these studies did have problems in that the dielectric constant of the insulation material was measured to be approximately that of free space – i.e., air bubbles beneath the material could not be seen. (The materials dielectric constant was not known by the manufacturer prior to these measurements.) It was also found that thin films of water on the ice surface shorted out the input voltage signal.

Ice/water measurements might use a laser system, perhaps with a blue-green output. This possibility has not been explored.

A theoretical study shows the same results as those performed in the lab on the insulation materials. Theoretical and experimental investigations are continuing into tile measurements and noninvasive techniques for launching the input pulse.
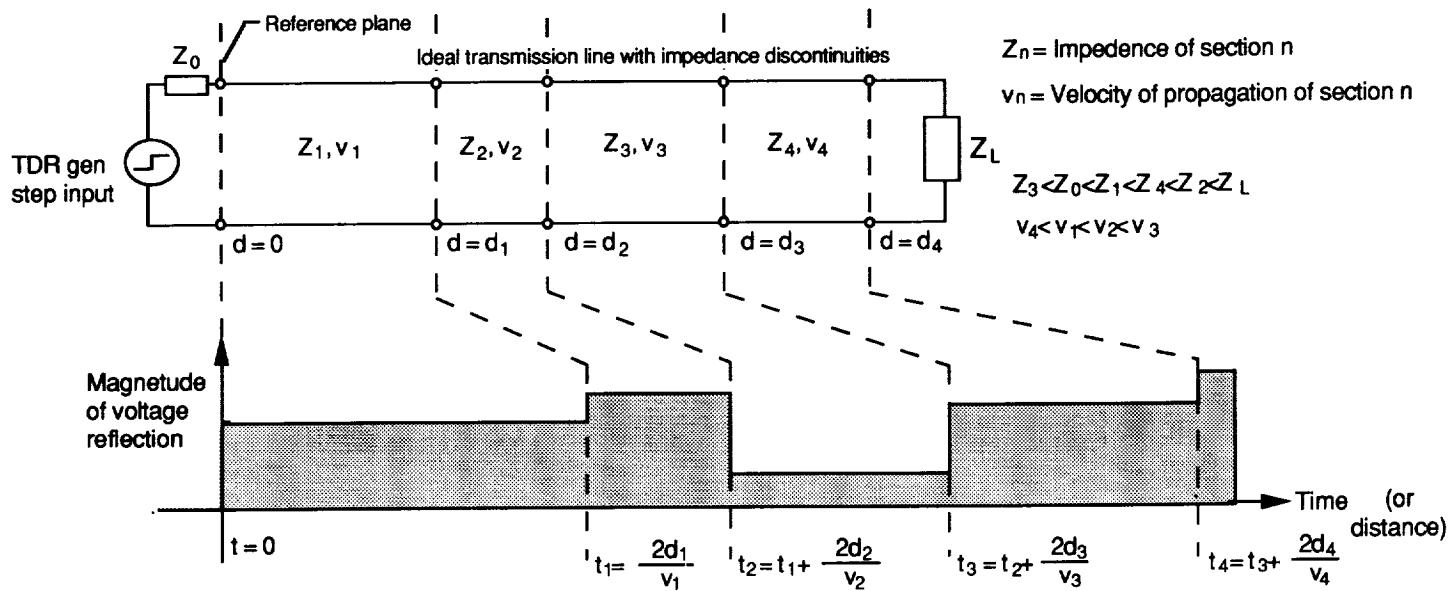

Diagram of test setup.

Wireless Infrared Data Acquisition System

PI: K. F. Dekome/EE6
Reference STT 14

The Wireless Infrared Data Acquisition System (WIRDAS) is being developed to be a simple and reliable means of interfacing a Personal Computer (PC) to remotely located devices. The link is established via a free-space transception of optical energy so cabling is not necessary. Light-Emitting Diodes (LEDs) are intensity-modulated with a digital bitstream propagating throughout the enclosed area of usage. Light-colored walls, ceilings, and floors are usually good reflectors of the infrared energy, and enough can be collected using short chains of cheap, wide acceptance angle photodiodes to maintain the link.

The hardware is being built in two versions to accommodate two anticipated general uses – transceiving serial commands and data at rates of up to 19.2 K-band, and monitoring of remote analog processes. The analog hardware is configurable at a total design throughput of 10,000 samples/second which can be employed all the way down to 1 channel sampled at the 10 kHz rate.

The base unit that interfaces with the PC host will be able to communicate through either a parallel/serial port or the reconstructed analog waveforms being input to a user-provided analog Input/Output (I/O) board residing in the host. These capabilities should offer maximum user flexibility and result in a spin-off of NASA-sponsored technology that will be readily accepted by the commercial sector. This hardware is being developed through the Johnson Space Center (JSC) Technology Utilization Office and is funded by Wilton Industries.

A receiver block diagram is shown in the following figure.
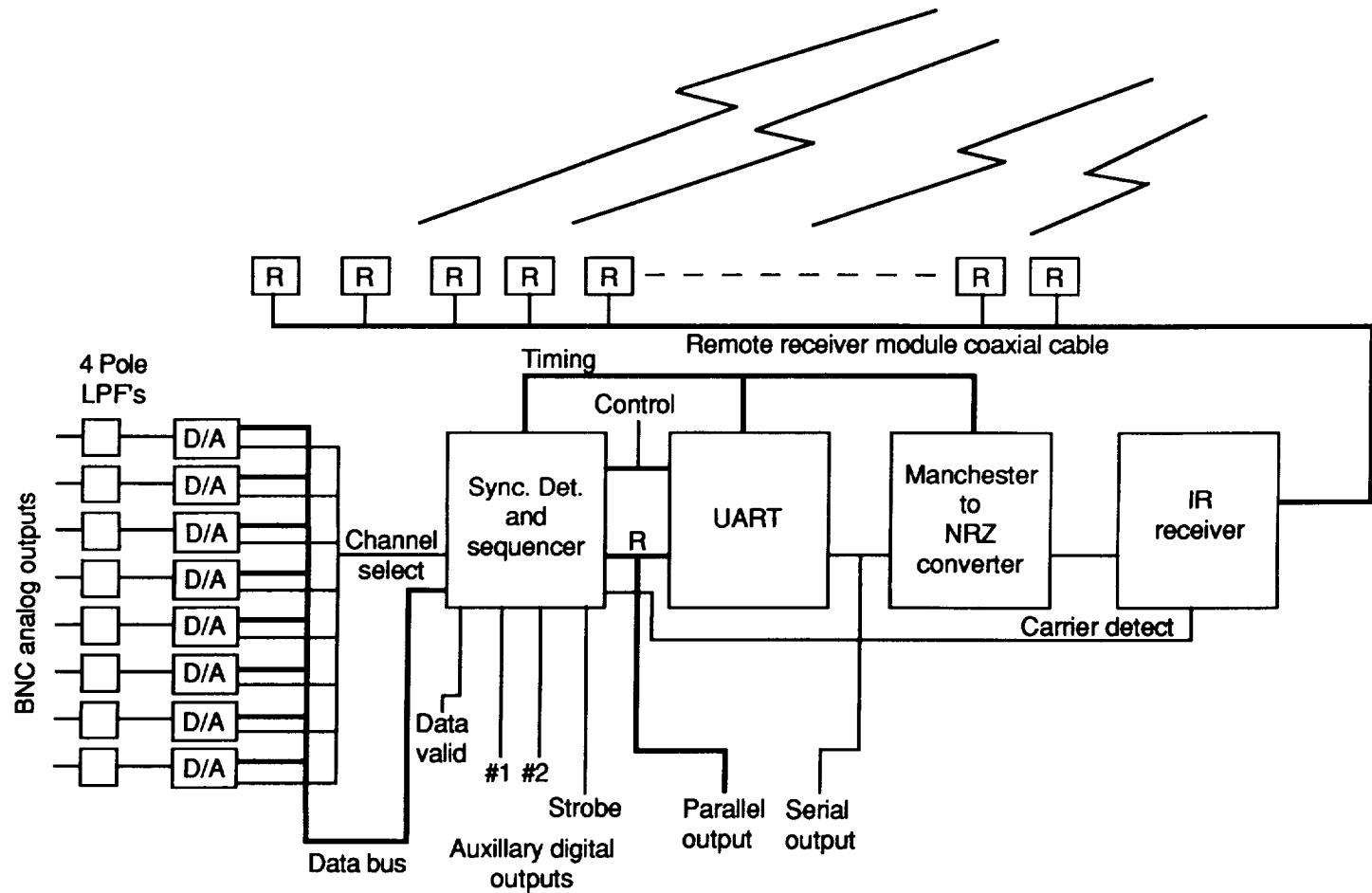
Receiver block diagram.

Surface Acoustic Wave Device for Wide-Angle Laser Scanning

PI: K. F. Dekome/EE6
Reference STT 15

As a means of developing non-mechanical hardware for steering laser beams quickly in space applications, a research and development activity investigated the applicability of using Surface Acoustic Wave (SAW) device technology. The SAW devices work by imposing a localized diffraction grating in an optical waveguide material through the peizo-electric effect.

The SAW causes periodic changes in the waveguide index of refraction, from which incident laser energy can be optimally deflected if Bragg angle constraints are met. The waveguide material employed was AlN which was grown on a silicon substrate. Metal electrode structures were deposited on top to form the launcher of the SAW. These integrated optic devices have inherently high bandwidths (1 to 3 GHz) and provide a more efficient means of coupling to laser sources than conventional types.

The possibility of using high-spatial frequency grating to deflect light out-of-plane of the waveguide – which would allow use as a two-dimensional scanner instead of a one-dimensional type – was also investigated. This work is being performed by APA Optics under a Phase I Small Business Innovation Research (SBIR) contract.

An experimental arrangement for demonstrating acousto-optic deflection in AlN thin film waveguides is demonstrated in the following figure.

Experimental arrangement for demonstrating acousto-optic deflection in A1N thin film waveguides.

Hierarchical Three-Dimensional and Doppler Imaging Ladar

PI: James C. Lamoreaux/EE6
Reference STT 16

Both manned and unmanned spacecraft require a tracking sensor to measure the relative position (azimuth, elevation, and range), attitude (roll, pitch, and yaw), and rates to another space object or landing site. Operations requiring this capability include robotic vision and space-borne target tracking for rendezvous and docking, remote manipulator and autonomous robotic operations, satellite servicing, proximity operations, and lunar/planetary landing. User spacecraft include the Shuttle, Space Station, Orbital Maneuvering Vehicle, robotic manipulators, free flyers, and Mars and lunar orbiters and landers.

The Hierarchical Three-Dimensional (3-D) and Doppler Imaging Ladar is a significantly improved imaging ladar which is being developed as a Small Business Innovation Research (SBIR) project. This 3-D mapper measures range, range rate (Doppler), and the reflectance of any object within the ladar's field of regard at each pixel position (instantaneous field of view). It achieves this with a programmable/adaptable scan capability patterned after the human eye which can point a fine resolution fovea (Narrow Field of View (NFOV)) to a region of primary interest, while providing lower resolution, peripheral vision (Wide Field of View (WFOV)) for simultaneous monitoring and avoidance of other objects. Both fine and coarse resolution regions can be independently placed anywhere within a ±20-deg field of regard. In addition to such high- and low-resolution capabilities, a Peripheral Mini-Gimbal (PMG) provides hemispherical coverage. Range and Doppler velocity information is vital for rendezvous, docking, and grappling maneuvers. and it can provide additional discriminators for object recognition.

Doppler Imagery could also be useful in identifying the rotation axis of a spinning satellite to aid with approach and grappling.

Phase I of the SBIR produced a working laboratory model that was successfully demonstrated in 1988. A prototype being developed in Phase II (its delivery is scheduled for September 1990) should be integrated with the Extravehicular Activity (EVA) Retriever or other robotic ground demonstration device.

The Hierarchical 3-D and Doppler Imaging Ladar is significantly improved over previous imagers in versatility, resolution, and speed. Principal system performance parameters are listed in the table. The figure below shows the physical configuration of the prototype system, including a removable handheld ladar for manned EVA.

SYSTEM PARAMETERS

CO_2 Ladar:	2 W, 10.6 micron, Heterodyne
Registered Imagery:	Range, velocity, intensity, visible video
Peripheral Scan:	Hemispherical coverage – PMG
Foveal Scan:	±20 deg WFOV/NFOV
Angular Resolution	0.5 to 12.5 mrad
Transmitter Waveform	CW, AM, FM, AM/FM
Maximum Range:	3000 ft: Skin targets, NFOV
	100 n. mi.: 3-in. retroreflector
Pixel Format:	1 Hz to 100 kHz $(1024)^2$ programmable
System Controller:	Transputer network (12)
Sensor Head Size:	1 ft^3
Electronics Size:	19-in. rack, 10 in. high
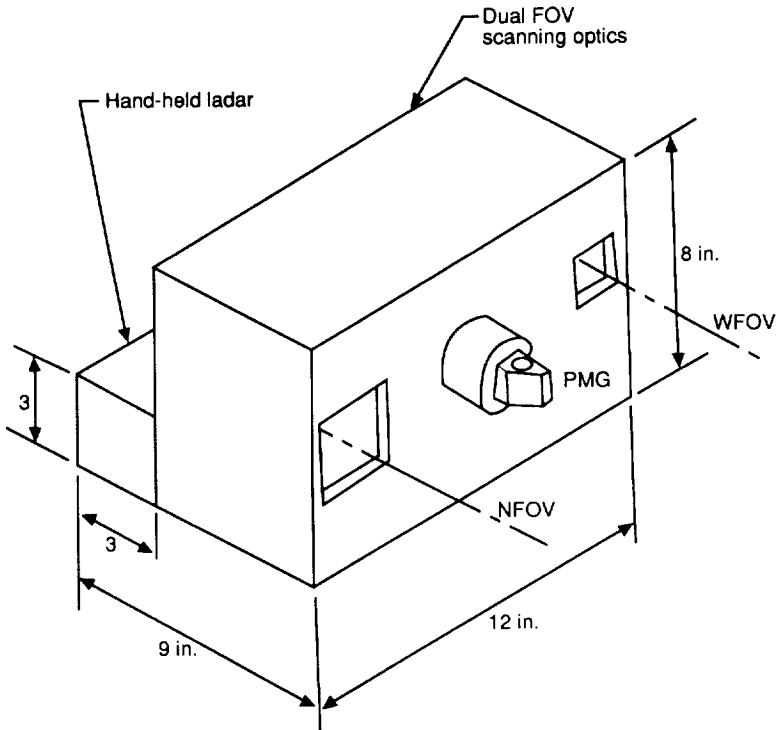
Prototype 3-D range/Doppler imaging ladar.

Docking Aids

PI: Richard D. Juday/EE6
Reference STT 17

Simulations performed in the Shuttle Avionics Laboratory (SAIL) show an incipient problem in docking the Shuttle and Space Station. Stacked translation dispersions at time of contact will require a 1-ft capture radius ability of the docking ports. A substantial reduction in cost, weight, and volume (applying to each Shuttle flight to the Space Station) would result if the stacked dispersions could be brought down to a 6-in. capture radius. A straightforward approach to the problem is to use a port-mounted Television (TV) camera with a Cathode Ray Tube (CRT) display to the crewmember doing the docking. However, the crew wants a backup method.

Thus, the Tracking Techniques Branch has proposed several alternative docking target methods. They are: (1) a coherent fiber-optic imaging bundle; (2) moiré reticles, one mounted on the Space Station and the other replacing the Crew Optical Alignment Sight (COAS); and (3) carefully determined laser beams and indicial marks for them. The National Space Transportation System (NSTS) Integration Office is funding the development of all three methods.

A 4-degree-of-freedom, full-scale motion base simulator has been constructed, the only such in existence for simulated docking. This simulator is adequate without being over engineered. Three axes of translation are achieved by crossed rails and the elevation crank on a camera tripod mount. One axis of rotation is achieved by a power seat drive mechanism from a 1965 Buick.

The simulator is voice activated; e.g., the operator commands "Forward!" and the assistant pushes the carriage in the appropriate direction. The simulator carries all four methods of docking alignment – i.e., moiré reticles, a TV camera, laser beams, and an imaging fiber-optic bundle. Operational parameters are being refined by its use – among them base frequencies and chirps in the moiré reticles; number and size of fibers in the coherent bundle; and distances over which each technique will work; to name a few.

Infrared Communications Flight Demonstration

PI: J. L. Prather/EE6
Reference STT 18

A proof-of-concept and evaluation experiment of an Infrared (IR) crew communications system successfully flew on Space Transportation System-26 (STS-26) in September 1988. This system was developed to provide better coverage and voice transmission than that available with the interim Radio Frequency (RF) system used on previous Orbiter flights and to provide secure communications without requiring an encryption device on crew-worn units.

Lower frequency RF systems can exhibit fading due to multipath interference within a conductive enclosure; e.g., a spacecraft. IR systems are virtually free of this phenomenon because of their extremely short wavelength (less than 1 λ). Susceptibility to electromagnetic interference, which can occur with RF systems, is also reduced. Secure onboard communications can be achieved by selecting IR wavelengths that will not pass through the spacecraft windows.

The IR crew communications system was provided as a middeck payload. The Johnson Space Center (JSC) task manager developed all requirements and specifications; procured and modified off-the-shelf hardware, generated and coordinated all documentation, test plans,

and procedures; arranged and chaired necessary design and program reviews; and coordinated all acceptance and qualification testing. The project provided valuable hands-on experience with flight hardware from conception to operational demonstration.

In Fiscal Year 1989 (FY 1989), onboard and downlinked voice tapes were analyzed and used in conjunction with crew interviews to determine system performance. Results were included in the final report. The hardware was also used for evaluations in the KC-135 as a candidate communications system.

A typical IR communications system crew unit is displayed in the figure below. This IR system, shown in use on STS-26, also appears in the following illustration.

IR communications system in use on STS-26.

Very lightweight headset —

Receiver modules —

Crew unit —

Receiver module

Transmitter modules —

Battery pack →
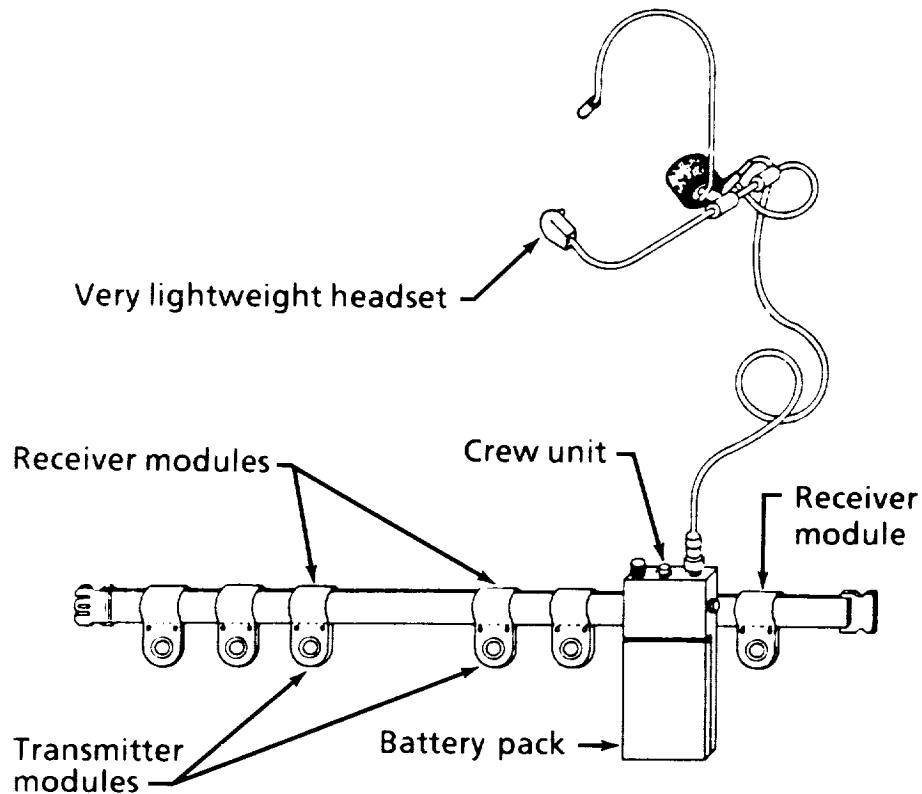
IR communications crew unit.

98

Automatic Fluid Interface Mechanism Evaluation

PI: John P. Masetta/EP4
Laura Louviere/EP4
Reference STT 19

A satellite requires propellant to maintain its orbit around Earth. Once the supply of propellant is exhausted, it is no longer a valuable spacecraft. By resupplying these satellites on orbit, they could continue to perform for many years. In 1982, the Johnson Space Center (JSC) initiated the Orbital Refueling Experiment (ORS) to demonstrate some satellite resupply tools and techniques. The ORS was used to demonstrate hydrazine propellant transfer in an orbital environment. But orbital refueling systems of the scale required for future satellites must be more sophisticated, and they will likely be automatic with electrical as well as fluid couplings.

The primary objective of the Automatic Fluid Interface Mechanism Evaluation was to functionally demonstrate prototype hardware that is under development for on-orbit servicing of satellites, evaluate the hardware designs, and provide test results to the Satellite Servicing Systems working group. A secondary objective was to evaluate systems that have been designed to improve operations with the Shuttle Remote Manipulator System (RMS). Testing was conducted with cooperation from the Manned Systems Division in the Manipulator Development Facility (MDF) and was based on simulated satellite servicing operations in the Shuttle payload bay.

Two types of prototype interface mechanisms were tested in the MDF. The first was the Remote Interface Mechanism (RIM) developed by Fairchild Space Company. It is a docking interface as well as a fluid and electrical automated coupling mechanism. The couplings are mounted internal to the docking structure, and engagement is accomplished through actuation of the docking mechanism. This test simulated using the RMS to maneuver the satellite to the tanker, which was located in the payload bay, and aligning the two halves of the RIM.

The second was the Automatic Umbilical Connector (AUC) developed by Moog, Space Products Division. It is an automated connector for both fluid and electrical couplings. The AUC differs from the RIM in that it is an automated coupling mechanism only. However, the AUC could be located in a docking structure or external to it. This test simulated using the RMS to maneuver the tanker half of the AUC to the satellite requiring service, which was located in the payload bay, and aligning it with the satellite half.

The systems evaluated that were designed to improve operations with the RMS include the Tracking and Reflecting Alignment Concept (TRAC) and the Magnetic End Effector (MEE), developed by the New Initiatives Office at JSC, and the Force Torque Sensor (FTS) developed by the Jet Propulsion Laboratory. The MEE, which replaced the RMS standard end effector for these tests, uses an electromagnet to grapple payloads to the RMS and includes two closed circuit television cameras that can be used for payload manipulation. The FTS is attached to the RMS between the MEE and RMS wrist joint and transmits forces and moments developed at the payload interface to a monitor located in the aft flight deck. The TRAC is a method of aligning two objects by projecting an image reflected from a mirror on the target through a video camera located on the payload to a monitor on the aft flight deck. TRAC was used by the RMS operator to align the interface mechanisms for these tests.

Testing was conducted by several crewmembers with a wide variety of experience on the RMS. Test results indicate that the on-orbit servicing of satellites could be accomplished using interface mechanisms based on the RIM and AUC prototype hardware concepts and further improved with the systems used to modify the RMS demonstrated in these tests. These results are being used by the Marshall Space Flight Center (MSFC) and their contractors in the development of the Automatic Fluid Interface Mechanism (AFIS) study. Additionally, comments from the RMS operators related to the MEE, FTS, and TRAC have been given to the New Initiatives Office so they may be considered for design changes to any of these systems.
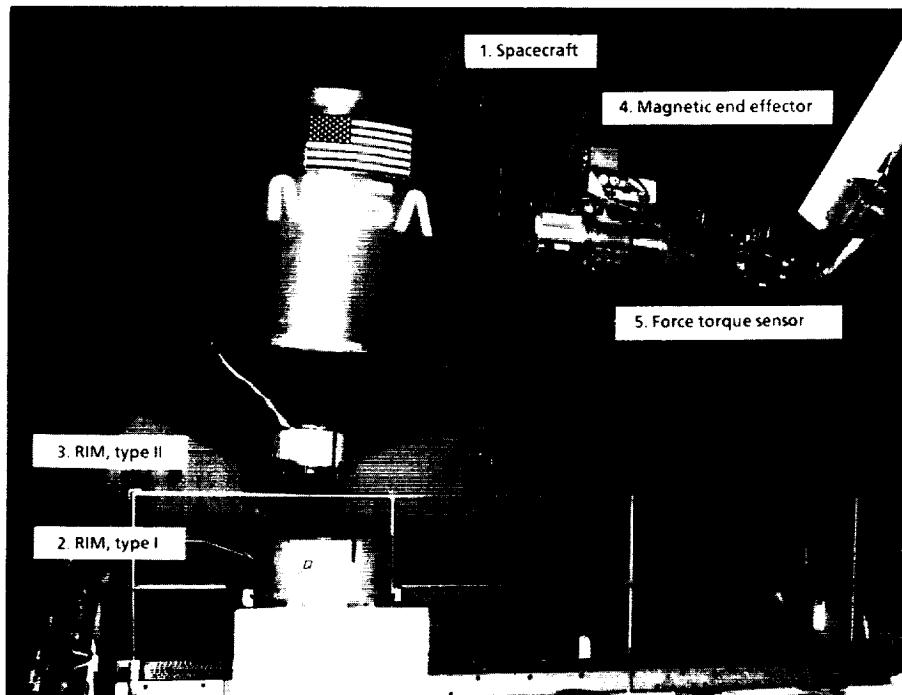
Automatic resupply system demonstration.
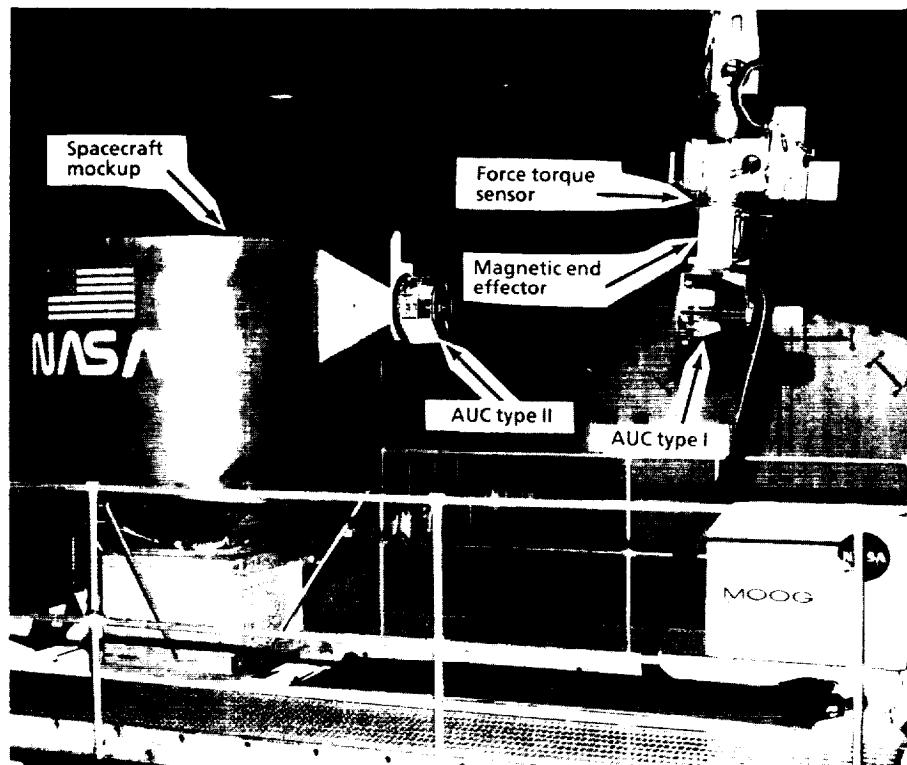
Automatic umbilical connector test setup.

Hydrazine Hazards Assessment

PI: Rex Delventhal/EP4
Reference STT 20

Hydrazine is a monopropellant used in a wide variety of jet aircraft and spacecraft applications. It has been used as a propellant for attitude control and orbit adjustment in satellites flown on the Space Shuttle. Hydrazine is used in the Space Shuttle Auxiliary Power Unit to drive hydraulic actuators and will be the propellant for reboost of the Space Station. Jet aircraft employ hydrazine as an auxiliary power source. Shuttle payloads that contain propulsion systems often select hydrazine for its simplicity and energy storage. Hydrazine is a colorless, toxic, corrosive, strongly reducing compound. In vapor form, it is flammable and detonable. Even though it is extensively used, only a limited amount of technical information which could be used in hazards assessments has been formally documented. In the past, users had to perform a detailed literature search of often unpublished information to determine important compatibility, reactivity, and explosive characteristics for hazard assessments. Even then, the available literature was often outdated.

A joint NASA Johnson Space Center/U.S. Air Force Space Division program was initiated at the White Sands Test Facility (WSTF) in Fiscal Year 1986 (FY 1986) to prepare a single reference manual that would characterize hydrazine and its hazards. To fulfill this objective, the WSTF conducted an extensive literature review and organized the data into a comprehensive manual. The WSTF then conducted tests in the areas where data was lacking. Detonation studies of neat hydrazine vapor and liquid, rapid compression studies in which liquid hydrazine is accelerated into an inert gas environment and then rapidly brought to rest, and material compatibility studies using an Accelerating Rate Calorimeter (ARC) have been performed. This information is included in the manual.

More than 100 requests have been received from the aerospace community for this 200-page reference manual entitled *Fire, Explosion, Compatibility, and Safety Hazards of Hydrazine*. Periodic updates to the manual will be made to add data from future material compatibility studies with the ARC and hydrazine vapor detonation studies with diluents and oxidizers. New issues such as the explosion characteristics of hypervelocity impacts on hydrazine vessels will also be discussed in these updates.

The WSTF program will proceed into similar assessments of liquid propellants used in the Space Transportation System. These will include monomethylhydrazine and nitrogen tetroxide, the propellants used in the Orbital Maneuvering System and the Reaction Control System.
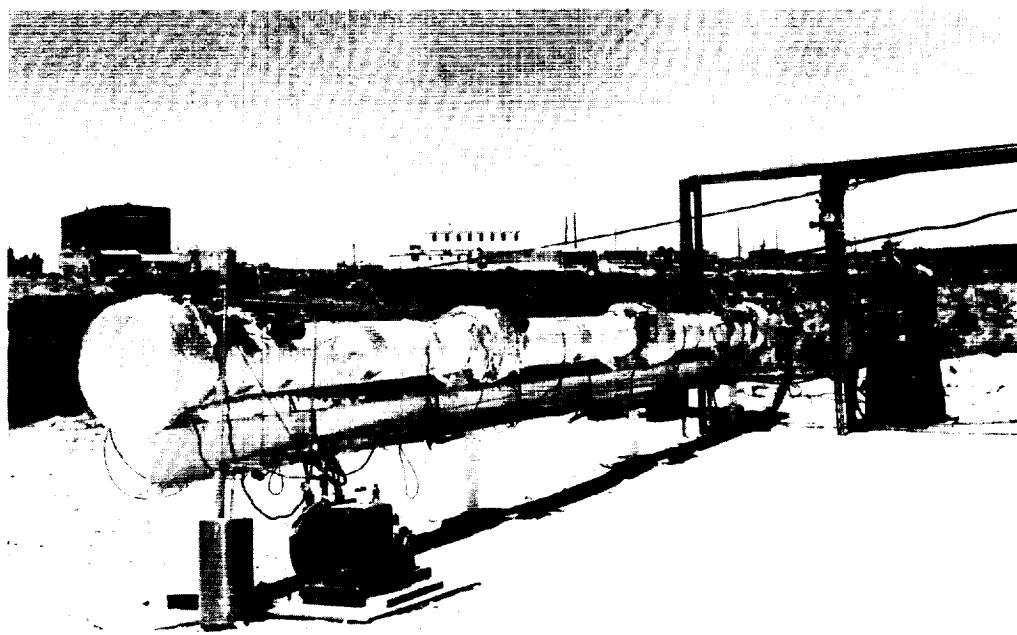
Shock tube used for vapor phase detonations studies at WSTF.

# Primary Remote Control System Direct Acting Valve

PI: Dennis L. Wells/EP4
Reference STT 21

This new valve design has the potential to increase the life expectancy of the Shuttle Primary Reaction Control System (RCS) thruster, reduce thruster cost as much as $200,000 per thruster, eliminate crevice corrosion and uncommanded opening, and reduce the occurrence of seal leakage.

An initial development phase of the Direct Acting Valve program has been completed. Eight of the 10 new prototype II valves were subjected to verification testing at the White Sands Test Facility (WSTF). The eight were mounted on four sea-level thrusters and test fired interactively on the aft RCS qualification test module.

The unique test firing profiles were designed to bring out any potentially damaging system interaction problems. Testing was successful in finding three unexpected problems: A fuel valve failed internally because its poppet locking mechanism was not engaged properly during assembly; two oxidizer valves experienced severe seal damage, indicative of zots (intra-injector explosions); and an apparent poppet instability (not to be confused with combustion instability) was caused by system line pressure surges. The planned life cycle testing using propellants has been suspended indefinitely.

The eight tested valves have been disassembled, and data analysis is being performed to understand and solve the problems experienced.
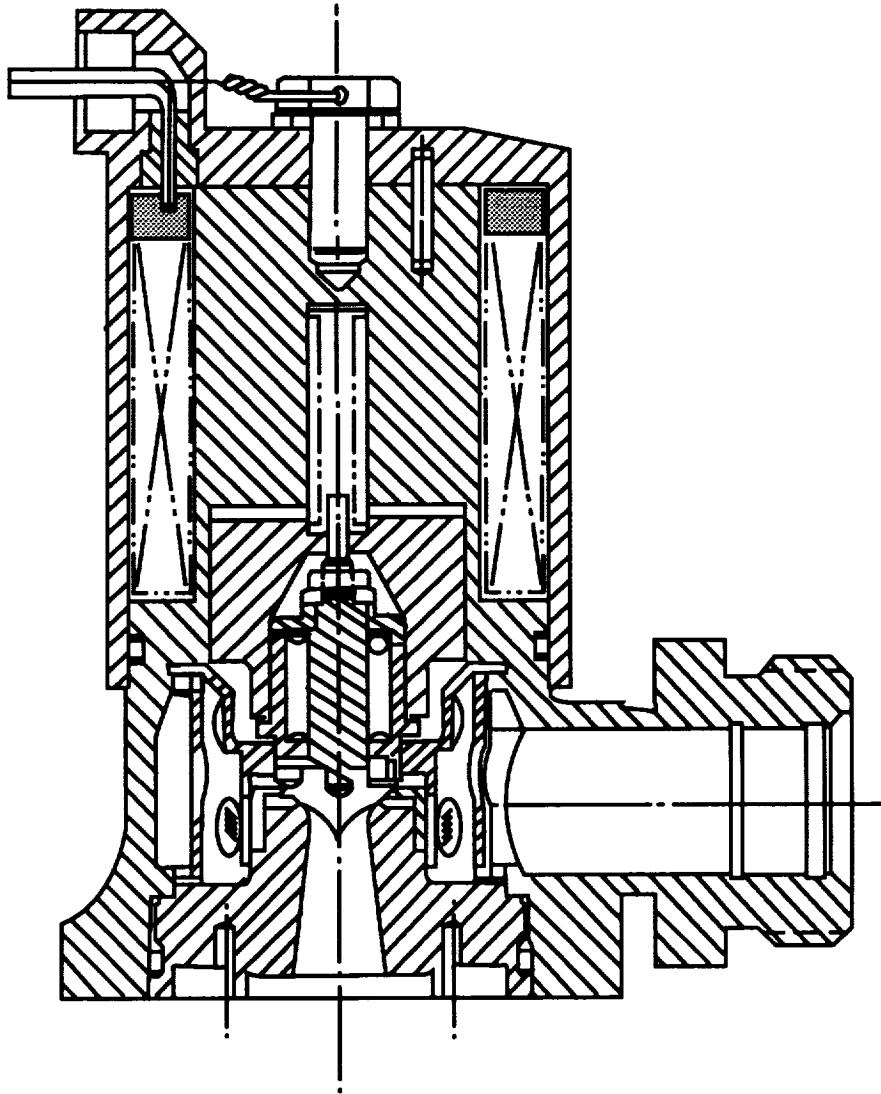
Direct acting valve.

Superfluid Helium Orbital Resupply Coupling

PI: Richard J. Schoenberg/EP4
Reference STT 22

Orbital consumables replenishment provides an attractive method for extending the useful life of today's costly and complex satellites and is a key part of the economical and practical commercial development of space. An important element which enables this replenishment capability is a coupling (quick disconnect) between a supply tanker and the receiving spacecraft to allow fluid transfer. The Johnson Space Center (JSC) is responsible for the development and application of orbital resupply technologies for both Earth-storable and cryogenic applications. Work is currently being done at JSC on the development of both Earth-storable and superfluid helium tankers.

The objective of this effort is to develop a coupling for the transfer of superfluid helium (He II) in zero-g. The coupling was designed for use on the Superfluid Helium On-Orbit Transfer (SHOOT) flight experiment. This flight experiment is managed by the Goddard Space Flight Center (GSFC) and is designed to simulate a satellite servicing operation.

The coupling is designed to minimize heat leak (under 1.0 W) to maximize the amount of fluid transferred. Owing to the supercryogenic nature of He II (temperature below 2 K), the coupling must isolate the cold inner portions from the ambient outer portions. The coupling incorporates the necessary redundancy features to comply with safety requirements for performing resupply operations in the Orbiter payload bay and at other on-orbit servicing locations and is readily modifiable for automatic operation. The coupling may be subsequently incorporated into He II flight systems such as the Superfluid Helium Tanker (SFHT), the Space Infrared Telescope Facility (SIRTF) and the Particle Astrophysics Magnetic Facility (ASTROMAG).

The effort in Fiscal Year 1989 (FY 1989) focused on a demonstration of the applicable technologies through the design, fabrication, and assembly of development-level hardware. Accomplishments during FY 1989 included testing of critical subassemblies such as thermal isolation jackets and the cryogenic seals. The majority of the parts required for the two development units were fabricated in FY 1989. Buildup of the ambient and cryogenic test facilities are nearly complete. Assembly of the first development unit was begun in FY 1989 and will continue into early FY 1990. Also accomplished was a series of tests performed in the Weightless Environment Training Facility (WETF) at JSC to aid in the coupling design from an Extravehicular Activity (EVA) standpoint and to investigate possible EVA scenarios.
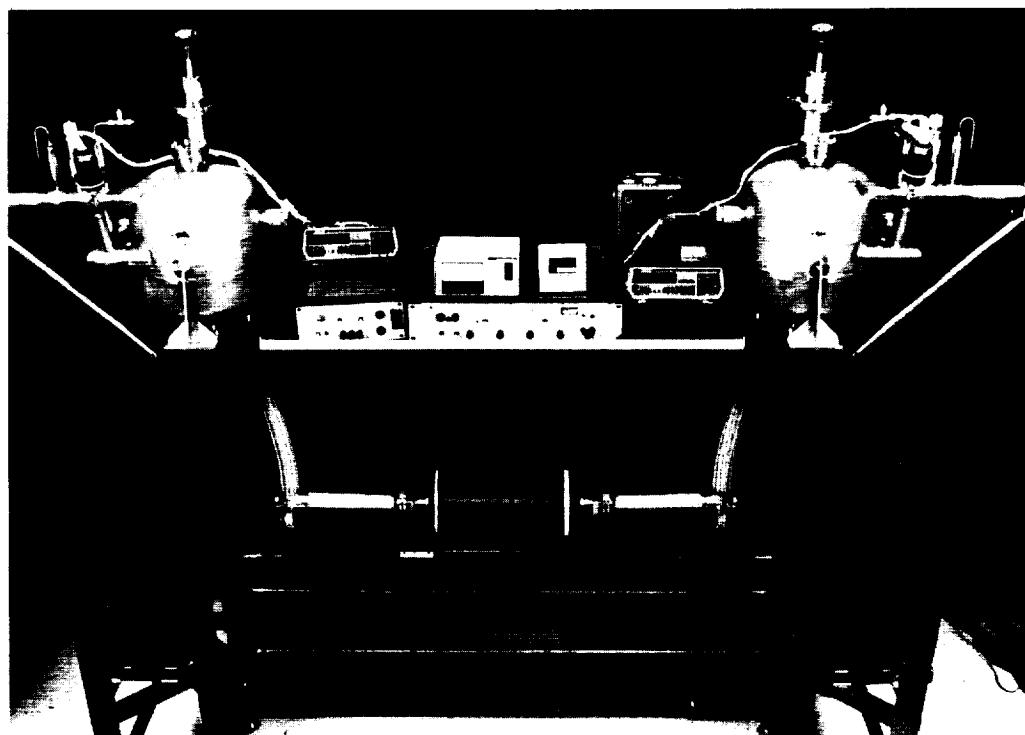
HE II coupling cryogenic test fixture shown with coupling simulator.

Uprated Orbital Maneuvering System Engine for Upper Stages

PI: William C. Boyd/EP4
Reference STT 23

The Space Shuttle Orbital Maneuvering System (OMS) is a pressure-fed propulsion system that utilizes the storable propellants nitrogen tetroxide (NTO) and monomethylhydrazine (MMH). An uprated pump-fed version of the OMS Engine (OME) can provide significant benefits for the National Space Transportation System (NSTS), including increased Shuttle Orbiter payload and altitude capability, and a high-performance, man-rated engine for upper stage applications.

The effect of the Uprated OME (UOME) is a significant increase in Shuttle mission manifesting and operational flexibility. The improved OMS performance increases Shuttle payload lift capability by up to 1300 lb. This type of increase significantly helps to regain much of the Shuttle lift capability lost due to recent hardware and operational modifications. It also provides positive lift margin to missions which currently have negative margins, including many of the defined Space Station element delivery missions and several Department of Defense (DOD) missions.

Alternately, by loading additional propellant into the excess OMS tankage made available by the higher engine performance, an increase in orbital altitude of 15 to 20 nautical miles can be achieved. If the UOME could have been made available for Hubble Space Telescope (HST) delivery, the additional altitude would delay the first required reboost mission by at least 2 years. For telescope reboost, the UOME effectively eliminates every other dedicated reboost mission, saving the cost of a total Shuttle mission.

As the latest state-of-the-art in pump-fed storable propellant rocket engines, the UOME has become a leading candidate for future space transfer vehicles and upper stages using NTO and MMH. Its thrust level of 6000 lb is near optimum for satellite delivery to Geosynchronous Earth Orbit (GEO), and its combustion chamber pressure of 350 lb/in^2 allows the use of conventional materials and cooling techniques, thus providing a high level of operational reliability. Many of the components of the engine are taken directly from the existing pressure-fed OME, while the remaining modified components utilize existing technologies to minimize engine development risk.

The objective of the UOME advanced development program is to conduct the analysis, design, fabrication, and test efforts necessary to demonstrate the performance and operational goals of a complete pump-fed version of the Space Shuttle OME. Predevelopment activities since Fiscal Year 1985 (FY 1985) have verified the performance capabilities of the critical components, including the turbopump, gas generator, main combustion chamber injector, and the regeneratively fuel-cooled combustion chamber. In FY 1989, these components were assembled into a complete engine which was successfully hot fired at ground-level environmental conditions. Designs were also finalized for additional components which will allow engine testing at simulated space vacuum conditions. These altitude tests are planned for March 1990 at the NASA White Sands Test Facility.
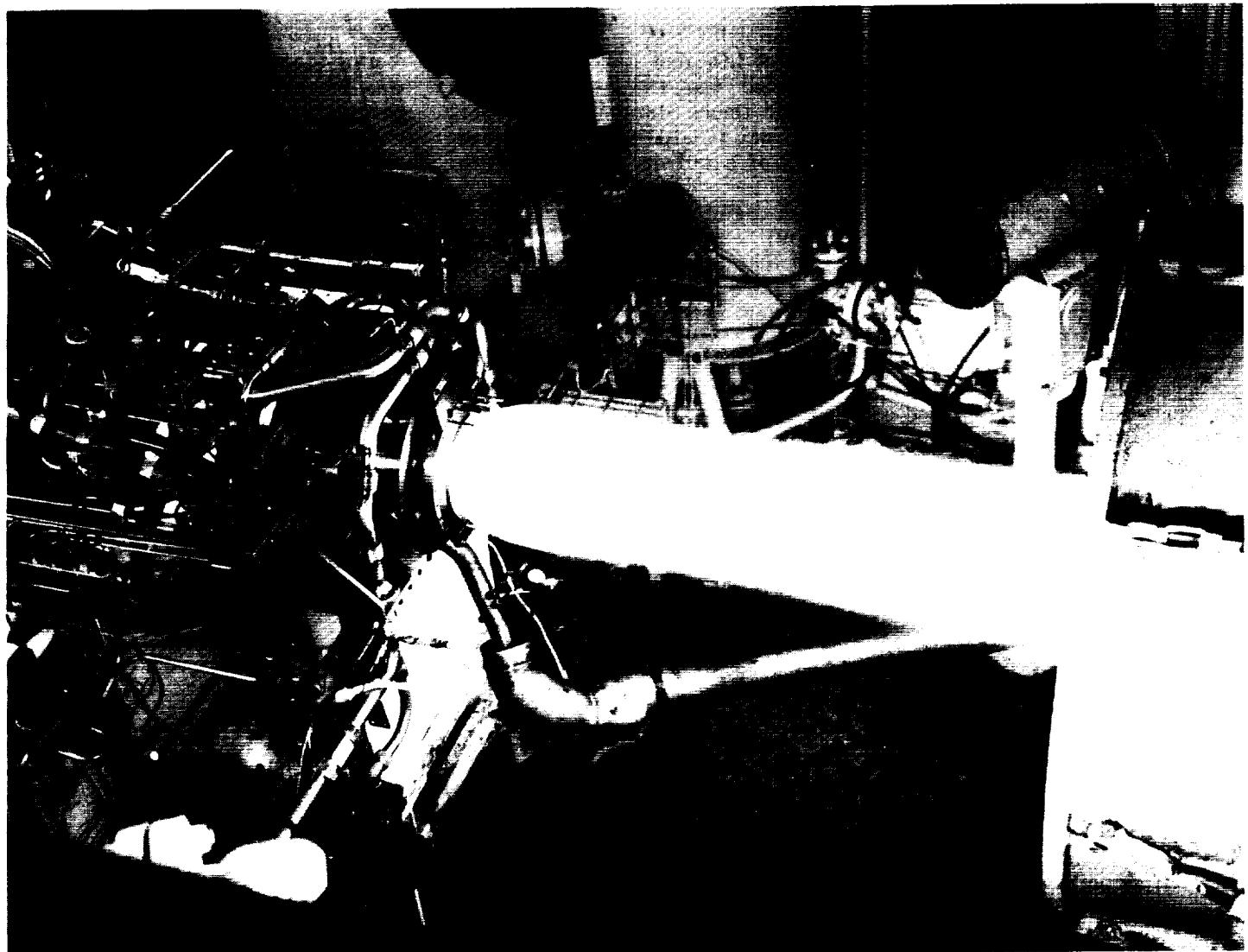
Sea-level test firing of the prototype uprated OME.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Zero-Gravity Gaging for Cryogenic Fluids

PI: Nancy E. Munoz/EP4
Reference STT 24

The routine, reliable, and safe handling of large quantities of subcritical cryogenic fluids, under conditions of low to zero-g, is essential to the resupply of future space-based systems such as an Orbital Transfer Vehicle (OTV). Cryogenic liquid oxygen (LO_2) and liquid hydrogen (LH_2) will be handled in large quantities on orbit for use as rocket propellants in a fully reusable space-based OTV propulsion stage for large payload mass delivery to geosynchronous Earth orbit and/or manned planetary missions. Technology areas critical to on-orbit management of these fluids include storage, thermal control, acquisition, transfer, and quantity gaging. Zero-g fluid quantity gaging is an essential element in an integrated gaging system for continuous monitoring of consumables, for determining resupply intervals, and for verification of fluid quantity transferred to or from the user. The Johnson Space Center (JSC) has been tasked to enable zero-g quantity gaging system technology, as it has been virtually nonexistent since the early 1970's. This activity will directly support a critical technology area for the on-orbit management of subcritical LO_2 and LH_2. The project is titled the Cryogenic On-Orbit Liquid Depot Storage, Acquisition, Transfer (COLDSAT), and it consists of a subscale experimental flight testbed to be manifested on an Expendable Launch Vehicle (ELV).

The objectives of the JSC activity are to develop a zero-g quantity gaging system capable of an accuracy to within 5 percent, for application to large oxygen and hydrogen tankage to support OTV resupply, and to deliver flight gaging system hardware for test verification in the COLDSAT. Under this contracted effort, analysis and trade studies were performed to assess candidate zero-g gaging concepts. The Radio Frequency (RF) Modal gaging system concept was determined to be the most promising concept which had the capability to achieve the required accuracy in zero-g. The design of the RF Modal gaging system concept, along with feasibility testing to identify potential problem areas and to determine the sensitivity of RF gaging to more realistic zero-g fluid behavior (multiple bubbles, and fluid along the tank walls) was accomplished in previous years' work. Data from subscale tests were used to develop a mass computational algorithm, which proved to be capable of predicting the mass of randomly placed wax blocks in a tank to within 2 percent.

In Fiscal Year 1989 (FY 1989), work proceeded toward developing a mode tracking and identification algorithm which would be required as input to the mass computational algorithm. A combined algorithm was pursued that would identify and track the proper modal frequency and, using this information, compute the mass inside the tank. The figure below illustrates the integrated algorithm math model. It took the full spectrum of modal responses that would be encountered in actually "sweeping" the tank with frequencies to determine loaded tank mass. Implementation of the math model to 36 test cases gave the accuracy performance histogram shown in the second figure. The results show that the integrated algorithm met the required accuracy.
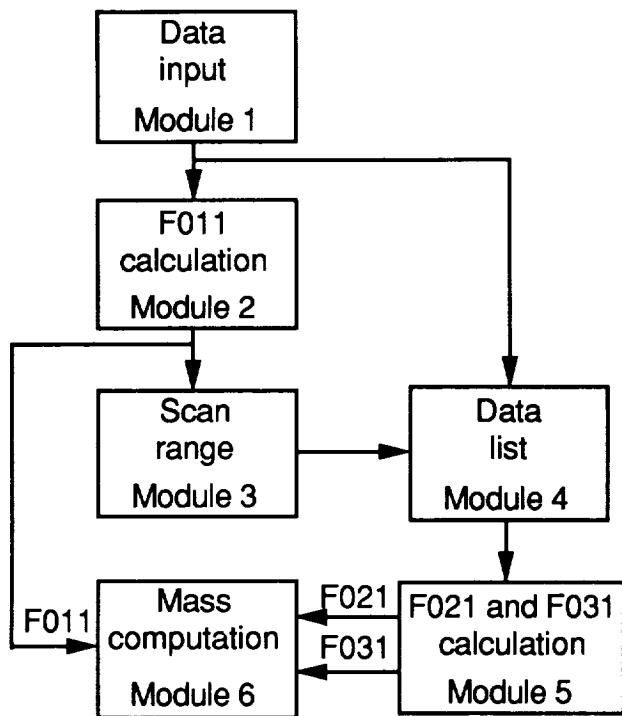
Module	Function
1	List all modal frequencies in 330 to 879 MHz range
2	Use first 3 modal frequencies to calculate F011
3	Use F011 to determine frequency range for F021 and F031 arrays
4	Sort list all modal frequencies into F021 and F031 arrays
5	Use array compression and final averaging rules to determine F021 and F031
6	Compute mass using F011, F021 and F031 in least squares curve fit equation and adding a correction

Integrated algorithm math model.
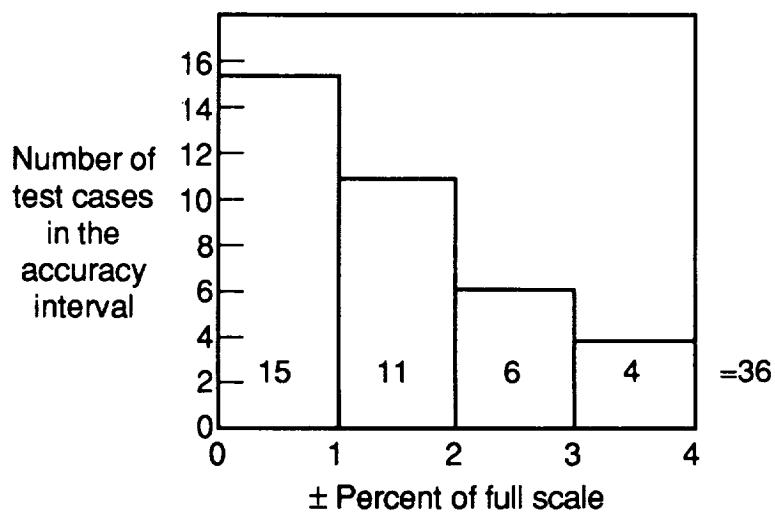
Math model accuracy.

Lunar-Based Propulsion System Analysis

PI: Chris Popp/EP4
Reference STT 25

For the mature lunar surface base, it is anticipated that lunar base independence from Earth-supplied materials will be a high priority. One way this can be achieved is to generate lunar-based propellant for lunar orbit/surface operations.

The objective of this study was to develop concepts for propulsion systems utilizing lunar surface materials for propellants. After conducting theoretical performance calculations for different lunar-derived propellants, aluminum and oxygen (fuel and oxidizer, respectively) were baselined as propellants.

A preliminary tradeoff analysis of candidate propulsion concepts resulted in two concepts being chosen for further conceptual development: an aluminum rod end-burner in a liquid oxygen bath, and an aluminum-liquid oxygen slurry.

Conceptual analysis and layout of these systems indicated that both systems are possible, although both have inherent design difficulties and safety hazards. For example, the aluminum rod end-burner may be difficult to cool (and maintain controlled combustion) owing to the high aluminum-oxygen combustion temperature, the high thermal conductivity of aluminum, and the decreased cooling capability of liquid oxygen under two-phase conditions. The aluminum-liquid oxygen slurry concept has inherent safety issues (because the fuel is suspended in the oxidizer media) as well as erosion and non-Newtonian fluid behavior concerns. Additional definition and analysis of these systems are ongoing.

<u>Typical</u>

Thrust = 12 500 lbf
Isp - 285 sec
OX FU ratio = 2.0
Chamber pressure = 200 psia
LOX flow rate = 29.3 lbm/sec
Aluminum burn rate = 0.039 in./sec
Total impulse = 12.3E6 lbf-sec

Typical thrust chamber cross section near wall

Thrust chamber wall
Regenerative cooling tubes (LOX)
Insulator
Aluminum rods
Rod diameter = 0.22 in.
Alternate hypergolic ignition system
6.08 in.
6.08 in.

Main LO₂ feedline

75.72 in.

Ignition fuel tube   Spark rod

Ignition system details

Regen cooling inlet

37.92 in.
126 in.
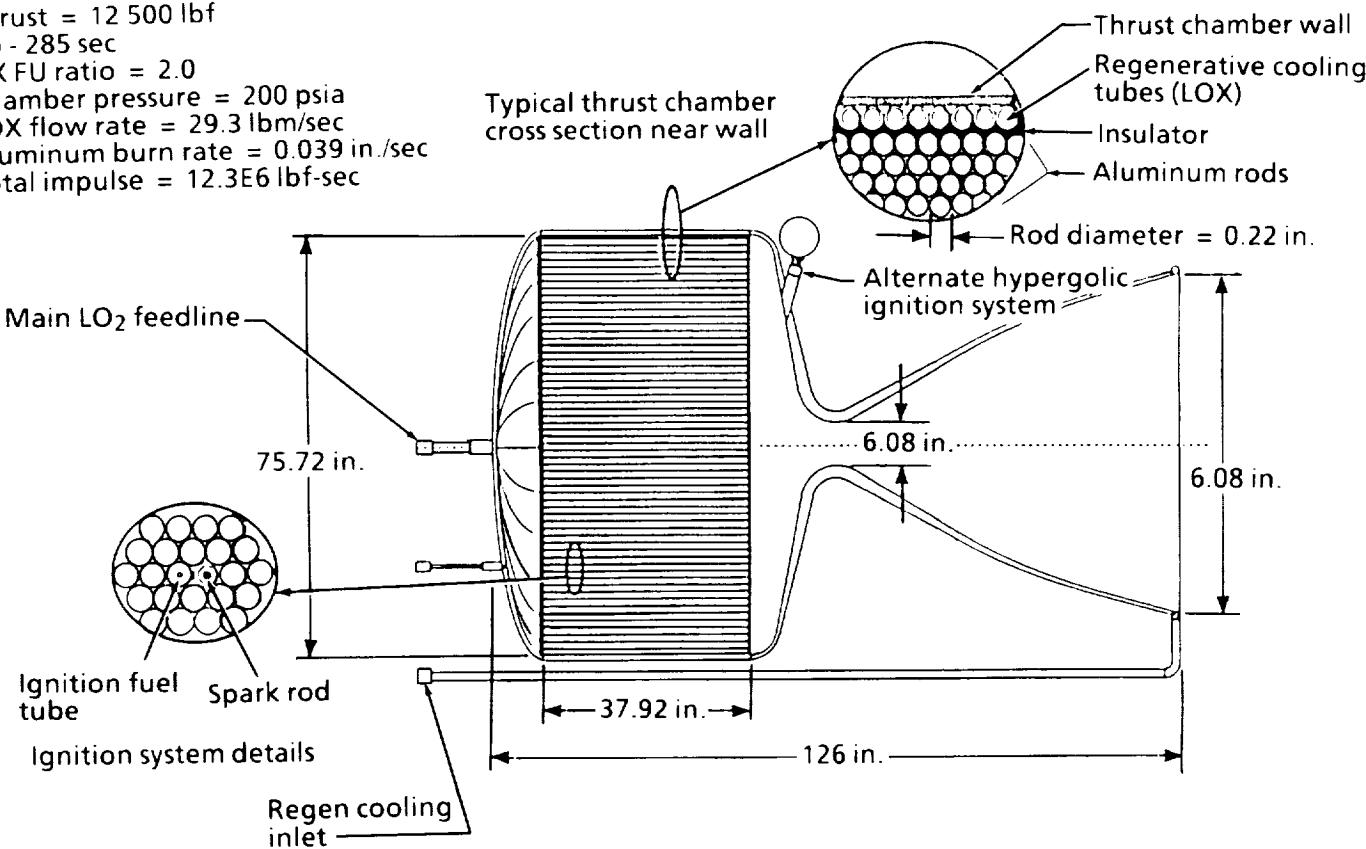
Lunar base propulsion systems.

108

4.86 in.

48.6 in.

To LOX
coolant tank

LOX regen
cooling

Like-doublet
pairs

7.7 in.

2.0 in.

Plumbing to primary tankage
Flow valves
Throttling valves

Ring grooves
Dome manifold
Ring manifolds
Radial and transverse passages

5 ft 7.40 in.
(67.4 in.)
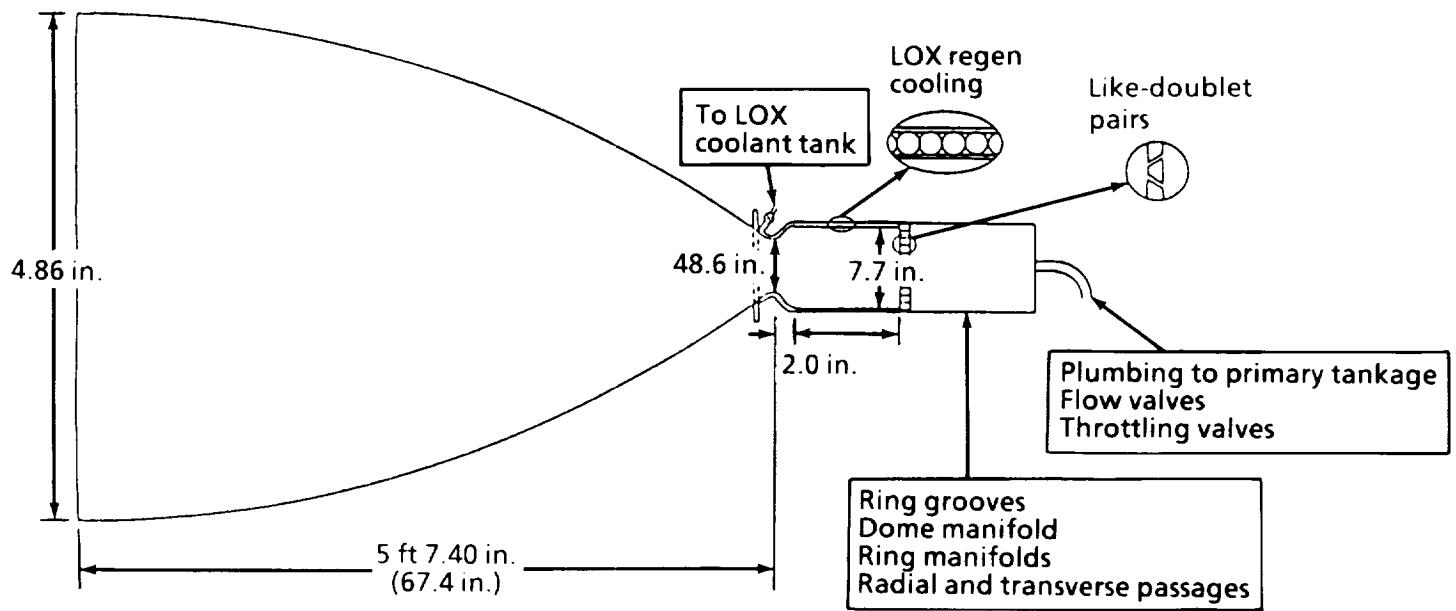
Pressure fed AL/LOX slurry engine
Isp = 285 sec (Theoretical ideal)
Isp = 263.1 sec (Delivered)
Thrust = 7500 lb
Pc = 200 psi
Expansion ratio = 100
Engine weight = 648 lb
Mixture ratio = 2.3 slurry, 2.1 average
Propellant flow rate = 28.5 lb/sec

Preliminary AL/LOX slurry engine concept.

Space Station Integration Propulsion Test Article

PI: John Applewhite/EP4
      Rex Delventhal/EP4
Reference STT 26

Space Station Freedom's operational requirements dictate the need for a long-life, high-efficiency propulsion system to provide impulse for orbital reboost and attitude control. Among the propulsion systems considered was a hydrogen/oxygen-based system that integrated the functions of propellants production, propellant storage, propellant distribution, and thrust production. The proposed gaseous hydrogen/gaseous oxygen (GH_2/GO_2) system utilizes high-pressure electrolysis of water, obtained from the Integrated Waste Fluid System and orbiter resupply, to produce gaseous hydrogen and oxygen. The propellants are then stored in high-pressure tanks at up to 3000 psia until thruster operation is required for stationkeeping activities.

The Integrated Propulsion Test Article (IPTA) was developed in-house by the Johnson Space Center's (JSC's) Power and Propulsion Division (PPD) in an effort to provide an early testbed for the evaluation of gaseous hydrogen and oxygen propulsion system concepts for use on the Space Station. Phase I testing was completed in March 1989 and successfully demonstrated the end-to-end operation of the integrated propulsion system.

In the Phase I configuration, water was electrolyzed at 3000 psia by a Hamilton Standard Oxygen Generation Plant (OGP). The gaseous propellants were then passed through desiccant dryers and conditioned to a -100 °F dewpoint prior to storage in spherical stainless steel tanks at pressures up to 3000 psia. The electronic, closed-loop control of the propellant mass flow and mixture ratio was accomplished using Marotta Electronic Variable Pressure Regulators (EVPR) in pressure regulation, allowing operation down to tank pressures approaching the regulator set pressure. Single engine pulse and steady-state operation was evaluated using a Rocketdyne 25 lbf thrust engine (1706 sec total burn time) and a Bell 50 lbf engine (76 sec). Successful variation of mixture ratio and control of propellant mass flow was demonstrated during tank balancing runs.

A significant portion of the Fiscal Year 1989 (FY 1989) effort went into reconfiguring the test article for Phase II testing, scheduled to begin in February 1990. Phase II IPTA will reflect evolving concepts for the GH_2/GO_2 Space Station propulsion system. A comprehensive test matrix will evaluate multiple-thruster operation under various mission duty cycles. A dual-pressure regulator, low-pressure propellant distribution system will also be evaluated. Propellant thermal condition capability to -130 °F will be a Phase II addition.

Electronically Variable Pressure Regulator

PI: Eric Hurlbert/EP4
Reference STT 27

The Johnson Space Center (JSC) is responsible for the development of a family of orbital tankers that can resupply orbiting spacecraft with propellants, gases, and other fluids. These tankers will operate from the Space Shuttle payload bay, from the Space Station, and while attached to unmanned vehicles, such as the Orbital Maneuvering Vehicle (OMV). One of the first in the family of tankers will be the Orbital Spacecraft Consumables Resupply System (OSCRS), which will be capable of resupplying hydrazine fuel and high-pressure gas to satellites, or water to the Space Station.

A key element of the design of systems such as OSCRS is to provide a means for pressure control. The primary requirement for this pressure control is the need to vary supply system set point pressures to tailor OSCRS to each system that OSCRS will resupply with fluids. In particular, careful control of feed system pressure is required to assure that fluid pressures and flow rates are within the limits of the system being serviced. The need to avoid harmful transients requires a ramp control of the pressure rise rate within the fluid system. Additional applications of OSCRS include its use on propulsion systems to set feed system pressures for propellant mixture ratio control, and for control of mass flow of gaseous oxygen and hydrogen for Space Station propulsion.

The program is complete. Two series-redundant prototypes were manufactured. The testing completed has shown that the concept is capable of regulating pressure. The design selected utilizes a ball poppet, positioned by a rotary-to-axial drive element, driven by a three-phase, eight-pole electrically commutated motor. The design minimizes the small orifices by using the single-stage design as opposed to piloted, which should improve resistance to propellant contamination failures. The electronic controller is an IBM-PC-comparable computer using a "canned" control software to control the regulated pressure from zero to 500 psia. This software allows real time changes to the PID control constants. The prototypes are currently being delivered to JSC, where additional testing will be conducted to evaluate performance.
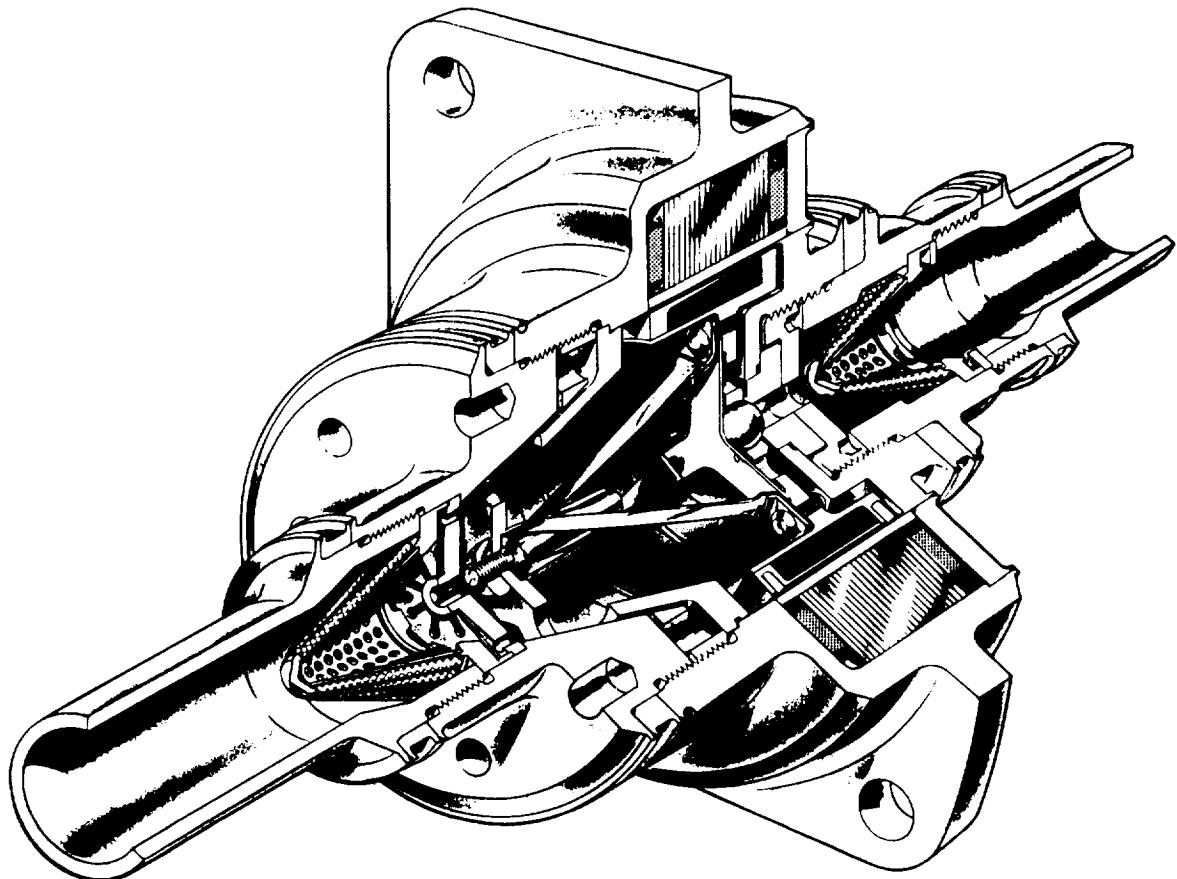
Electronically variable pressure regulator.

Magnetic Grapple Using the Force Torque Sensor and the Magnetic End Effector

PI: Leo Monford/IC
Reference STT 28

Future efforts involving deployment or erection of space structures, satellite servicing, and assembly and checkout of Space Station Freedom are heavily dependent upon telerobotic systems. Several problems, however, continue to plague current and projected Remote Manipulator Systems (RMSs). Lack of force feedback to the operator has precluded using the Shuttle RMS in constrained motion and prevents application of precise torques to an object being manipulated. In addition, the current RMS end effector is an extremely complex mechanical system, with numerous single point failures. The Johnson Space Center's (JSC's) New Initiatives Office, in cooperation with the Jet Propulsion Laboratory, is currently developing new end effector technology to help alleviate these long-standing problems.

Incorporating a Force Torque Sensor with a Magnetic End Effector (MEE) can virtually eliminate the mechanical limitations associated with the current Space Shuttle End Effector (and its numerous single-point failures). Forces and torques will be displayed graphically in real time to the RMS operator, allowing for significantly increased robotic dexterity. Payload capture and handling will be performed by an electromagnet rather than by mechanically "grasping" a grapple fixture protruding from the payload. Since electromagnets require no moving parts to develop their magnetic force, the reliability of such a system is very high, while servicing requirements are minimal. Additionally, one of the more significant side benefits of this system will be the elimination of the existing large-geometry, grapple fixture that must be attached to every payload. Instead, a small, light grapple plate will be used as a "target" for the MEE. This change will significantly reduce payload weight, size, and complexity.

Precision alignment capability will also be significantly increased with the use of a new alignment system (TRAC) being developed in conjunction with the MEE. This revolutionary system replaces an offset alignment target with a mirrored surface and cross hairs which the operator uses to align a tracking camera mounted in the centerline of the RMS. This system has demonstrated the capability to increase RMS alignment accuracy from $\pm$ 1 in. to $\pm$ −.05 in.

These new technologies have already been successfully test verified, using first-generation prototype hardware in JSC's Manipulation Development Facility, and it is anticipated that zero-g conditions will only enhance the dynamics of this new manipulation technique. A Space Shuttle flight experiment is currently being planned for the early 1990's to validate the concepts in space.

Considerable interest has been expressed in the advanced application of the MEE—especially in exploring the capability of transferring data, power, and perhaps fluids, using the MEE as an active interface. As a result, project efforts this year have gone well beyond development of advanced prototype hardware. Work continues in this area, which, when brought into operational service, will significantly expand current Space Shuttle telerobotic capability and set the standard for all future manipulator systems.

Force/torque sensing
system enhancing
RMS capabilities
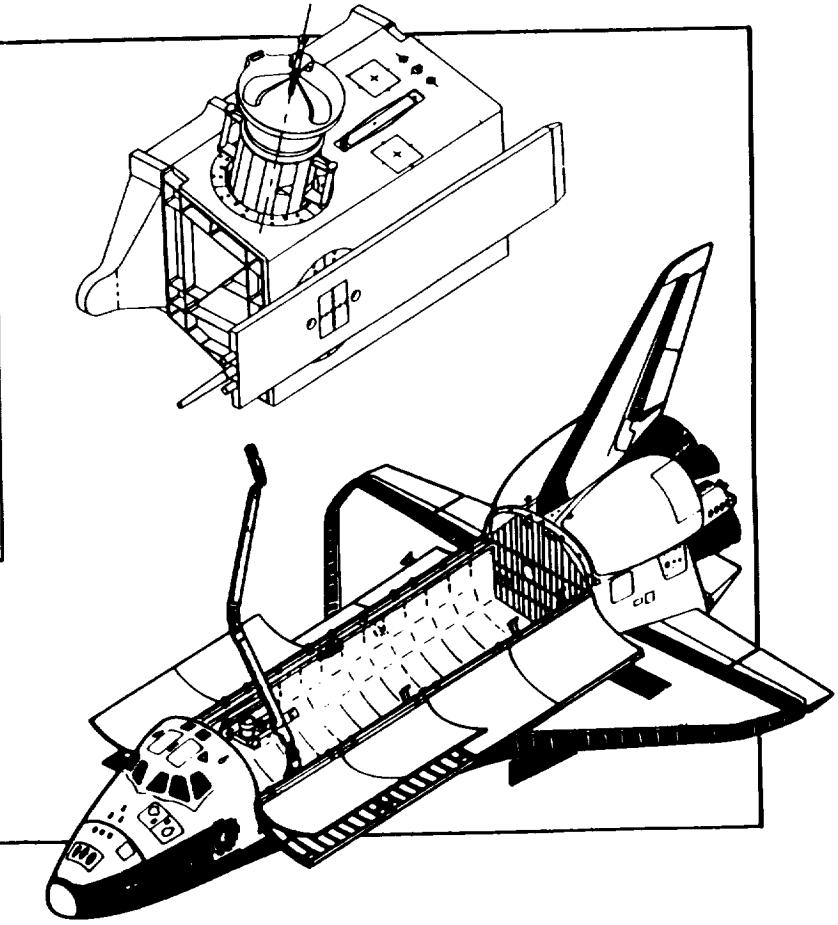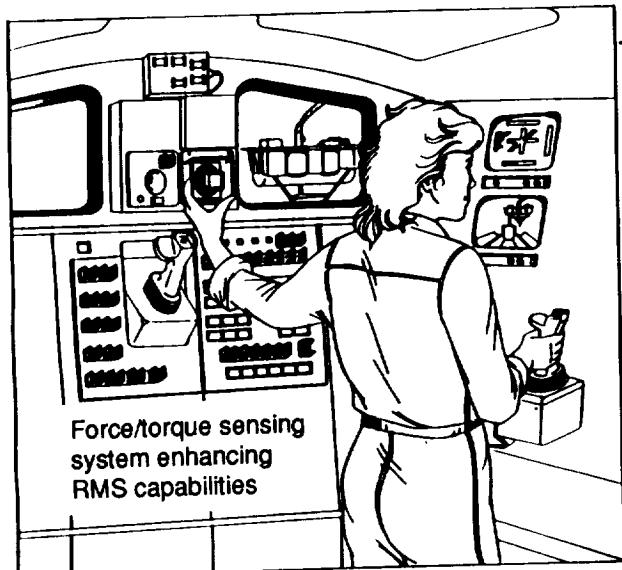
Dexterous end effector.

Space Systems Technology

Summary

Space Systems Technology

The Space Systems Technology section comprises eight technical areas, including Life Support, Space Station Extravehicular Activity, Human Factors/Man-Machine Engineering, Control and Guidance, Materials and Structures, Spaceflight Experiments, Automation and Robotics, and On-orbit Assembly and Construction.

These research and technology categories represent current Johnson Space Center (JSC) efforts, which are preparing avenues for NASA future programs and the new technologies they require. They support endeavors such as Space Station Freedom; Space Shuttle enhancement and evolution; Earth orbit operations; advanced space vehicles, both manned and unmanned; and Moon, Mars, and other interplanetary missions. Excellent progress in the year 1989 has been demonstrated in these JSC studies. They are summarized below.

In the area of Life Support research, a regenerative fuel cell promises to meet future high-demand requirements for increased specific energy density and power levels.

In the area of Extravehicular Activity (EVA) development for Space Station Freedom, several efforts are focused on humidity control, enhanced and extended space suit performance and flexibility, and improved space suit visors for eye protection.

Future manned vehicles and space station will require intelligent design of the interface between human beings and the machines or computers they employ. Several research areas demonstrated significant progress in this Human-Factors/Man-Machine engineering arena. Included are continuing research in human-computer interactions, merging human and intelligent systems for fault detection and diagnosis, a data collection system that does not intrude into a crewperson's physical activity, laundering and hair cleaning systems for use in weightlessness, and an innovative and efficient method of inventory control.

The realm of vehicle Flight Control and Guidance has long been a traditional discipline, but now it involves completely new applications; namely, the prediction of rarefied aerodynamics for Space Station Freedom, autonomous landing upon planetary surfaces, and a vehicle control design method that explores a new approach to assemble a controller out of discrete parts.

Since Space Station Freedom will be required to perform usefully over its 30-year lifetime, advances in Materials and Structures are needed. Research into long-life protectile coatings produced promising results in selecting candidate materials resistant to thermal fatigue.

Theoretical predictions and even ground test results do not always reflect actual performance of an engineering design. Thus, Space Flight Experiments are often valuable for validation of a system. Complex fluid interaction and behavior will be addressed in research flight experiments such as (1) pressure decay boiling experiments and (2) superfluid helium couplings investigations. These experiments respectively support applications in fluid management (1) onboard a space station or (2) during satellite refueling operations from the Space Shuttle.

Automation and Robotics continues to extend its research into advanced areas of more generalized ways of grasping objects, robotic vision, force and torque feedback control, and autonomous rendezvous and docking.

Lastly, and related to robotics, is research investigating robotic On-Orbit Assembly and Construction of a heat shield for a proposed aerobraking vehicle.

Space Systems Technology

Significant Tasks

Unitized Regenerative Fuel Cell

PI: Michael Pham/EP5
Reference SST 1

Power generation systems for spacecraft in the past have used hydrogen-oxygen fuel cells for relatively short-duration missions, such as Apollo or Shuttle. Projected requirements for future space missions emphasize the need for regenerative energy storage systems with high specific energy density at power levels of from 1 to 300 kW. Studies of various regenerative energy storage systems show the potential of fuel cell and electrolyzer technology for such applications.

Fuel cell and electrolyzer technology employ a fundamental "electrochemistry" concept. The term "electrochemistry" implies the use of devices that convert chemical energy into electrical energy (for fuel cells) and vice versa (for electrolyzers). These devices are usually composed of some number of individual cells that are connected together to form a dedicated fuel cell stack or a dedicated electrolyzer stack. The hydrogen-oxygen fuel cell and the electrolyzer both use a Proton-Exchange Membrane (PEM) as the sole electrolyte and have been under continuous development for over 30 years. They are both mature technologies, represented in numerous practical applications. Water is a light, chemically stable, non-corrosive liquid, and high current densities have been demonstrated in both electrolysis and fuel-cell-type devices. The conventional approach to regenerative systems is to have a dedicated electrolysis subsystem for recharging and a dedicated fuel cell power plant subsystem for electrical power generation. The advantage of dedicated subsystems is the ability to employ state-of-the-art components and designs. However, the state-of-the-art of the dedicated PEM hydrogen-oxygen regenerative fuel cell is not without disadvantages. In total, the dedicated hydrogen-oxygen regenerative fuel cell system would use in the range of 4 to 6 rotating devices, not including redundancy, to provide fluid transport and/or phase separation. Additionally, on the order of twice as many individual cells would be required for the fuel cell and the electrolyzer stacks. The complexity, in terms of dynamic components and the large part count, with double the number of cells, relegates the state-of-the-art dedicated regenerative fuel cell to a lower reliability than the unitized (reversible) system.

With complexity and lower reliability identified as major concerns in the hydrogen-oxygen regenerative fuel cells, manufacturers have begun to respond with a variety of approaches. A unitized regenerative fuel cell has been developed under NASA's sponsorship. Recent efforts have been aimed at testing and developing such a design. This design can improve reliability and reduce complexity, which further improves the mass advantage over dedicated systems. New technologies and developments include:

- Reversible PEM cell
- Passive fuel cell product water separation and removal
- Passive electrolyzer process water feeding
- Passive electrochemical gas pumping
- Passive heat management

The recent development of the aforementioned technologies has shown successful operation in ground testing. These testings have successfully demonstrated the viability of the unitized concept for regeneration fuel cell systems. Although passive fluid phase separation was successfully used in the Gemini and Biosatellite PEM fuel cell systems, none of the described simplified features has actually flown in space.

Under NASA sponsorship, a flight experiment of a unitized regenerative fuel cell is being studied. If selected for actual flight under the NASA Office of Aeronautics and Space Technology (OAST) Outreach program, several of these advanced features will be tested in space. The objective of the flight experiment is to test the space viability of the incorporated features. With a successful flight experiment supported by terrestrial experiments, the system designer can select the proven advanced system features that are appropriate for any particular extraterrestrial application.
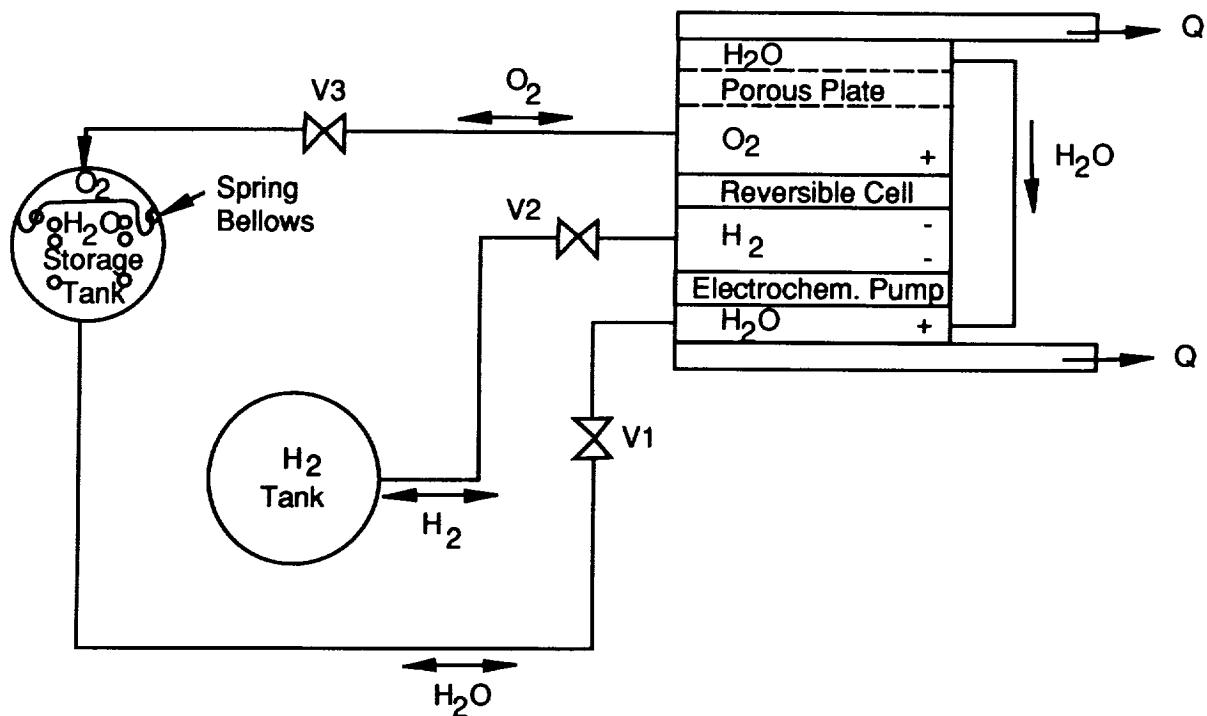
Unitized regenerative fuel cell system schematic.
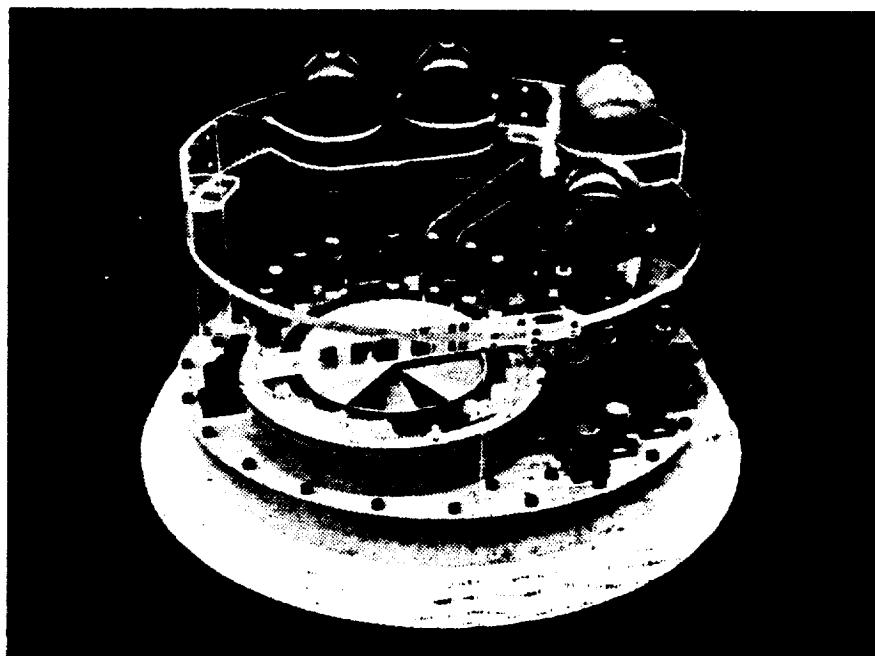
Unitized regenerative fuel cell mockup.

Humidity Control Via Membrane Separation for Advanced EMU application

PI: Mariann F. Brown/EC5
Reference SST 2

The humidity in the Extravehicular Mobility Unit (EMU) must be controlled to prevent fogging of the visor, to prevent water from accumulating and blocking the flow of air through the vent or from eventually corroding system components, and to keep the person inside comfortable and productive. The objective of this program was to design, construct, and test a breadboard module for controlling humidity with a membrane water-vapor separation technique for advanced EMU application. The membrane technology is being pursued for potential savings in weight, power, and volume over previously developed humidity control methods. The program started in April 1988 as a follow-on to a previous investigation of the same technology for cabin humidity control. The work was completed in February 1989. Tasks performed during the research included membrane screening, module configuration selection, and fabrication and testing of modules to meet the requirements for EMU humidity control.

The objective of membrane screening was to identify membranes that would minimize the size, weight, and energy consumption of the membrane-based dehumidification system. The type of membranes considered for the dehumidification process were Thin Film Composite (TFC) membranes. These consist of a very thin skin deposited on a porous support membrane (flat sheet or hollow fiber). The thin skin can be highly selective and allow high fluxes, but cannot support itself without the porous support membrane, which is optimized separately to minimize its resistance to flow.

After the membrane screening, selection of the type of module configuration (plate and frame, hollow fiber, or spiral-wound) was performed. Because of severe pressure-drop problems associated with hollow fiber and spiral-wound modules for gas separations, the late and frame module was superior from a performance point of view. During the course of the program, it was found that hollow fiber membranes could be made of much higher diameter than was previously possible, substantially decreasing the pressure drop. Because the hollow fiber module has a much higher membrane area to module volume ratio than the plate and frame module, the hollow fiber is the most practical configuration for the EMU application.

The hollow fiber membranes and the modules were optimized for the application, and breadboard modules were fabricated to meet the dehumidification requirements. The breadboard modules were tested under conditions expected to be present in the EMU. Long-term (90-day), parametric, and microbiological testing was performed. The modules showed reliable, long-term performance over the 90-day period. The testing indicated that a module containing 1 square meter of membrane area would meet the EMU dehumidification requirements.
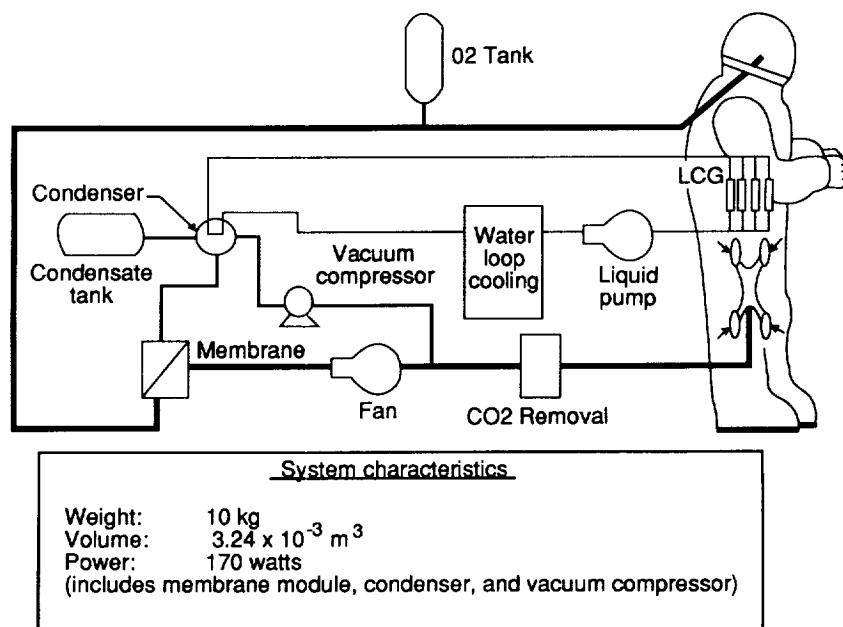
* Note: If venting of water vapor were allowed only the membrane and PLSS fan would be necessary

Schematic of PLSS with membrane-based dehumidification.

Advanced Extravehicular Activity Glove Development

PI: Joseph J. Kosmo/EC3
Reference SST 3

The challenge presented to glove designers is to preserve and maintain the unique functional aspects of the hand, while at the same time providing adequate physical protection worn by astronauts as part of their space suits when working outside the spacecraft. The EVA gloves must provide hand protection to maintain space suit oxygen pressure, to enable the astronaut to perform useful hand functions, and to protect against extravehicular (EV) environmental hazards. These requirements constitute capabilities for pressure retention, for load-bearing capacity (both man-induced loads and pressure loads), and for thermal, meteoroid/debris, chemical/propellant, abrasion, and puncture protection.

The current advanced glove designs represent a continuing level of evolutionary engineering efforts aimed at systematically improving higher operating pressure (8.3 psi) extravehicular activity (EVA) glove performance capabilities. The key glove performance issue becomes one of finding the proper balance between the basic protective requirement (i.e., EV environmental hazards) and the mobility performance requirement of the fundamental glove assembly. Gloved hand productivity for EVA requires a high degree of mobility, comfort, and tactility as well as safety assurance between the glove and the vacuum of space and with the EVA mobility task requirements.

Parallel task activities were continued for the design, development, and testing of prototype 8.3 psi EVA assemblies by David Clark Co. and ILC/Dover. A series of mobility joint elements is currently under development. Low torque finger joint elements consisting of both tucked fabric material construction features and a woven, link-net cord construction approach are being investigated. Design emphasis is being placed on the metacarpal joint area of the glove prototypes to provide overall functional performance capabilities for grasping activities. Both glove concepts incorporate a rolling convolute joint design for wrist mobility application.

A series of glove box fit check activities and Weightless Environment Test Facility (WETF), test and evaluation exercises were conducted using astronaut crewmembers. The phase IV glove effort represents the latest configuration, based on previous "lessons learned" during the various manned testing activities. The photograph shown below represents a current advanced technology 8.3 psi glove prototype currently planned for evaluation for use in the Space Station Program.

Prototype 8.3 psi glove assemblies developed by David Clark Co. and ILC/Dover have been delivered to NASA-JSC for preliminary test and evaluation activities. Follow-on design and development activities for enhancing the various glove mobility features are planned, based on results of the unmanned testing activities.
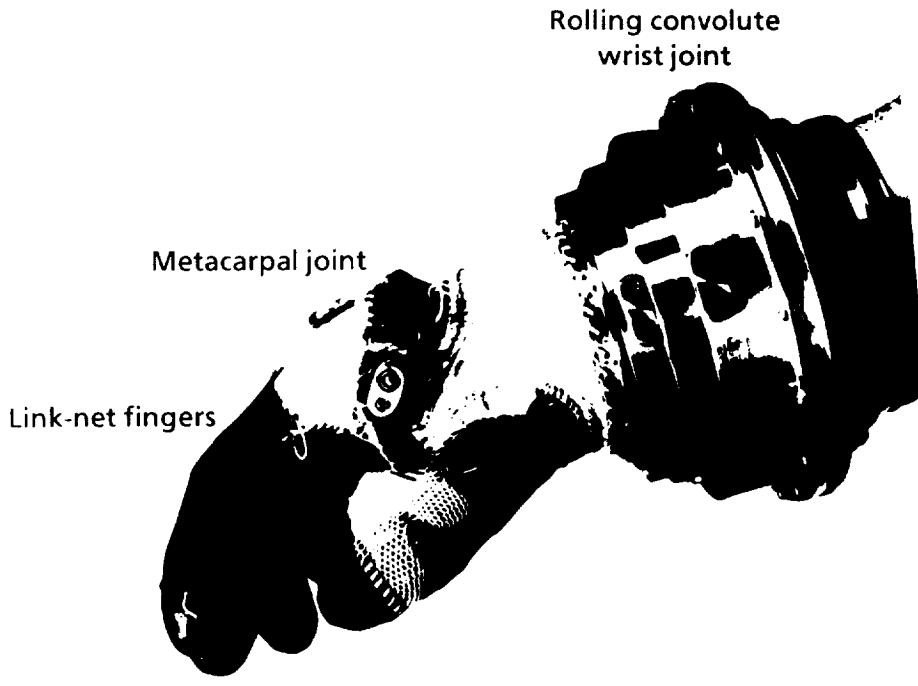
Prototype phase IV 8.3 PSI glove.

Space Suit Testing

PI: Philip R. West/EC3
Reference SST 4

The requirements for Extravehicular Activity (EVA) aboard the Space Station Freedom (SSF) have driven the design of new space suit technologies. The SSF EVA suit requirements include higher operating pressure (8.3 psi), on-orbit maintainability and size-ability, and rapid don/doff capability. Suit technologies that meet these requirements are represented in two space suits: The AX-5, developed at the Ames Research Center (ARC) and the Mark III, developed at the Johnson Space Center (JSC).

To select the best suit technologies from these candidates for the SSF application, information is necessary on all aspects of suit component performance. To this end, a comprehensive test and analysis program was designed. The pro-gram includes manned tests in the Weightless Environment Training Facility (WETF) and KC-135 aircraft, as well as a variety of unmanned tests and analyses.

In the WETF, EVA crewmembers experience simulated weightlessness, as their space suits are loaded with weights to achieve neutral buoyancy. Activities performed in the WETF include evaluations of mobility, reach, dynamometer exercises, and performance of EVA tasks. The dynamometer exercises measure the force transmission capability of various suit/subject combinations. This effort was expanded in 1989 to include exercises that subjects perform until they reach a predetermined level of fatigue. Metabolic energy expended is measured and compared to mechanical energy generated through the dynamometer. Various EVA tasks give the astronaut test subjects the best idea of how the suit tech-nologies would allow them to perform during an actual EVA. These include the truss assembly tasks that were flown as EVA flight experiments on STS 61-B in late 1985. Metabolic rate is measured during this activity as well.

In NASA's KC-135 aircraft, microgravity is simulated as the aircraft flies parabolic paths. Ease of donning and doffing the suit and hand-over-hand translation are evaluated in the KC-135.

The quantitative data from this manned testing is combined with subjective comments made during the tests to form the manned test database. Unmanned tests of suit joint torque, range, cycle life, and environmental protection characteristics are added to complete the database. This comprehensive test program will allow selection of the best space suit technologies for the SSF. A technology selection recommendation.is expected by the second quarter of fiscal 1990.

In addition to supporting this effort, the WETF reach and mobility evaluations should prove useful tools to aid EVA worksite designers plan foot restraint positions and task locations. The metabolic rate data will likely help designers of a self contained life support system currently under investigation at JSC for use in neutral buoyancy facilities.
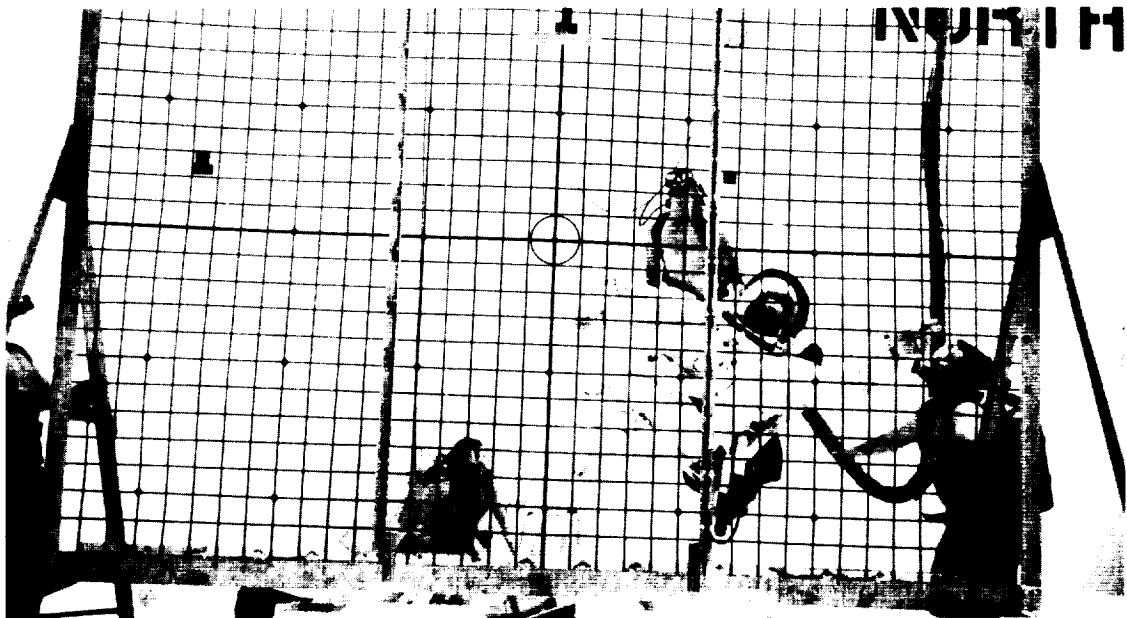

Figure 1.- A one-handed reach envelope is generated by this subject in the STS space suit. The STS suit is used as the baseline to which the AX-5 and Mark III technologies are compared.
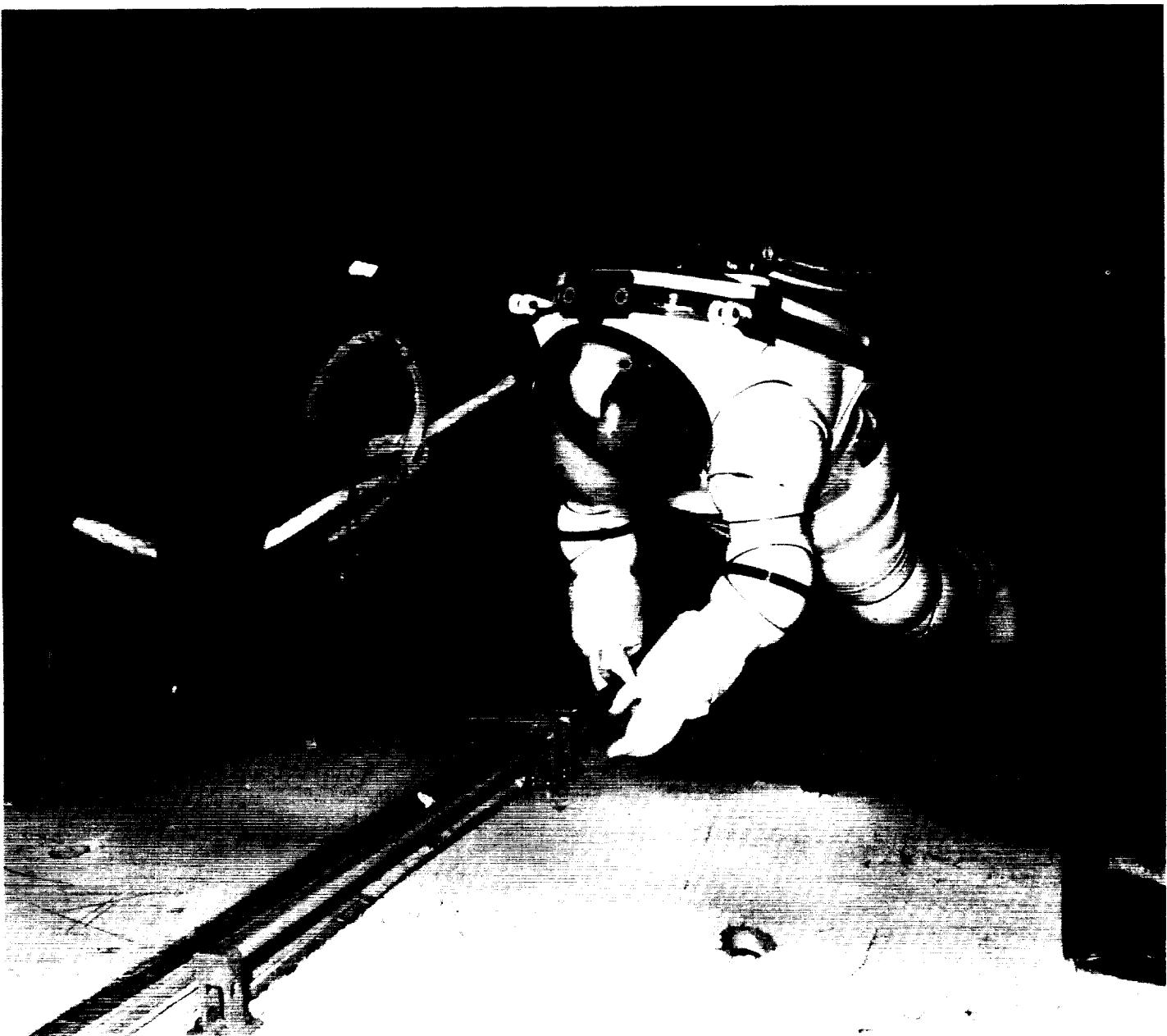
Figure 2.- A suited subject wearing the AX-5 space suit translates along a handrail in the simulated zero-gravity of the KC-135 aircraft.

Mark III 8.3 psi Space Suit Development

PI: Joseph J. Kosmo/EC3
Reference SST 5

The Mark III space suit represents an 8.3 psi technology demonstrator model of a zero-prebreathe suit currently being evaluated for use in the Space Station Freedom Program. The suit contains a series of high-mobility joint assemblies in the shoulder, elbow, waist, hip, knee, and ankle areas. The shoulder incorporates a two-bearing, rolling, convolute joint element that provides multi-axis motion. Single-axis, all-fabric flat-patterned joint systems are utilized for the elbow, knee, and ankle joints. Potential advantages of fabric joint elements in the arm and leg areas of the Mark III suit include wearer comfort, less-costly, simple construction features, and good mobility range.

A three-bearing hip assembly and a single-axis rolling convolute waist joint provide torso mobility. Sizing accommodations are provided by quick changeout sizing ring elements utilizing a wire cable attachment method. Donning and doffing of the Mark III suit are achieved through a vertical rear-entry closure. Various technology aspects of the Mark III suit are being pursued by the Space Shuttle Program in a design effort to upgrade the on-orbit operational performance characteristics and to enhance the mobility features of the current Shuttle space suit.

The Mark III suit, shown in the figure below, recently completed a series of test and analysis activities evaluating its operational and performance characteristics. The test program included both manned and unmanned evaluations. The manned activities were conducted in the Weightless Environment Training Facility (WETF) to access general suit mobility, range of motion and reach, maximum force transmission capabilities, translation, airlock and foot restraint ingress/egress, and simulated Extravehicular Activity (EVA) task operations. In addition, KC-135 aircraft zero-gravity tests were conducted to evaluate donning and doffing of the Mk. III suit, as well as reduced gravity translation mobility capabilities. Finally, unmanned mobility and torque range measurements were performed for individual suit mobility joint systems (shoulder, elbow, and knee). Unmanned component cycle verification tests are to be conducted to evaluate the functional performance of the elbow, knee, and shoulder joints for a predetermined number of cycles that the components would encounter during a year on orbit of Space Station EVA operations.

Meteoroid/debris protection and chemical/propellant protection are being evaluated, based on test and analysis of material sample lay-ups. Radiation and thermal protection characteristics of the Mark III suit are being assessed by analysis.

Currently, over 125 hours of man-testing activities while pressurized at 8.3 psi have been conducted with the Mark III suit at the Johnson Space Center. This includes 37 hours of walking treadmill activities in support of CO_2 helmet ventilation washout testing. In addition, approximately 48 hours of man-testing activities have been conducted in the WETF with various crewmember test subjects.
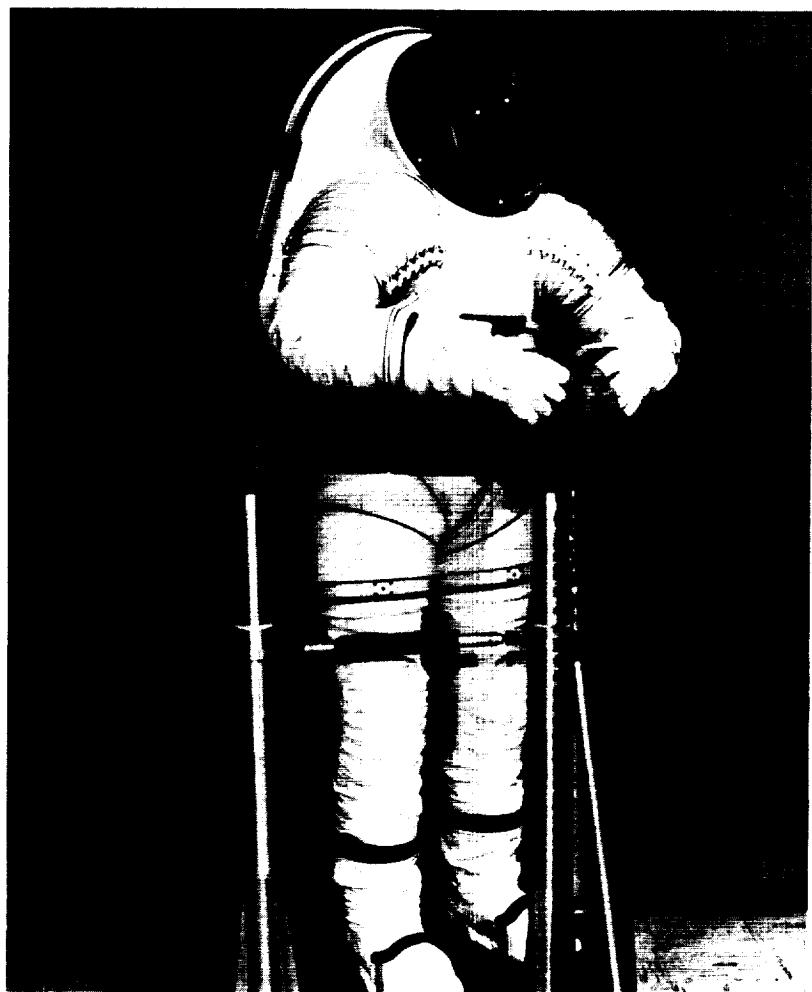
The Mark III space suit.

Research in Human-Computer Interaction

PI: Marianne Rudisill,
Ph. D./SP34
Reference SST 7

The Human-Computer Interaction (HCI) Applied Research Program emphasizes the importance of effective communication between humans and computer systems. Several HCI-applied research issues of importance, and directly applicable to current and future missions, were examined. Results from this work were used to develop user interface guidelines, requirements, and standards; to design HCIs for space-based systems; and to feed into the NASA Man-Systems Integration Standards and the Space Station Freedom Program Human-Computer Interface Guide. Knowledge gained from this base research was also provided to support systematic evaluations of HCI prototypes developed for the Space Station Freedom Data Management System.

Experiments were carried out that examined graphical interfaces, the electronic display of procedural information, and the usefulness of coding techniques in displays. Results from a series of studies which examined properties of graphical interfaces demonstrated that a user's understanding of graphical information is influenced by the perceptual and informational complexity of the graph, the relation between the figure and the axes, and the physical elements of the graph. A single, integrated model of users' interactions with graphics is currently being developed. Experiments were also conducted to investigate the use of highlighting, color, and other coding techniques as enhancements for information retrieval in displays. Preliminary results suggest that highlighting significantly reduces search time for a target; and, in comparison to a no-highlighting condition, the presence of highlighted non-target items in a display does not adversely search performance fo for the non-highlighted target item.

Experiments also examined the use of direct manipulation techniques. A quantitative model which describes human performance is being developed. Selection of displayed text using a point-click or a point-drag sequence was analyzed in terms of human operation time and errors; different parameters were found to influence performance with the two techniques.
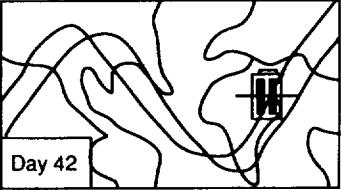
Research was initiated in the areas of cognitive modeling, cognitive engineering, and knowledge acquisition. Two experiments have looked at the rules by which an operator's knowledge of physics is applied to problem solving and decision making. Results have shown that subjects with little physics knowledge may be generating rules "on the fly," and that these rules are often not consistently applied. These results suggest that experience should be considered during the design of the user interface. Experiments are also currently being designed to examine the appropriate level of abstraction at which an intelligent system should display information to a user, depending on that user's expertise.

In the area of knowledge engineering, the HCI mental models of naive computer users, software developers, and human factors engineers were compared. Several similarities and differences were found in the mental representations of the three groups. The results from this analysis will be used to provide guidelines for communication among the groups during user interface design. Development continued on the Knowledge Acquisition and Representation Toolkit (KART), an interactive computer program used to elicit knowledge from an expert about his/her area of expertise. When completed, KART will be systematically compared with other knowledge engineering tools. Finally, early planning was begun for a Cognitive Modeling Workshop at which participants will identify and discuss the most pressing issues in this rapidly growing area of research.

Prototype display, using window for procedures checklist, surrounded by supporting information.

Initiate	Update	Exit

SSIG GN&C

Nominal monitoring

Guidance
Vehicle rate (deg/sec)

	Command	Actual	Delta
Roll	0.00000	0.00000	0.00000
Pitch	0.00000	0.00000	0.00000
YAW	0.00000	0.00000	0.00000

Attitude
LVLH vehicle position (deg)

	Command	Actual	Delta
Roll	0.00000	0.00000	0.00000
Pitch	0.00000	0.00000	0.00000
YAW	0.00000	0.00000	0.00000

Day 42

Navigation

Inertial state vector
(nautical miles)

S-M axis:	0.00
Apogee:	0.00
Perigee:	0.00

Command moment gyros (CMG)

		Commanded rate (deg/sec)	Actual rate (deg/sec)	Actual angle (deg)
Inner gimbal	CMG 1	0.00000	0.00000	-90.00000
	CMG 2	0.00000	0.00000	-90.00000
	CMG 3	0.00000	0.00000	-90.00000
Outer gimbal	CMG 1	0.00000	0.00000	-180.00000
	CMG 2	0.00000	0.00000	-180.00000
	CMG 3	0.00000	0.00000	-180.00000

Reboost status

Station reboost
06/09/94

Propellant (lbs)

Required	0.00
Available	0.00
Margin	0.00

Prototype text/graphics display of information for monitoring Guidance, Navigation, and Control spacecraft system.

Variable Transmittance Electrochromic Space Suit Visor

PI: Susan Schentrup/EC3
Reference SST 6

During an extravehicular activity, sharp changes in direct and indirect solar flux may occur, which can cause damage to a crewmember's eyes. Therefore, visor assemblies must provide protection against these sharp gradients. Current methods for protection of the crewmember from excessive solar glare consist of a gold visor and opaque blinders, each of which are manually deployed.

Since these methods require the crewmember to free a hand to pull down the visors, and since the crewmember either has some shading or none at all, work is now being done to provide variably transmittant electrochromic visors. The transmittance of the visor can be adjusted electrically by the crewmember or automatically controlled, using a photocell/feedback mechanism, with the option of manual override. The electrochromic technology is based upon reversible chemical reactions that go through coloring and then bleaching when an ion is shuttled across an ion conductor between two substrates. A small power source in the range of from 1 to 2 V is used to produce the electrical current responsible for the H+ shuttling. The system is based on amorphous tungsten trioxide ($a\text{-}WO_3$) and amorphous iridium oxide (IrO_2). Thin films of these oxides color and bleach synchronously in a laminated structure. The device can be laminated between the polycarbonate and polysulfone substrates structure used on the helmet assembly. The figure below shows the cross-sectional diagram for the electrochromic device.

The Phase I Small Business Innovative Research focused on producing a switching device on a polymer substance like that used in a space suit visor assembly rather than like the previous work that had produced devices on glass substrates. The fabrication process had to be altered for the polymer substrates, since the plastics reacted unfavorably in the acidic environments used in the glass process. The Phase I activity also identified the importance of depositing an even layer of electronically conductive material (tin-doped idium tin oxide, or ITO) on the polycarbonate and polysulfone substrates. Currently, the Phase II activity is focusing on achieving adequate layer thickness through improved deposition techniques. The techniques established must also work well for the coating of a hemispherical surface, since this is the first time an electrochemic device has been produced on a curved, polymer service.

In the Phase I program, luminous transmittance ranges from 13 percent to 64 percent have been demonstrated using the electrochromic system. The goal is to provide an 11- to 70-percent window, per the requirements imposed on the space suit visor. This will be done by optimizing the composition and thickness of the electrochromic layers.

The successful completion of the Phase II activity will result in a variable transmittant visor, integrated into the laminated structure of the advanced space suit helmet protective visor. The crewmember will no longer have to manually deploy the visor, and the transmittance level can be adjusted to achieve optimum working conditions.
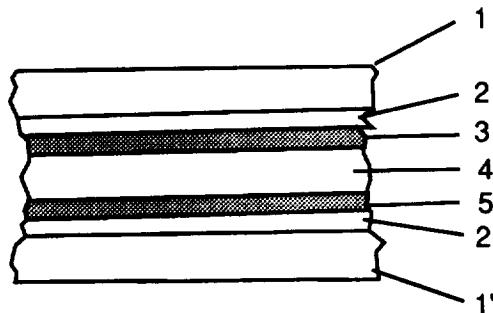
1,1' - Glass or Polymer Substrates
2 - Two Transparent Electrical Contracts (e.g., ITO)
3 - An Active Electrochromic Layer (e.g., $a\text{-}WO_3$ or $a\text{-}(Mo_xW1\text{-}x)O_3$)
4 - Transparent Ion Conductor (e.g., polyAMPs)
5 - An Electrochromic Counter Electrode (e.g., IrO_2)

Cross section of electrochromic switching device.

Non-Intrusive Data Collection System

PI: E. F. Mount/SP34
Reference SST 8

The focus of NASA's manned space program has been directed increasingly toward commercially productive work on long duration spaceflights. Consequently, research on human factors in space—specifically, investigating ways to reduce the mental and physical effort of working in space, to minimize the time needed to do work and habitability tasks, and to increase the quality of living in space—will become an increasingly important source of information for use in spacecraft design. Most of the information concerning in-flight productivity and habitability currently comes from postflight debriefings. Since crew time is at a premium in flight, crewmembers do not have the time to record their own or other crewmembers' behavior systematically. Therefore, having an in-flight data collection system that makes minimal demands on crewmembers will provide an avenue for significant data currently unavailable for human factors analysis.

Crew activities can be examined at several different levels: a description of a crewmember's behavior; the functions of the behavior; the visual, auditory, or other information underlying the behavior; the muscular activity that produces the behavior; and the mechanics of the movements that make up the behavior. These different kinds of data about crew activities could influence the design of crew equipment and spacecraft environments. While all of the data about crew activities are useful, the system focuses on three specific types: (1) behavioral, (2) physiological, and (3) biomechanical.

Under this nonintrusive data collection system, the Infrared Physiological Data Link (IPDL) developed earlier was validated in laboratory conditions by collecting identical information by hardwire to a recorder and using the IPDL. The signals were monitored on an oscilloscope, stored on a portable 7-channel FM tape recorder, and recorded on a stripchart recorder. This prototype was also used in connection with other biomechanics studies in one-g and in simulated reduced-g conditions. Human factors inputs are being provided during the development of a second-generation unit. A complementary investigation of new sensor technology and ways to make data collection equipment less intrusive while collecting information was also initiated.

Validating the Prototype Infrared Physiological Data Link with hardwire recording in the Anthropometry and Biomechanics Lab.

Single-Phase Laundry System

PI: Phyllis Grounds/SP44
Reference SST 9

Long-duration spaceflights will most likely require an onboard laundering facility to reduce the logistical requirements of resupplying clean clothing, bedding, and towels. The concept investigated in this research area offers solutions to two major concerns associated with microgravity clothes-laundering, namely high energy consumption and waste streams comprising air and water as a two-phase mixture. The use of microwave energy as a means of drying the clothes was investigated as well as a concept for evacuating the washing vessel to eliminate the air prior to the wash/ rinse cycle.

A single-phase (water) clothes-laundering apparatus was designed, and a prototype was built that could be completely evacuated (29.9 in. Hg vacuum), filled with water, agitated, and drained without the introduction of air, as shown in the figure.

A microwave generator (Magnetron) was mounted outside the vessel. The microwave energy was beamed into the contents of the apparatus for drying. Tests were conducted to verify that a single-phase operation is feasible and that microwave energy is a viable method for the drying cycle. The prebreadboard model that was developed and tested produced no foam or bubbles during the wash and rinse cycles. Good clothing agitation was accomplished, which provided efficient cleaning action. The use of microwaves to dry the clothes was also successfully demonstrated. Air flow during the drying cycle was shown to be sufficient to provide movement of the clothes during this function.

The primary potential application of this laundering facility is for use in microgravity environ-ments, where two-phase (air/water) systems present a serious materials handling problem. Air entrained in water decreases the efficiency of pumps and storage vessels in microgravity environments. Power consumption of this was minimized by using microgravity energy for the drying cycle. The air/water phase separation problem was eliminated by producing a single liquid-phase water waste system, which eliminated the power usage of the phase separation system. A commercial application of this concept would allow the use of cleaning agents that are currently unacceptable because of their aggressive foaming action. Microwave drying offers power savings, clothing sterilization, low shrinkage, and low lint production.

The next phase of research to be performed on this single-phase laundry system will optimize the level of microwave energy required to dry the clothes and will also refine the internal geometry of the container to facilitate uniform drying of the clothes. The configuration of the washing vessel will be defined and will include a bellows-type agitation system for evacuating air from the container. The wash/rinse cycles will be analyzed to determine the best combination of wash/rinse cycle times.
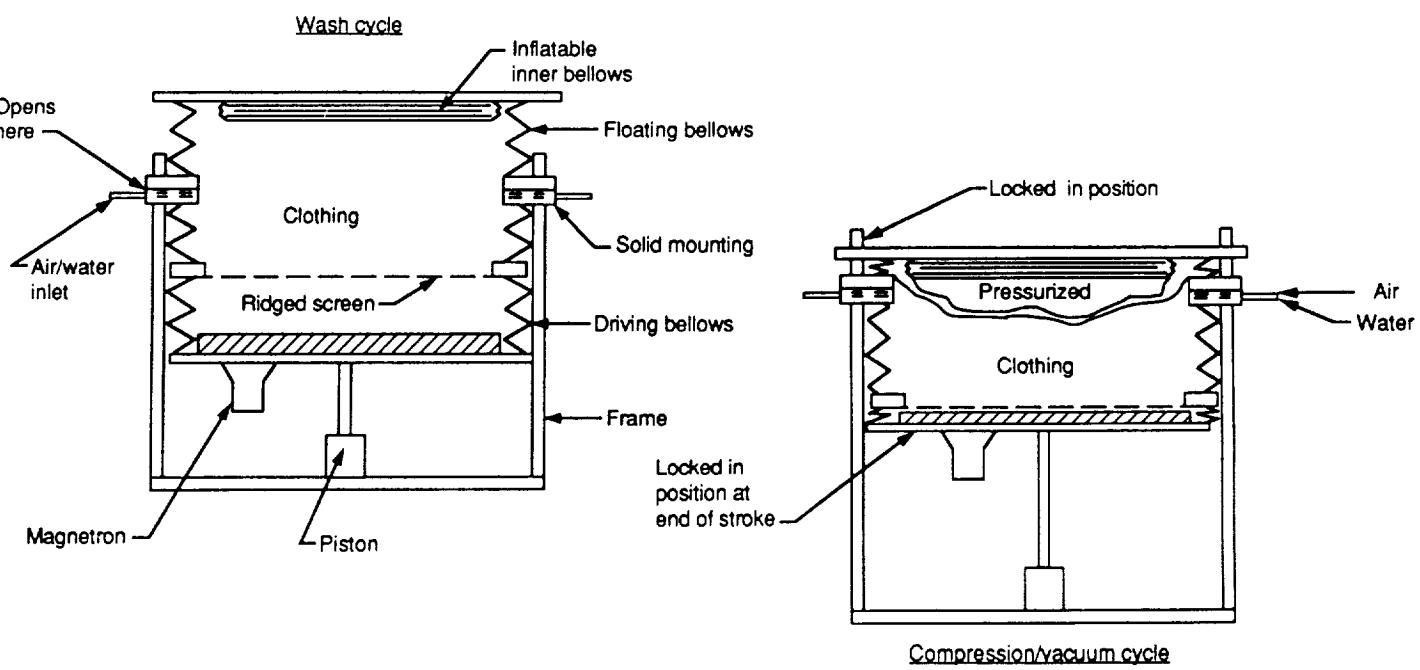
Single-phase clothes-laundering apparatus

Inventory Tracking into the Next Decade

PI: L. W. Lew/SP33
Reference SST 10

A key objective of the Space Station logistics is to simplify daily tasks to achieve a high level of astronaut productivity. One of the most mundane activities facing the astronauts will be the onboard management of approximately 50,000 inventory items. Tracking of inventory items may be critical under emergency situations where astronauts must be able to immediately locate vital items, such as required tools and equipment parts. In addition, an accurate account of inventory is required to maintain supplies and materials onboard the spacecraft.

The current state-of-the-art bar code inventory management system falls short in satisfying all the needs of the Space Station and other long-duration missions: the system is unable to locate a missing or misplaced item. This could have serious ramifications when a new item may not be available until the next resupply mission. Furthermore, the bar code system is not suited for the harsh unpressurized exterior environment, and it requires a large amount of crew time for manual scanning of the bar code labels. This becomes quite tedious and monotonous when a crewmember may have to scan as many as 200 a day (meal items alone for 8 crewmembers per day). When inventory control operations become complicated and tedious, crew productivity can be severely affected.

Developing an inventory tracking system that is simple to use, uncomplicated, functional, reliable, and maintainable can be accomplished by the use of miniature, multiple-read, passive (non-battery powered) electronic tags. Electronic tags offer significant benefits: minimizing crew time, improving the quality of input data, removing physical location barriers, increasing read speed, and cost savings. For example, an electronic tag reader could be positioned in the inlet of the trash disposal area, thereby quickly reading all items as they are consumed from the onboard inventory. This capability eliminates any unnecessary manual operations, as required with a bar code reader.

Three inventory tracking studies were pursued. Off-the-shelf Radio Frequency (RF) systems were investigated to determine if miniaturization of an existing system could be accomplished. This study revealed that an RF tag could be miniaturized to meet NASA's requirements. The passive tag would be the size of a penny (0.6" × 0.6" × 0.1"), have a read range of about 40 feet, address 21 bits of data, and can be interrogated at a rate of at least 4000 tags per second for a community of 2 million tags. A smaller version, 0.35" × 0.35" × 0.1", would have a read range of 10 feet. Plans have been made to build miniaturized RF tags, a matching interrogator, and to integrate the system with a direction finding/tracking technology. This project, when completed, could produce a truly automated inventory tracking system.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Lockheed air terminal's
passive electronic tag
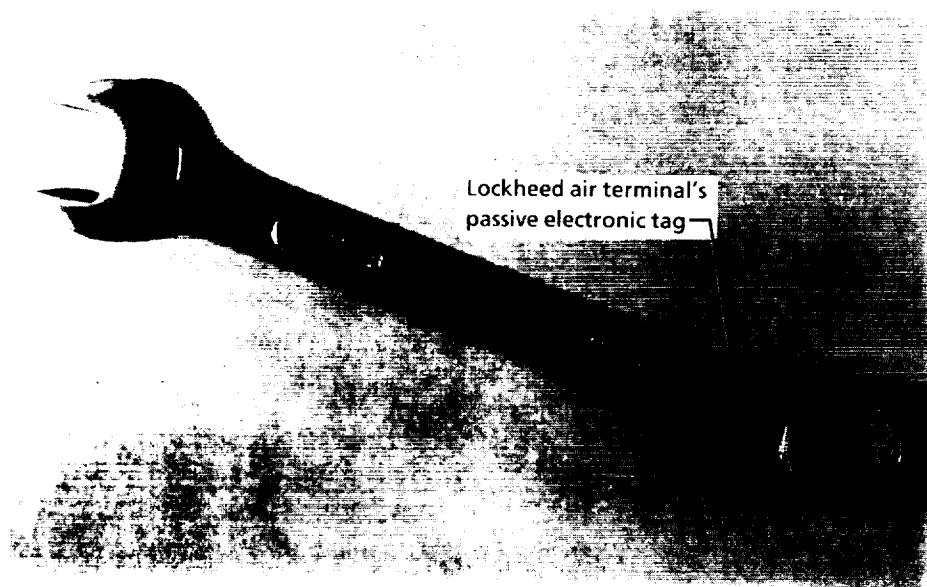
Lockheed Air Terminal's passive electronic tag (current size).

Lockheed air terminal's
passive electronic tag
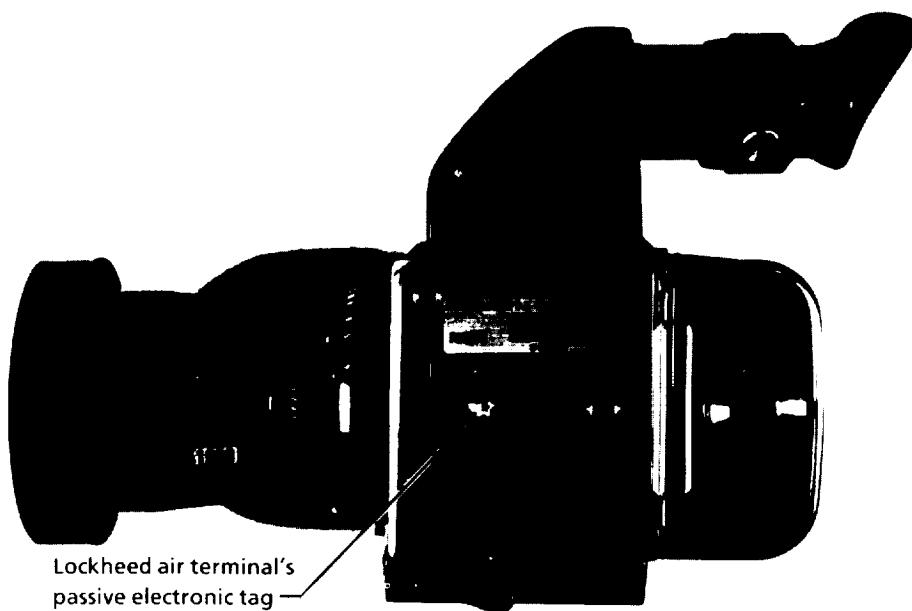
Lockheed Air Terminal's passive electronic tag on 70 mm camera.

Lockheed air terminal's
passive electronic tag
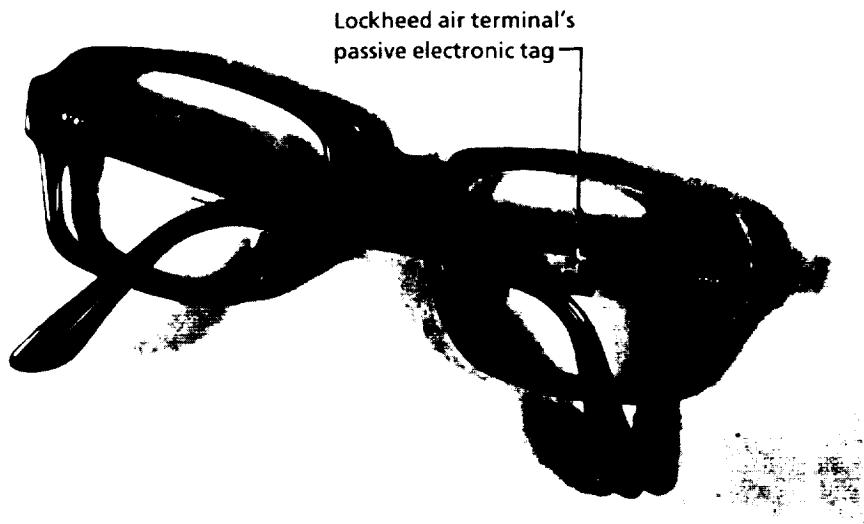
Inventory tracking of personal items (eyeglasses).

Hair Cleansing System

PI: Rafael Garcia/SP4
Reference SST 11

Debriefings of crewmembers from Space Shuttle missions have identified hair care to be one of the primary personal hygiene problems. With the advent of extended-duration Shuttle missions (i.e., more than 16 days) and the potential of very long exploration missions, the need for a hair cleansing system will become even more apparent. The current research provided perti-nent data necessary for the development of an optimal zero-g hair cleansing system through the evaluation of proposed hair cleansing systems. The most effective method was selected based on operational efficiency and effective perform-ance and was further evaluated aboard the KC-135 zero-g aircraft.

Three hair cleansing methods were identified, as follows:

(1) Wet hair Cleansing System (shower cap) - A process in which the normal shampooing process is done in an enclosed system, thus preventing water and other materials from escaping into the environment.

(2) Wet/Wipe Cleansing System - A process in which the hair is wet with water, washed/wiped with a pad impregnated with a shampoo, and then towel dried (no rinsing required).

(3) Dry/Wipe Cleansing System - A process in which a polypropylene fiber sheet was used as a dry wipe to clean the hair.

The research program was conducted in two parts. Part I consisted of a two-week prescreen evaluation of the systems and equip-equipment. Part II involved a four-evaluation of the proposed methods of hair cleansing, using human test subjects. In addition to the operational tests and evalua-tions, microorganism samples were also collected and analyzed by the Biomedical Laboratories of the JSC Medical Sciences Division. Protocols were controlled to simulate as closely as possi-ble the operational constraints of a crewmember in flight (i.e., sub-jects were asked not to wash their hair or use any hair products such as styling gels for at least 48 hours prior to each test).

The Wet/Wipe hair cleans-ing system was tested under microgravity conditions aboard the KC-135 zero-g aircraft. The Whole Body Shower stall and support equipment were used dur-ing this test. The test subjects followed the same procedures gen-erated for the laboratory testing. Results from these microgravity tests demonstrated that the Wet/Wipe Hair Cleansing system will work in a microgravity environ-ment.

Based on the results of the data collected, the Wet/Wipe Hair Cleansing System was selected as the best overall system to meet the hair cleansing requirements for an extended Shuttle mission. Future development efforts should concentrate on improvements to the wet/wipe cleansing method, with considerations given to the addi-tion of a conditioner to the wipe to prevent excessive dryness of hair and scalp. The wipe could also be manufactured as a hand glove for ease of use. Future goals are to certify this system for evaluation onboard upcoming Shuttle Trans-portation System flights.
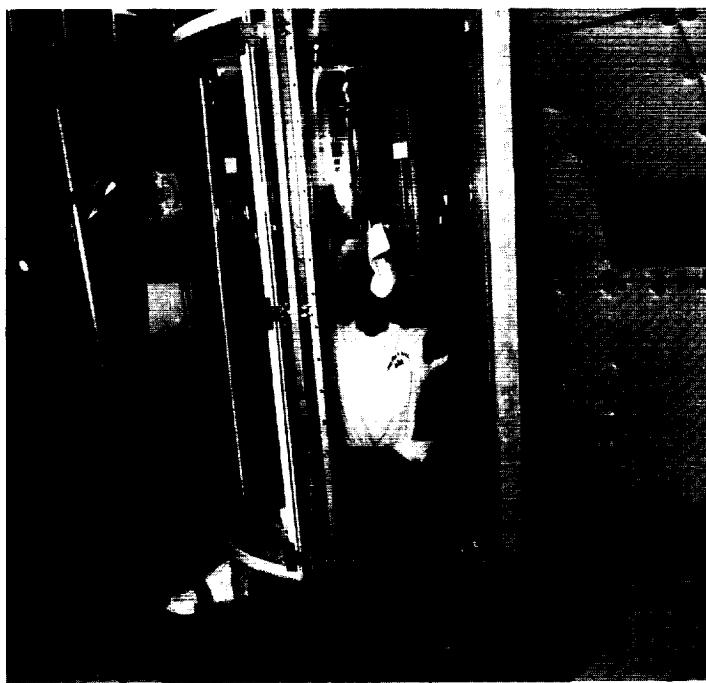
Figure 1. Zero-g test in progress aboard KC-135 aircraft.
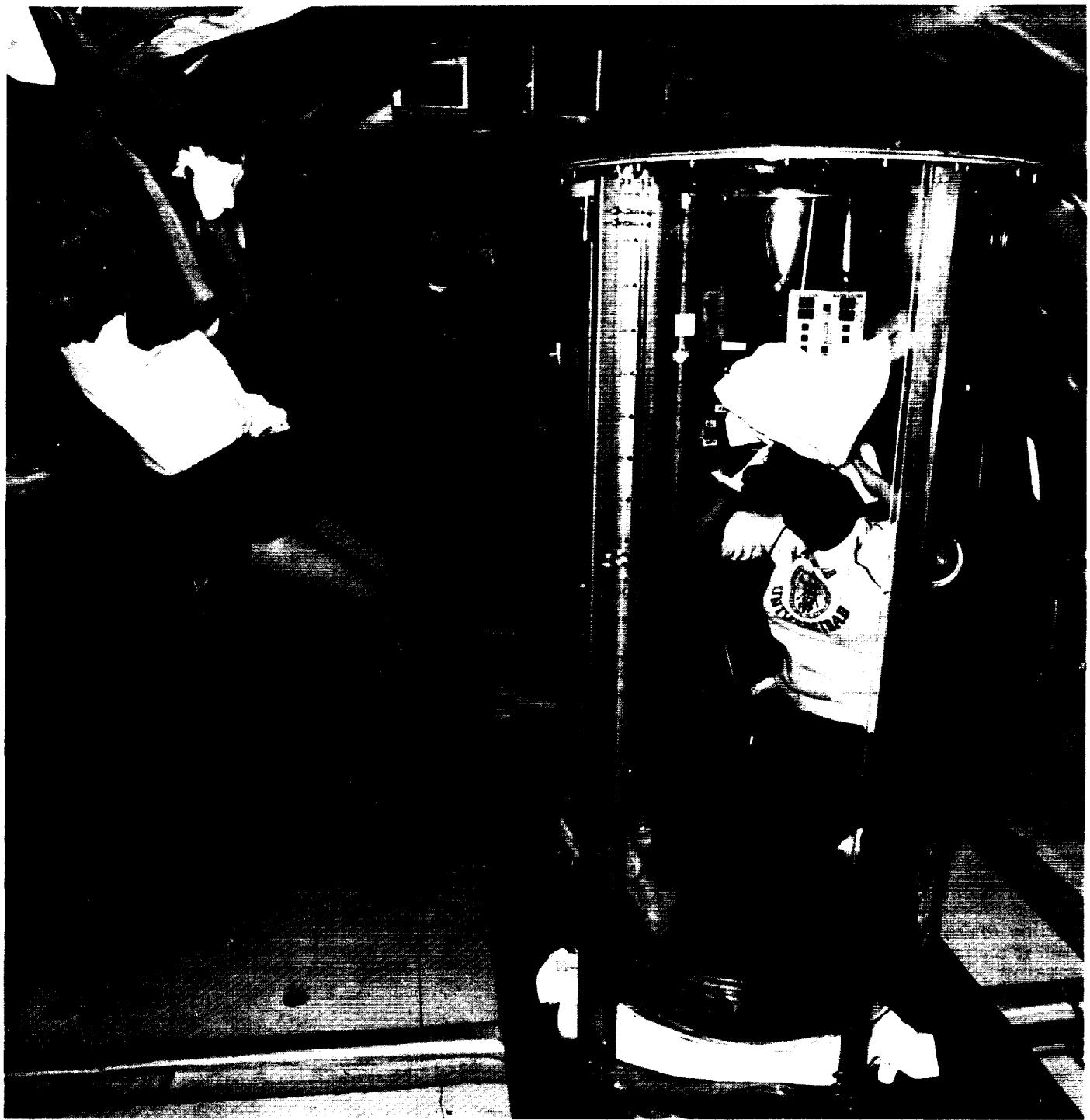
Figure 2.- Subject wipes hair during zero-g test.

Toolkit for Computer-aided Engineering and Operation of Intelligent Systems for Monitoring and Fault Management

PI: Jane T. Malin/EF5
Reference SST 12

A critical area of technology for future man-machine aerospace systems is advanced automation and intelligent systems. Human operators will use intelligent systems to automate and assist many tasks, including monitoring, diagnosis, and management of degraded performance, faults, and failures in aerospace systems. Initial intelligent system software (whether model-based or rule-based) should be developed while the monitored system is being developed. This type of software should also be easy for operators to update as they gain system understanding and expertise.

The goal of this project is to develop and demonstrate prototype software tools to aid the timely development and continued updating of intelligent system software. Such software tools should also aid in the evaluation of system diagnosability and fault tolerance and should support analyses of system effects of degradations, faults and failures. In addition, use of these software tools should produce data bases that are reusable in online and offline operations analyses to aid fault management, in user interfaces, and in training.

In the first phase of this project, the CONFIG prototype has been developed. It integrates qualitative modeling and discrete event simulation technologies with interactive graphics, to provide an easy-to-use toolkit for analyzing dynamic processing systems. Four software modules support construction of models of systems of faultable components and analysis of effects on the system of local changes in its elements. The modules support construction of libraries of modeling elements, construction of specific system models using library elements, simulation of system behavior, and analysis of simulation experiments. Capabilities to analyze the digraph structure of specific system models, including reachability analysis, are also available.

Digital circuitry and a thermal bus model have been used as test cases for development and demonstration of the prototype. In limited field tests, CONFIG has been used to analyze fault diagnosis and management capabilities in computer networks and in STS Space Transportation System Payload Deployment and Retrieval System (PDRS) remote manipulator subsystems. A software patent is pending. A chapter on CONFIG is found in Artificial Intelligence in Process Engineering (M. Mavrovouniotis, ed.). Papers on CONFIG were presented at the Fourth Artificial Intelligence and Simulation Workshop at the 11th International Joint Conference on Artificial Intelligence in August 1989, and at AIAA Computers in Aerospace VII in October 1989.

A Rule Checker tool has been developed to analyze the consistency and completeness of diagnostic rule sets that are generated using CONFIG or other rule-system development methods. This tool can be used to validate rule sets that conform to object-oriented types of syntax constraints. This tool is being redeveloped to be usable on diagnostic rule sets that are developed using the NASA CLIPS expert system development tool.

Plans for CONFIG for the next year include design of enhancements (including Rule Checker and a Fault Information Analysis Tool) to support development of a rule-based failure analyzer expert system for the STS PDRS, reimplementation of CONFIG for rehosting on engineering workstations, and completion of capabilities for partially automating and assisting model-based development and validation of fault management systems. A later version will be designed to support the reuse of CONFIG databases in online and offline operations analyses to aid fault management.
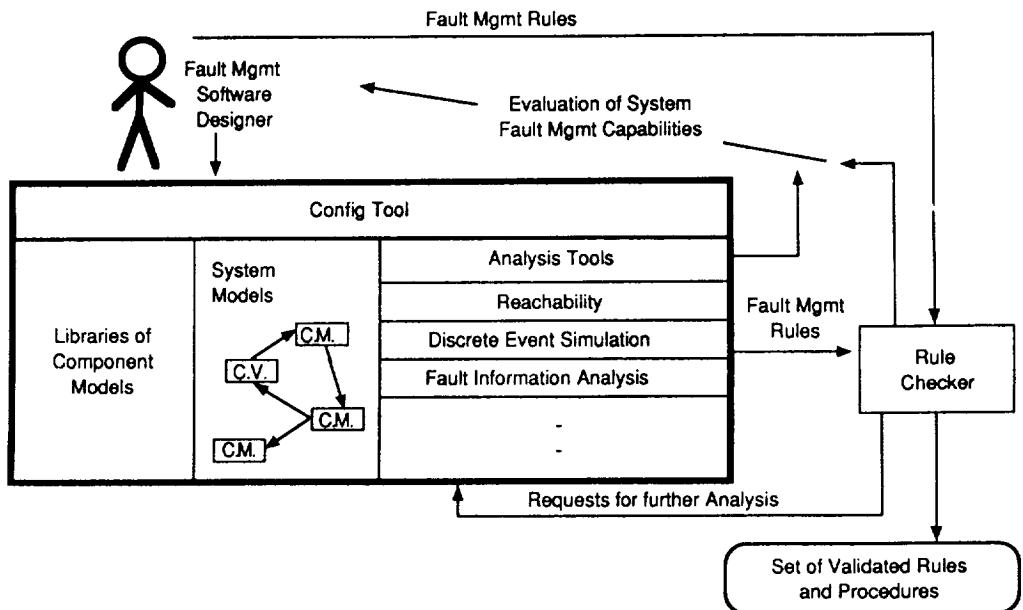
CONFIG is used in developing fault management systems.
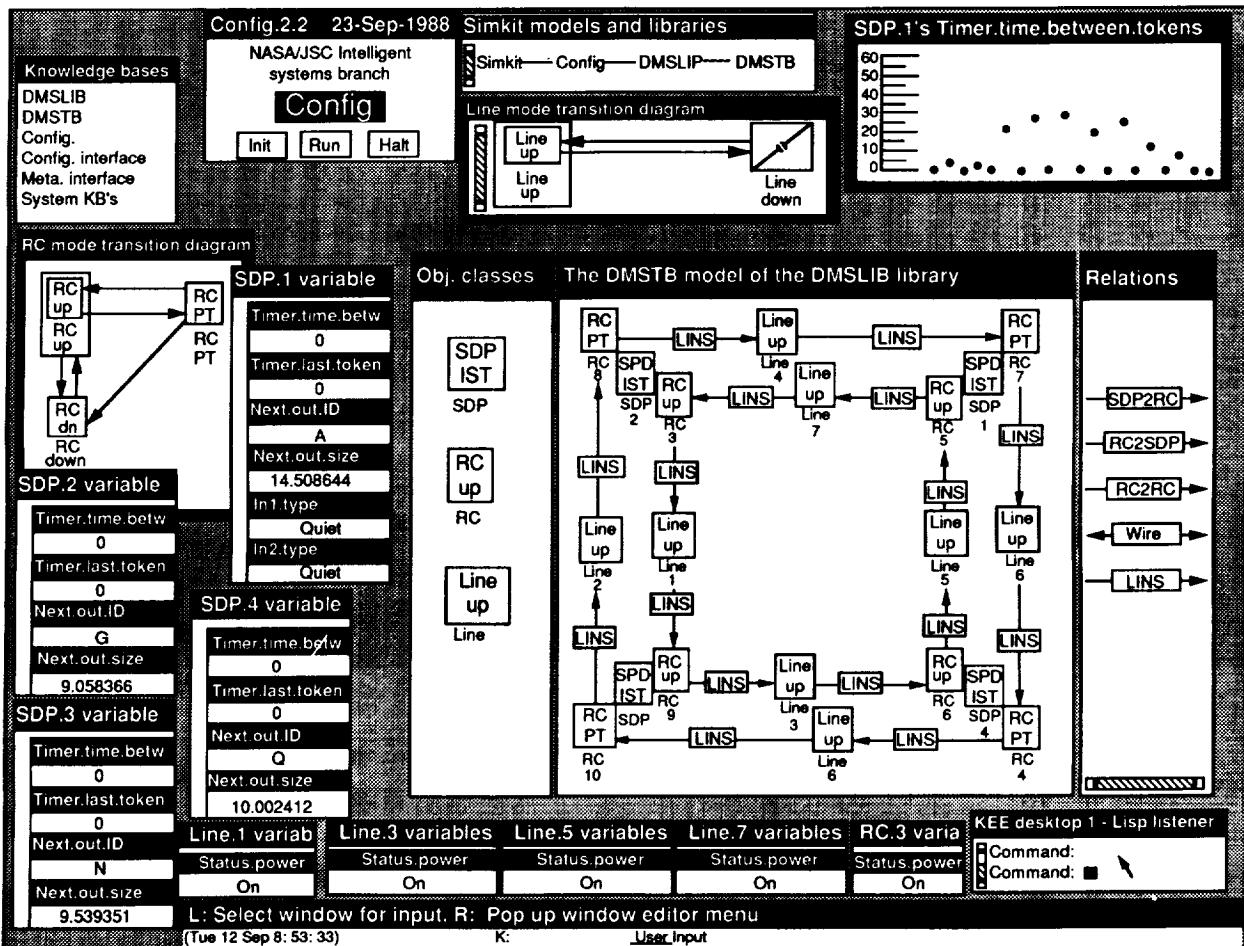
Space Station data management system testbed network model.

Techniques for Estimating Space Station Aerodynamics

PI: Matthew Ondler/ED3
Reference SST 13

Accurate determination of aerodynamic forces and moments acting on Space Station Freedom while on orbit is critical for control system design, propellant requirement prediction, and assessment of the local acceleration environments of sensitive experiments, as well as determination of spacecraft motion during periods of relaxed, or non-existent, control system activity. This determination requires knowledge regarding the on-orbit atmosphere, Space Station aerodynamic and mass characteristic, and the interaction of the Space Station with the atmosphere.

The planned orbital altitude of the Space Station places Freedom securely within the free molecular flow regime. At this altitude, the atmosphere is highly rarefied to the point where collisions between molecules are infrequent and may be neglected. This assumption gives rise to a subdivision of rarefied gas dynamics, termed free molecule flow. Historically, aerodynamic prediction codes based on 1960's free molecule flow theory have proved adequate for satellite-size spacecraft with relatively short orbital lifetimes. Due to the planned size, complexity, and longevity of Freedom, however, current free molecular flow codes will not be able to incorporate all of the physics involved in the interaction of the Space Station with its environment.

The calculation of energy and momentum transfer to a surface in orbit, and thus the prediction of aerodynamic forces, requires detailed knowledge of the interaction of a gas molecule with the solid surface. The character of the interaction is governed by the energy and direction of the impacting molecule relative to the surface, its molecular weight, the surface material and finish, and the electrical charge characteristics of both the impacting gas molecule and surface. Technology improvements required for accurate prediction of Freedom's aerodynamic coefficients include the ability to vary the gas-surface interaction characteristics over different parts of the Space Station as the material and orientation of the surfaces change. Current prediction methods are restricted to a single-interaction parameter for the entire vehicle, neglecting variations. In addition, current free molecular flow theories cannot account for the effects of charge attraction between ionic particles and an electrically charged surface, which may increase the impact momentum transfer and prove to be a significant phenomenon for the Space Station, with its large solar arrays.

Two additional elements of free molecular flow are surface shielding and the possibility of multiple reflected particles. Free molecule flow theory assumes that the incident flux of particles is undisturbed by the presence of the body–thus, there is no turning of the flow–and areas not facing the flow, or not shielded from it by another surface, receive no impacts. The present methodology calculates random molecular motion. While the neglected force component is relatively insignificant for smaller bodies, when applied to a large space station design the magnitude of the neglected force may influence station dynamics. Another force component which is historically ignored is the impact of multiple reflected particles restriking the surface and contributing to the net force calculations. The additional transfer momentum transfer is highly dependent on reflection characteristics and surface geometry and may be important for smooth, concave surfaces, such as solar dynamic collectors. These effects, while previously considered second order, are being investigated to reduce the uncertainty in aerodynamic coefficient prediction for Space Station Freedom.

As noted above, the prediction of aerodynamic forces and moments is highly dependent on the assumed character of the gas-surface interaction process. Using current methodologies, an investigation of the effects of varying interaction characteristics for the entire vehicle predicts greater than 50 percent variation in aerodynamic coefficients This highlights the requirement for improving knowledge of free molecular interaction processes. Additional studies and theory development will continue to investigate new requirements for Space Station aerodynamic calculations, with the goal of a state-of-the-art tool for free molecular flow aerodynamic predictions.

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Station alpha = 0.000
Station beta = 0.000
Solar beta = 0.000
Temperature ratio = 0.200
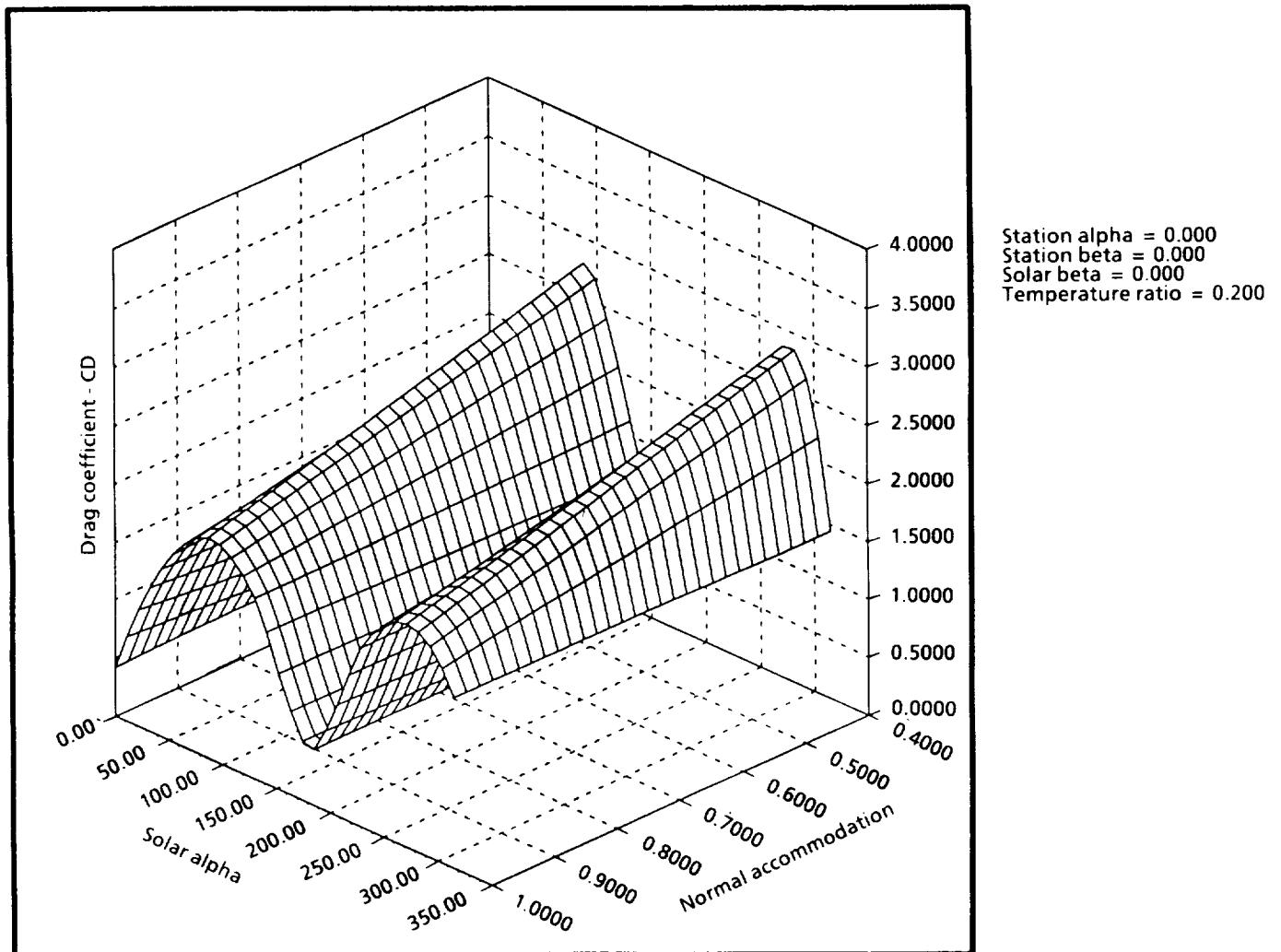
Space Station Freedom aerodynamic sensitivity study.

Autonomous Lander Project

PI: Ken Baker/EF5
Reference SST 14

The objective of the Autonomous Lander Project is to develop the technology required to land a planetary exploration spacecraft accurately (close to the area of mission interest) and safely in the face of surface hazards such as large rocks and locally steep slopes.

To provide a planetary exploration mission with a high probability of success (98 percent) without the payload penalty associated with a lander that is robust against surface hazards requires the ability to: (a) land within a small, safe area selected on Earth using information acquired from orbit before descent, or (b) detect from the lander during descent a safe landing area within its maneuvering range.

The three sigma probability landing error ellipse of the Viking landers, which were low lift-to-drag ratio (L/D) vehicles that did not control their aim point after the deorbit burn, was 120 km by 50 km. Although two Viking spacecraft landed successfully on Mars, postflight analysis indicates that the probability of landing failure due to the rocky terrain at the Viking Lander II site with a ground clearance of 22 cm exceeded 39 percent. A medium L/D entry vehicle (L/D = 1), using closed loop control with an inertial measurement unit (IMU) as its only sensor, would have a 3 sigma position error, at parachute deployment of about 10 km, when entering from a 500 km circular orbit. A typical next-generation planetary lander, such as for a Mars Rover Sample Return (MRSR) mission, with a ground clearance of 1 m, would have a probability of landing failure exceeding 5 percent at the Viking Lander II site.

Current project activity is focused on the definition of requirements for landing accuracy and safety, a comparison of alternate navagation approaches for accurate landing, and a feasibility study of onboard hazard detection and avoidance. The requirements definition work this year is be-ing accomplished by participating in the MRSR Phase-A study.

An initial version of a model for computing the probability of safe landing as a function of lander robustness and hazard frequency produced the estimates of landing failure referred to above. The addition of a hazard detection and avoidance function on the lander and information about the spatial distribution of landing hazards on planetary surfaces is needed to perform a tradeoff between lander robustness, landing accuracy, and onboard hazard detection and avoidance as ways of safe landing.

Linear covariance analysis of navigation errors shows that the addition of radio range/integrated-Doppler tracking from the descent vehicle of one or more beacons in orbit or on the ground improves the position accuracy from 0.5 to 2.0 km. Landmark tracking using optical images, as is done in the cruise missile, should improve this accuracy. This landing accuracy is comparable to that estimated only from guidance errors by MRSR in Pre-Phase A. A complete simulation of the entry and landing guidance, navagation, and control (GN&C) is needed to identify any guidance and control development that is required to make such landing practical.

We have just begun a feasibility study of alternate approaches to onboard hazard detection that is intended to result in the selection of several approaches for development, starting in mid-FY90.
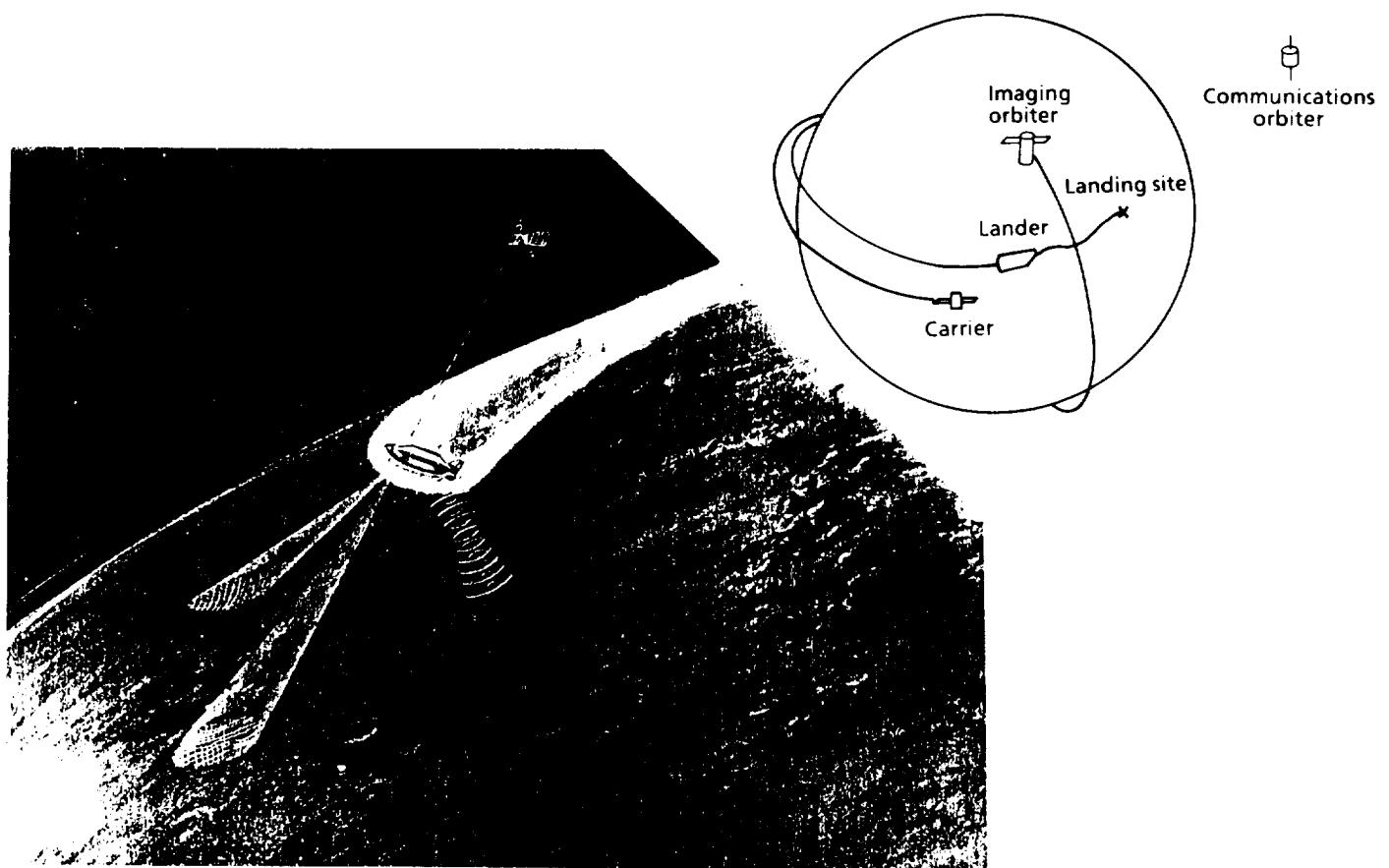
Vehicle trajectories.

Substructural Controller Synthesis for the Control Design of Flexible Space Structures

PI: Dr. Roy R. Craig, Jr.,/ASE-EM Department, The University of Texas at Austin, Austin, Texas 78712
Reference SST 15

Because highly advanced space technology has been made the construction of large space structures possible in the very near future, the problem of control of flexible structures has received a great deal of attention in recent years. A major difficulty that makes control of flexible structure different from other control problems is that a flexible structure is a continuum system, which, in theory, has an infinite number of degrees of freedom. Although, in practice, an evaluation model of finite dimension can be obtained by using some discretization approach along with modifications based upon system identification test data, the finite dimensional mathematical model of a moderately complicated space structure still has too large a scale for the direct application of any existing control design technique. In this research work, a novel control design approach called Substructural Controller Synthesis (SCS) has been developed to relieve the computational burden associated with the structural control problems.

A large space structure, like the Space Station Freedom, is composed of several components (or substructures), such as the main truss, solar panels, antennae, etc., and will be sequentially assembled in space within several Space Shuttle missions. For dynamic analysis, it is well known that the dynamic equation of the whole structure can be obtained by assembling together the dynamic equations of all the substructures. This property is, in fact, the essence of all "matrix assemblage" methods; e.g., the Finite Element Method and Component Mode Synthesis. For control design, it is also natural to seek a similar substructural synthesis procedure. The idea behind the Substructural Controller Synthesis method for structural control design is similar to the well-developed Component Mode Synthesis methods for structural dynamics analysis.

Substructural Controller Synthesis, which is depicted in the accompanying figure, combines substructural synthesis, model reduction, decentralized control design, subcontroller synthesis, and controller reduction into an integrated procedure for the design of reduced-order controllers for flexible structures. It is a decentralized control design procedure and has some advantages over a traditional centralized design approach. First, the computational burden associated with dimensionality is substantially reduced because the control design is carried out at the substructure level, which is of smaller size than a structure level control design. Secondly, the SCS controller is highly adaptable and is a natural approach for sequentially assembled space structures. Since the SCS controller is synthesized from subcontrollers, if one substructure has configuration or system parameter changes, the only subcontroller which needs to be redesigned is the one associated with that substructure. Therefore, the SCS controller can be updated very economically if part of the structure changes. Several numerical examples have demonstrated the applicability and efficiency of the Substructural Controller Synthesis method.

The success of an SCS control design for a large structure requires an effective model reduction scheme and an efficient controller reduction scheme. Component Mode Synthesis methods have been used as an effective model reduction tool for structures composed of many substructures. For controller reduction, an efficient scheme, called the Equivalent Impulse Response Energy Controller (EIREC) reduction algorithm, has been developed along with this research work to incorporate with the Substructural Controller Synthesis procedure. The EIREC controller reduction produces a reduced-order controller with useful properties and is more economical than existing controller reduction methods.

The results achieved so far in this research work have been presented in several technical conferences. Currently, application of Substructural Controller Synthesis to multi-flexible-body control problems is under way. Theoretical aspects of the SCS controller, e.g., suboptimality and robustness, are also being investigated. It is hoped that the accomplishment of this research work can provide an efficient and practical control design approach for future large flexible space structures.

Continuum
stucture
(dim → ∞)

Evaluation model
(dim ~ $\sum N_i$)

Substructuring decomposition

Substructure
(dim N_1)

● ● ●

Substructure
(dim N_i)

● ● ●

Substructure
(dim N_s)

Model order reduction (Krylov)

Reduced-order
Substructure
(dim n_1)

● ● ●

Reduced-order
substructure
(dim n_i)

● ● ●

Reduced-order
substructure
(dim n_s)

Controller design (LQG, LQR)

Subcontroller
(dim $2n_1$)

● ● ●

Subcontroller
(dim $2n_i$)

● ● ●

Subcontroller
(dim $2n_s$)

Substructural controller synthesis

Global controller
(dim ~ $\sum 2n_i$)

Controller reduction (EIREC)

Reduced-order
global controller
(dim r)

Performance evaluation

Procedure of SCS method.

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Anodized Coating Performance

PI: Stephen Jacobs/ES5
Reference SST 16

The most significant accomplishment in this technical area was the continued development of long life durable radiator coatings for Space Station Freedom. Acurex Corporation, under contract to the Johnson Space Center (JSC) (NAS 9-17430), developed a low solar absorptance, high-emittance, long-life coating over aluminum substrate. The baseline coating selected is 5657 alloy aluminum substrate, chemically treated to increase reflectance, and sulphuric acid, anodized to form a clear aluminum oxide coating. The anodic coating thickness is in the range of 0.5 to 1.0 mil, with emittance varying as coating thickness in the range of 0.80 to 0.85. The reflectance is 0.87.

Additional work was accomplished in 1989 by Boundary Technologies, Inc. (BTI) under a Phase I Small Business Innovative Research (SBIR) to JSC (NAS 9-18067). The focus was on understanding probable long-term failure mechanisms of the anodized coating; namely, cracking by thermal fatigue. During thermal cycling tests, some coatings developed a significant crack density, with sensitivity to increasing coating thickness and higher cycle temperature. A thermal fatigue (stress-strain) model was proposed by Southwest Research, Inc. (SwRI) for estimating coating lifetime from limited thermal cycling data. To select suitable test conditions, information is needed on the stress in the coating and its temperature dependence. BTI met the technical objectives of Phase I, (1) to determine the range of anodized coating stress and the temperature dependence, of stress, with alloys and process conditions of interest, (2) to estimate how accelerated thermal cycle tests can be done for such coatings, (3) to measure Tc, the temperature at which coatings crack on a single heating, and (4) to observe the dependence of Tc on alloy and coating stress. Measurements were made of coating stress as a function of process conditions, coating thickness, alloy type, and metal fabrication. The coatings were deposited in a sulphuric acid bath, using the recommended Acurex process, and were generally 0.4 to 1.0 mil thick, with a hot water (95 degrees C) seal. Thermal stress coefficients (psi-degrees C) of these coatings were measured. The experimental method was to anodize an aluminum strip on one side and measure the deflection of the tip after a process step or after changing temperature. Deflection was measured with a laser micrometer. Stress is proportional to deflection and was calculated from measured quantities using a classic equation. The temperature at which the average coating stress is zero was found to be always higher than 55 degrees F, the maximum operating temperature. Thus, the average stress in the coating is always compressive during operation. This should prevent crack initiation from thermal cyclic fatigue. However, there is evidence that the stress distribution in the coating may not be uniform, with an inner region under tension and an outer layer under compression. This makes it difficult to predict fatigue properties and to select accelerated test conditions without more information on coating properties.

A Phase II SBIR proposal has been received from BTI and is currently under review. Phase II will provide experimental information on behavior under cyclic thermal conditions, and models will be developed to determine stress distribution across the coating and for determination of thermal fatigue cracking. A brief description of the oxide coating structure will be helpful to understanding the objectives and work proposed for Phase II. The anodic oxide has a high density of fine pores penetrating the coating, aligned normal to the surface and arranged in a rough hexagonal cell pattern. Typical dimensions are 15 nm pore diameter and 42 nm cell diameter. This corresponds to 13-percent pore volume in the coating. The oxide is amorphous and has a density of 2.9 g/cc. During sealing, this oxide reacts with hot water to form a poorly crystalline hydrated oxide with a density of 2.4 g/cc. Water penetrates the pores, so the hydrated reaction product is in the pores and not on the surface. Since the hydrated oxide is of lower density than the anodic oxide, the reaction product expands into the pore channel. The sealing reaction takes place more rapidly in the outer portion of the pore, tending to close off the pore before the pore base region is fully sealed. In Phase I, it was found that, before sealing, the anodic oxide is always under tensile stress; and the stress appears to be uniform across the thickness. After sealing, the average coating stress is compressive and is not constant with thickness. The structure in the sketch emphasizes the possibility that the stress may be tensile near the metal surface and compressive in the outer portion.
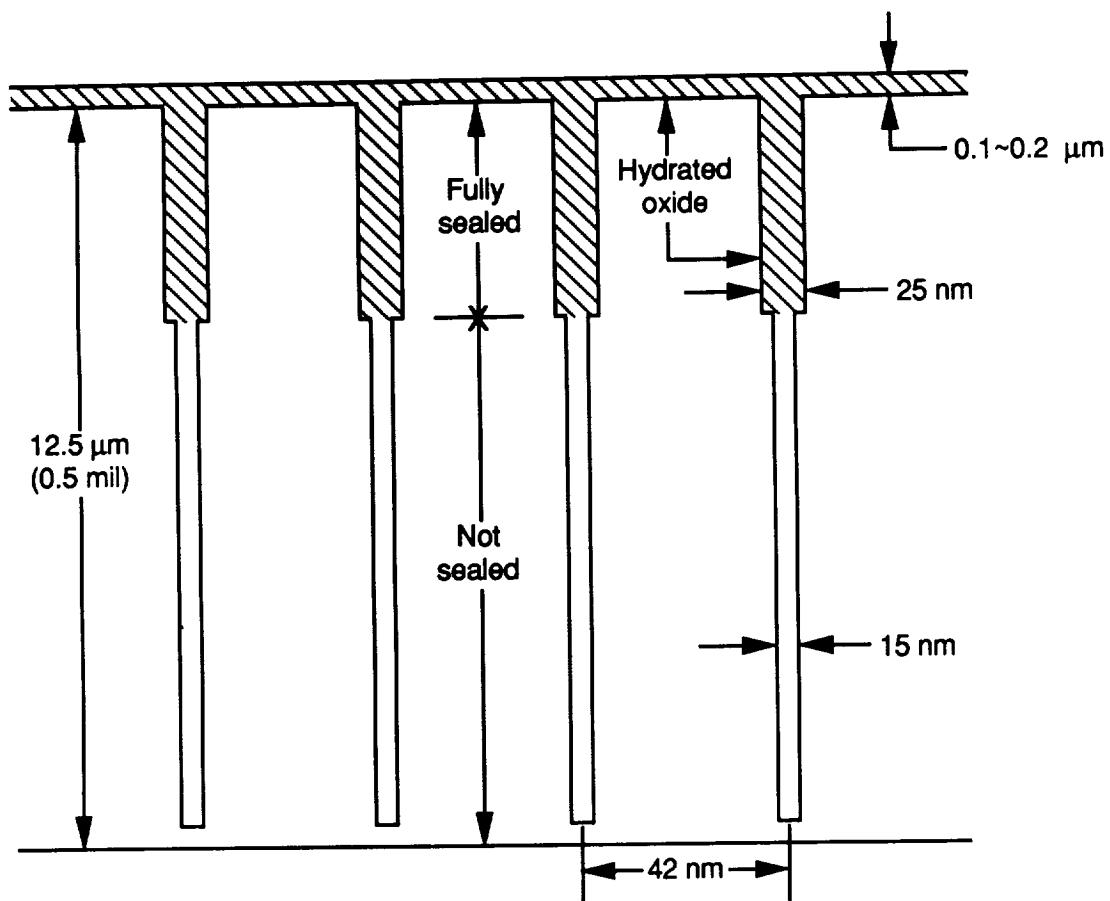
0.5 mil coating with 5 min seal.

Shuttle Main Propulsion System Gaseous Oxygen Flow Control Valve Investigation Program

PI: Chris Popp/EP4
Reference SST 17

In response to the STS-29 Main Propulsion System (MPS) gaseous oxygen Flow Control Valve (FCV) anomalies, a test program was initiated at NASA White Sands Test Facility (WSTF) and NASA Johnson Space Center (JSC) to investigate FCV performance. Uti-lizing FCV poppet sleeves made of Monel K-500 in-house at NASA JSC and a development oxygen FCV (DV-2), a series of oxygen and ambient tests was performed at NASA WSTF.

The first test series consisted of thermal transient tests in which the valve was chilled and then tested with high-temperature oxygen (simulating main engine startup). These tests showed that the valve became more susceptible to response anomalies due to thermal transient distortion as the diametrical clearance between the seal and sleeve was decreased.

The second test series demonstrated that contamination injected into the valve outlet while the valve was oriented in the vehicle vertical position could be ingested into the valve when launch prepressurization conditions were simulated.

The third test series combined the prepressurization/contamination ingestion simulation with the vehicle startup thermal transient conditions to determine if the STS-29 response anomalies could be duplicated. No repeatable valve performance anomalies were detected during these tests.

Following these tests, two seal/sleeve valve configurations were tested for life to determine if the qual/vehicle life-limiting wear patterns could be duplicated. The two units had diametrical clearances of 0.0010-0.0012 in. (flight) and 0.0020-0.0022 in., respectively. Each unit was subjected to 2500 ambient cycles, 2000 steady state high-temperature oxygen cycles, and 25 thermal transient tests. Vibration testing (3 hours per axis, 3 axes) is currently in preparation. At this time, the flight clearance unit is showing wear similar in nature and scope to that of the qual unit, while the increased clearance unit is showing similar wear that is much reduced in scope.
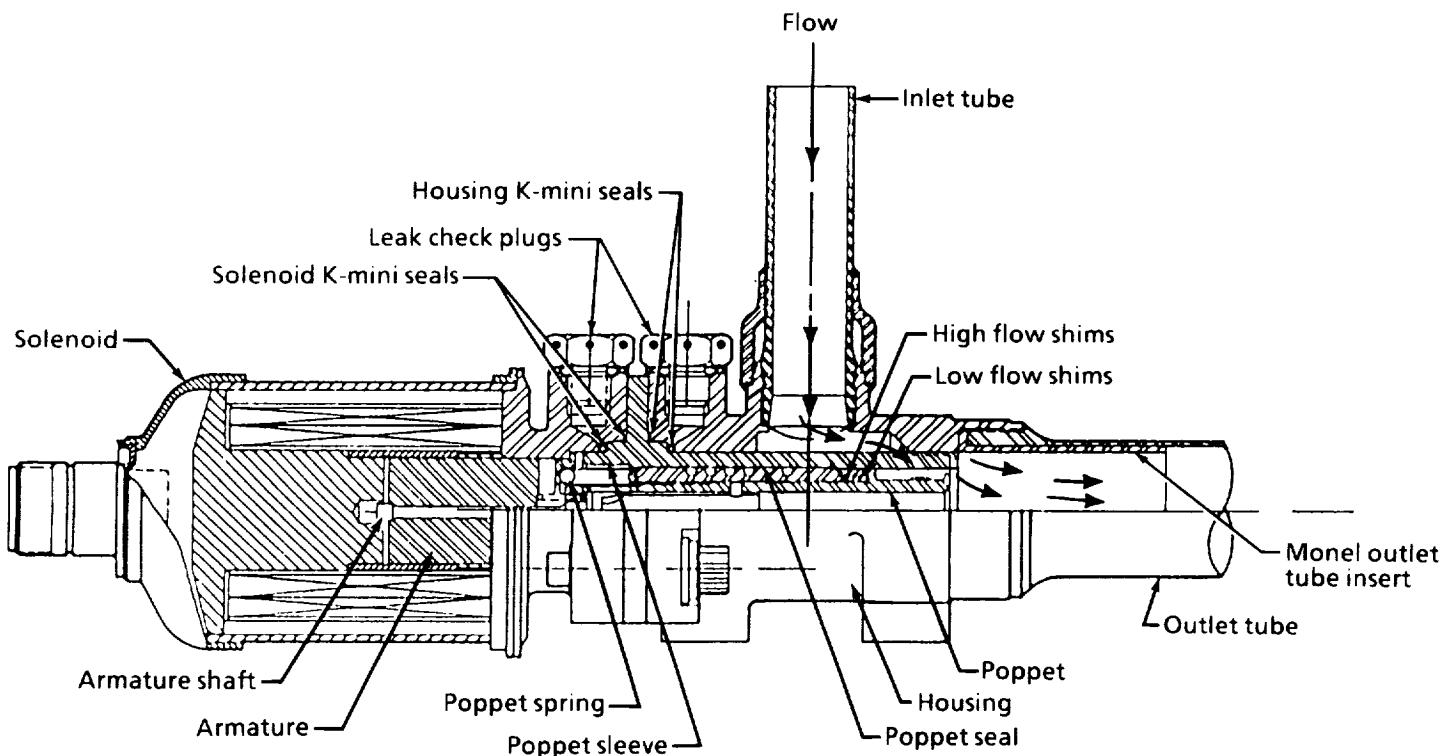
Shuttle MPS type IV GO$_2$ flow control valve.

Pressure Decay Boiling Experiments

PI: Nancy E. Munoz/EP4
Reference SST 18

The transfer and storage of liquids in a reduced gravity environment gives rise to thermohydraulic effects that could cause problems during the design and ultimate management of on-orbit fluid systems on Space Station Freedom and future space transfer vehicles. Processes such as the venting of pressure vessels and the transfer of fluids between storage tanks can lead to depressurizations, which can cause boiling in the liquid.

The objective of this activity is to provide a bubble growth theory and experimental technique that determines the boundaries of the different pressure decay boiling regimes when a liquid storage tank is subjected to a rapid depressurization in a zero-g environment. The boiling regimes of interest are surface evaporation, boiling which does not disrupt the gas/liquid interface, and boiling which does disrupt the interface.

The work of previous years provided an experimental apparatus designed to allow the observation of boiling under various rates of depressurization and other environmental conditions, a numerical method for estimating bubble growth under various conditions, and a criterion for determining when the effects of gravity in individual vapor bubbles ceases to be negligible. Ground test results have shown good agreement between the theory and the rate of bubble growth during a short period of time before gravity becomes important.

In Fiscal Year 1989 (FY 1989), work concentrated on developing a generalization of the influence of gravity on individual bubble growth, relating the effect of gravity on bubble growth to the rate of depressurization in the storage vessel, and characterizing the relationship between the incipience of nucleation in liquids and the rate of depressurization. In addition, nucleation data involving liquids with different levels of dissolved gases and contaminates was developed to determine the gases' and contaminants' degree of influence on nucleation.

A correlation between the rate of pressure decrease and the rate of bubble growth was generated for water, as shown in the accompanying figure. The developed correlation fit the experimental data with a root mean deviation of 7.6 percent. An experiment was proposed for possible future work on the KC-135 low-gravity aircraft, and eventually on the Space Shuttle. A final report has been written covering the work performed under the contract.
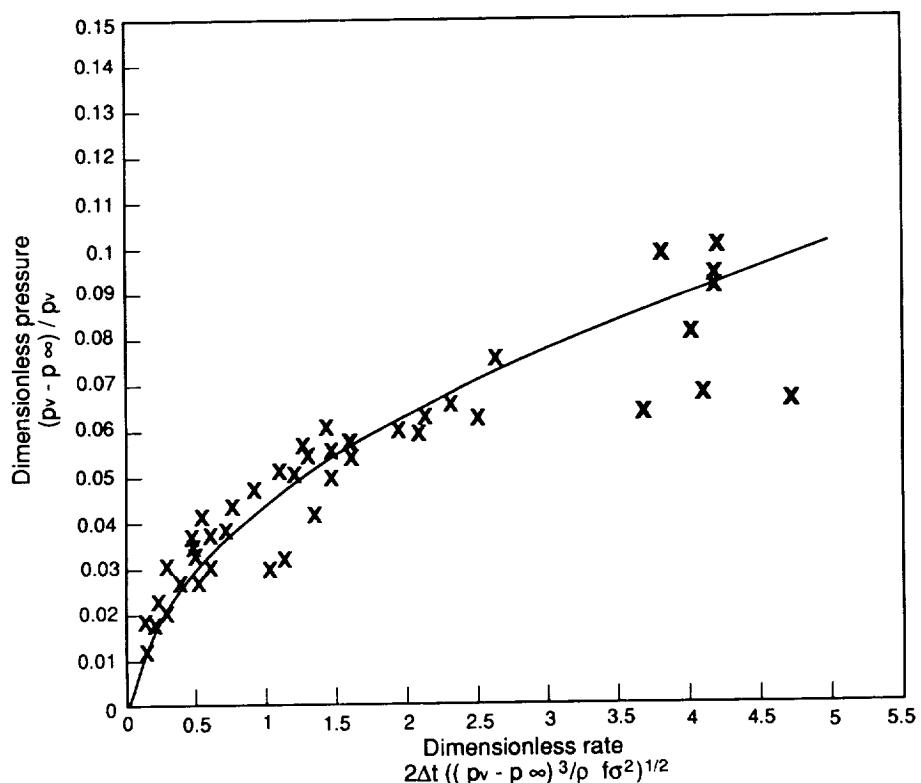
Incipience as a function of dimensionless depressurization rate.

Superfluid Helium Orbital Resupply Coupling

PI: Richard Schoenberg/EP4
Reference SST 19

Orbital consumables replenishment provides an attractive method of extending the useful life of today's costly and complex satellite and is a key part of the economical and practical commercial development of space. An important element which enables this replenishment capability is a coupling (quick disconnect) between a supply tanker and the receiving spacecraft, to allow fluid transfer. The Johnson Space Center (JSC) is responsible for the development and application of orbital re-supply technologies for both Earth-storable and cryogenic applications. Work is currently being done at JSC on the development of Earth-storable as well as superfluid helium tankers.

The objective of this effort is to develop a coupling for the transfer of superfluid helium (He II) in zero-g. The coupling was designed for use on the Superfluid Helium On-Orbit Transfer (SHOOT) flight experiments. This flight experiment is managed by the Goddard Space Flight Center (GSFC) and is de-signed to simulate a satellite-servicing operation.

The coupling is designed to minimize heat leak (under 1.0 W) in order to maximize the amount of fluid transferred. Due to the super-cryogenic nature of He II (tempera-ture below 2 K), the coupling must isolate the cold inner portions from the ambient outer portions. The coupling incorporates the necessary redundancy features to comply with safety requirements for performing resupply operations in the Space Shuttle Orbiter payload bay and at other on-orbit servicing locations, as well as being readily modifiable for automatic operation. The coupling may be subsequently incorporated into He II flight systems, such as the Superfluid Helium Tanker (SFHT), the Space Infrared Telescope Facil-ity (SIRTF), and the Particle Astro-physics Magnetic Facility (ASTRO-MAG).

The effort in Fiscal Year 1989 (FY 1989) focused on a demon-stration of the applicable technol-ogies through the design, fabrica-tion, and assembly of development-level hardware. Accomplishments during FY 1989 included testing of critical subassemblies, such as thermal isolation jackets and the cryogenic seals. The majority of the parts required for the two development units were fabricated in FY 1989. Buildup of the ambient and cryogenic test facilities are nearly complete. Assembly of the first development unit was begun in FY 1989 and will continue into early FY 1990. Also accomplished was a series of tests performed in the Weightless Environment Training Facility (WETF) at JSC to aid in the coupling design from an EVA standpoint, as well as to investi-gate possible EVA scenarios.
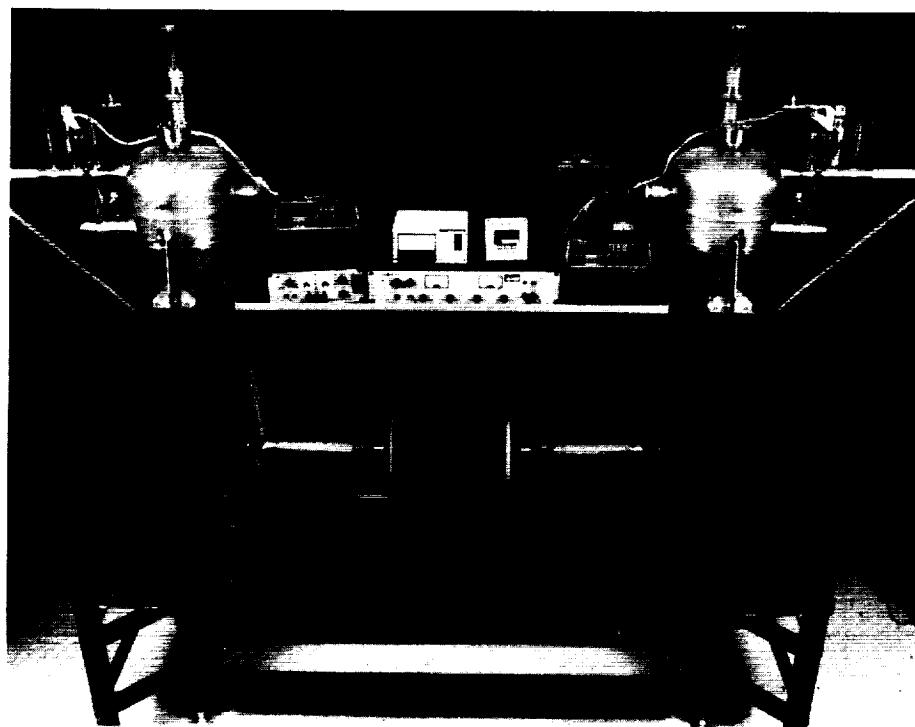
He II coupling cryogenic test fixture shown with coupling simulator.

Shuttle Infrared Leeside Temperature Sensing Experiment

PI: E. Vincent Zoby and David A. Throckmorton/LaRC
Reference SST 20

The Shuttle Infrared Leeside Temperature Sensing (SILTS) experiment obtains high-spatial-resolution temperature measurements of the leeside surface (wing and fuselage) of the Space Shuttle Orbiter during atmospheric reentry. These measurements are obtained by means of an imaging, infrared radiometer, located atop the vertical tail of the Orbiter Columbia. The SILTS experiment was first flown on Space Transportation System (STS) 61-C in January 1986. However, several experiment operational anomalies occurred on that flight, which significantly compromised the experiment results. Consequently, only limited data were collected, and those data yielded only qualitative results. Following STS 61-C, elements of the experiment hardware were modified to preclude a reoccurrence of the anomalies experienced on that flight.

The SILTS experiment was reflown on STS-28, in August 1989, and all hardware elements operated as intended. In its STS-28 configuration, the experiment obtained images of the left wing throughout the hypersonic portion of the atmospheric entry. A typical image obtained on STS-28 is shown in the figure. This is a false-color representation of the raw camera output signal, expressed in volts. Clearly visible in the image are the wing leading edge (with individual reinforced carbon-carbon panels discernible), the gap between the inbound and outbound elevon surfaces, and the orbital maneuvering system pod at the base of the vertical tail. These data will be further processed to infer quantitative surface temperature information. The additional data processing accounts for the calibration of the optical scanning system and its infrared detector, the emissivity of the viewed surfaces, and radiation from the window through which the camera "views" the wing.

The SILTS data characterize the thermal response of the Orbiter's thermal protection system materials to the complex, three-dimensional, vertical, separated flowfield which exists about the vehicle during atmospheric entry. Such a flowfield cannot be accurately simulated in wind-tunnel facilities. The SILTS data will be used as benchmark flight data with which to validate the capabilities of state-of-the-art computational fluid dynamic techniques for predicting this flight environment.
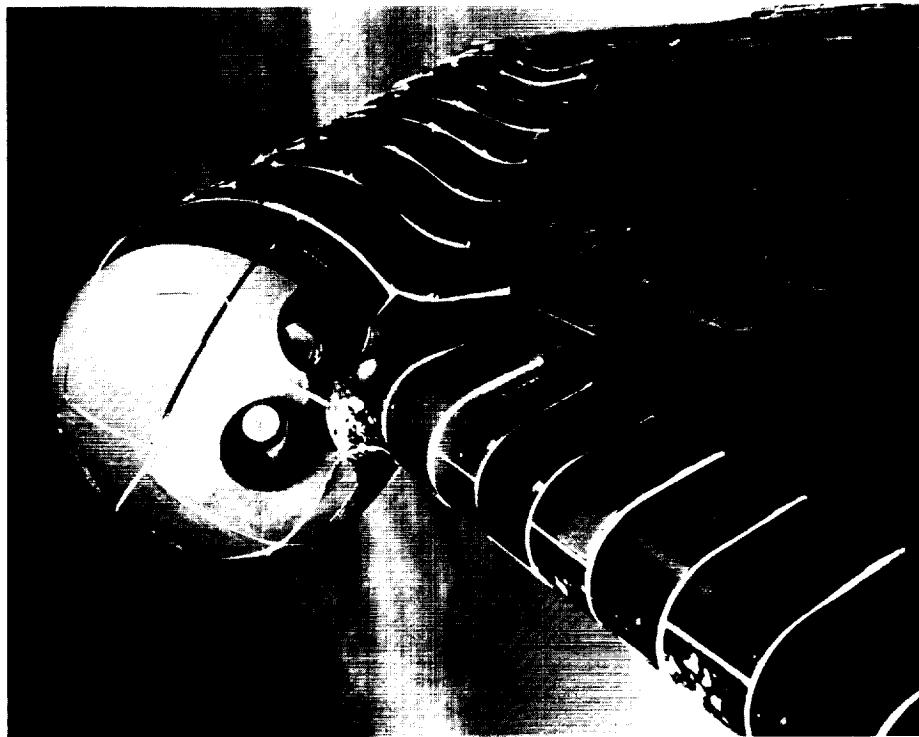
SILTS STS-28 wing data.

SILTS camera coverage.

IR camera

GN$_2$ coolant system
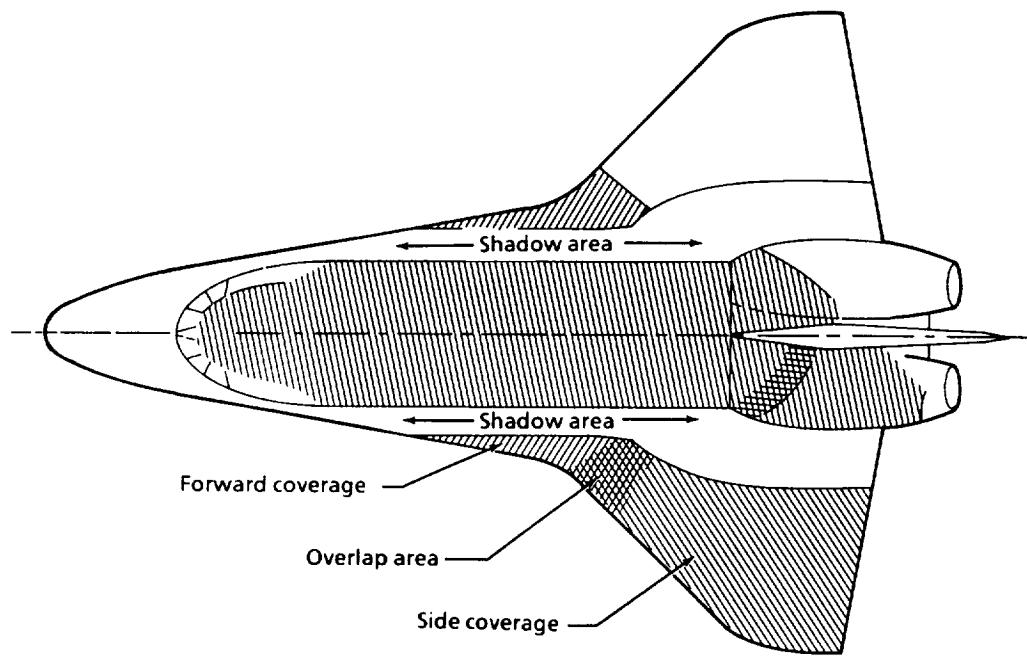
Data and control module
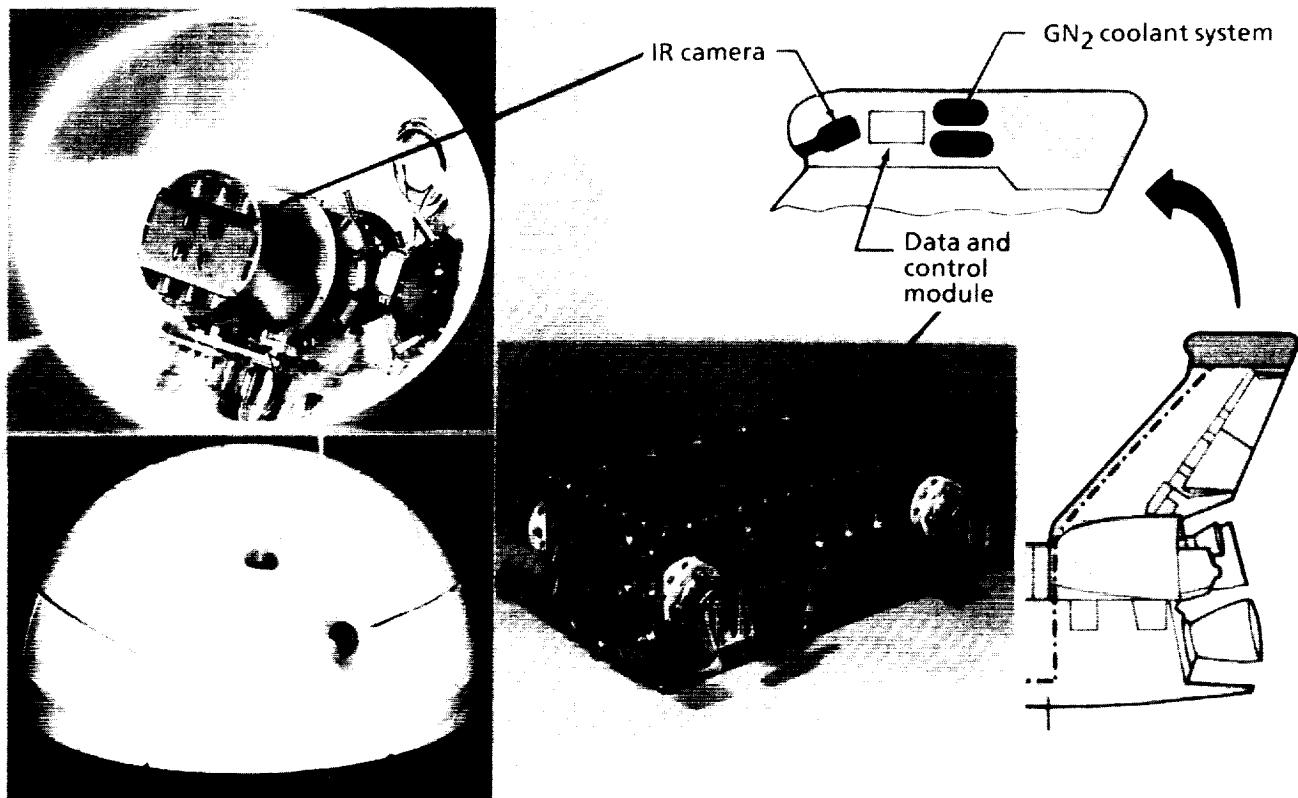
RSI dome for thermal test

SILTS engineering development.

347 Stainless
(N2 cooling tubes 6 places)
(>1200°)

Molded Carbon
Phenolic
(window mount)
(3000°F)

Silicon Windows
(2500°F)

Haynes 188 Plate
AMS 5608
(window spacer)
(>2200°F)

Inconel
(metallic seal)
(2300°-2437°F)

Haynes 188 Plate
AMS 5608
(window retainer)
(>2200°F)

Screw

Retainer

1/4 in. Forged AL
6066-T6
(dome) (>500°F)

6066 T6 AL
(window mount retainer)
(>500°F)
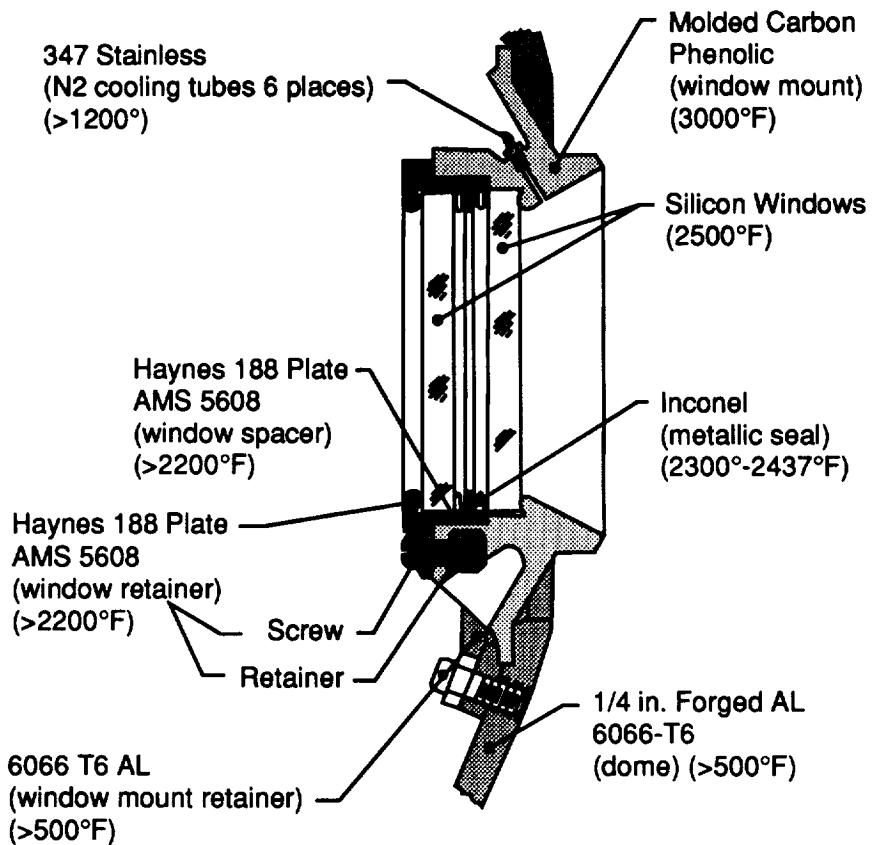
SILTS window mount assembly.

IR Camera

GN^2 Coolant System

Data and
Control
Module

Panel R-11
Control
Panel

Volume "D"
Recorder
I/F Module

F.S.
576

F.S.
1307
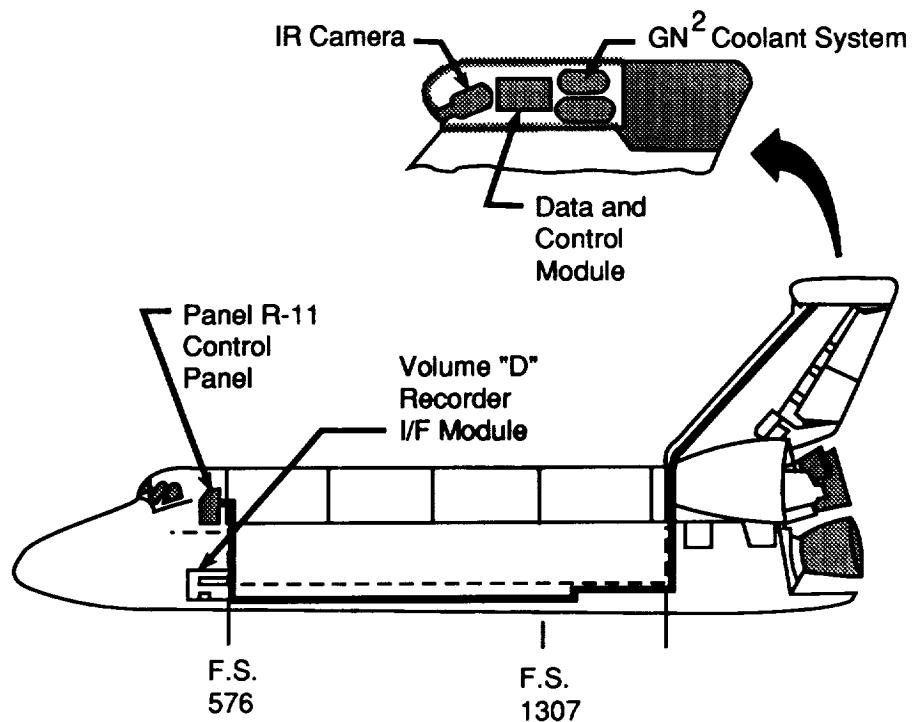
SILTS experiment and support hardware.

Shuttle Entry Air Data System (SEADS) Experiment

PI: Paul M. Siemers, III /LaRC
Reference SST 21

To accomplish accurate flight aerodynamic research, precise knowledge of vehicle attitude and state (or air data) is required. Air data, which include freestream dynamic pressure, angle of attack, and angle of sideslip, are not available from the Space Shuttle Orbiter for speeds greater than Mach 3.5; and the accuracy of the available air data does not meet research requirements. The Shuttle Entry Air Data System (SEADS) was developed to demonstrate the flush orifice air data system concept and to make the measurements required for precisely determining the required orbiter air data. The SEADS has been integrated into the Orbiter Columbia and consists of a baseline geometry nose cap that includes an array of 14 Columbium pressure port/penetration assemblies, associated pressure tubing, dual absolute pressure transducers, and system monitoring instrumentation. Data from the SEADS are transmitted to the support system for orbiter experiments (OEX) and stored in the OEX recorder for post flight reduction and analysis.

The SEADS has successfully flown on STS-61C, January 1986, and STS-28, August 1989, and obtained data across the atmospheric flight speed range (hypersonic through subsonic) at altitudes below 290,000 ft during both ascent and descent. Reduction of the flight data showed that the experiment functioned as designed. External inspection of the nose cap and pressure port/penetration/tube assemblies showed them to be in excellent condition, having been exposed to a predicted temperature of less than 2,500 degrees F. Pressure testing of the pressure port/penetration/tube assemblies verified the structural integrity of the system. Analysis of the STS-28 data showed excellent repeatability when compared to STS-61C data, with little or no change in the performance characteristics of the pressure transducers as a result of the 3-year down time.

The pressure anomalies observed in the STS-61C ascent data, which were theorized to be the result of the accumulation of water in the tubes, are not present in the STS-28 data. Therefore, the SEADS STS-28 ascent data, coupled with the baseline orbiter Ascent Air Data System (AADS) data and ascent Best Estimated Trajectory (BET), will be used to develop a preliminary SEADS ascent air data algorithm. The initial application of the descent air data algorithm has been accomplished incorporating both the on-orbit zero and entry bias corrections. The results show excellent agreement with the postflight descent BET. The analysis has also identified an atmospheric discontinuity (pressure decrease) at approximately 215,000 ft altitude. The possible causes of this discontinuity, as well as the impact of the discontinuity on the orbiter's aerodynamic performance, are being evaluated. The fact that the discontinuity occurred coincident with a planned orbiter roll maneuver is complicating this evaluation.

Analysis of the SEADS data will continue in cooperation with National Oceanographic and Atmospheric Administration (NOAA) and orbiter aerodynamic performance analysts to optimize the SEADS algorithm, to evaluate disagreements between the in-situ SEADS results and the BET, and to develop the air data baseline for STS-28.
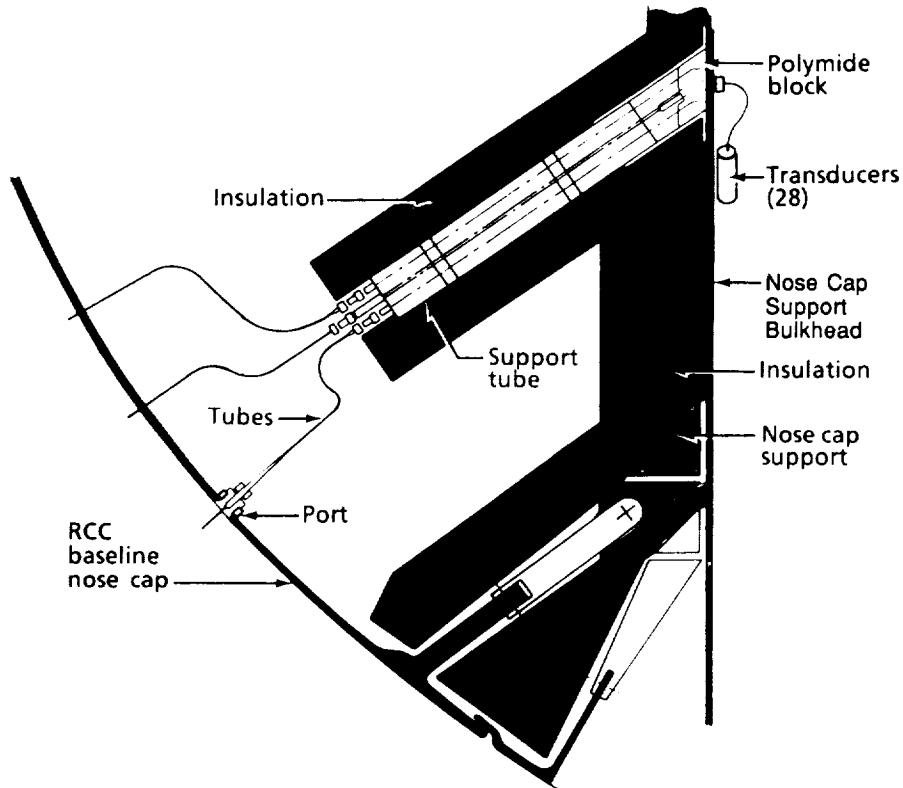
SEADS nose cap assembly.

Sensor-Based Whole Arm Manipulation for Adaptive Grasping

PI: Clifford W. Hess/EC5
Reference SST 22

It will be desirable for certain types of future robotic systems to have the capability to securely grasp items which are larger than the grasp envelope of their end effectors. One means of accomplishing this goal would be to provide a special interface for the end effector on the item to be grasped. A more general solution would use the arm surfaces of the robot to grasp the item, much like big fingers. Using arms in this manner is called whole arm manipulation, and the positioning of the arm links to achieve a secure grasp of an item is called adaptive grasping.

The use of whole arm manipulation for adaptive grasping of objects would enable a robot to interface with a larger class of items than could be achieved with the use of end effectors only, and would eliminate the need for special interfaces. One type of robotic system that could benefit from whole arm manipulation is the Extravehicular Activity (EVA) Retriever, a highly autonomous, free-flying, robotic system being developed at the NASA Johnson Space Center (JSC) to retrieve equipment and crewmembers that inadvertently separate from the Space Station. Having the capability to use its arms as well as dexterous end effectors to adaptively grasp items which must be retrieved will provide the EVA Retriever with the versatility of grasping various sizes and shapes of objects which are undefined when its retrieval mission is initiated. Whole arm manipulation technology could also be useful for the Flight Telerobotic Servicer and the Satellite Servicing System.

A Phase I Small Business Innovative Research (SBIR) project to determine the feasibility of whole arm manipulation for the EVA Retriever system was completed in Fiscal Year 1989 (FY 1989) by Intelligent Automation Systems, Inc. of Cambridge, Massachusetts. The project investigated the arm sensor and control requirements necessary to perform adaptive grasping, along with assessing the technology available to meet the requirements. Experiments with a prototype tactile sensor system were performed using a whole arm manipulator, located in Dr. J. K. Salisbury's laboratory at the Massachusetts Institute of Technology (MIT) Artificial Intelligence Laboratory. A two-dimensional grasping simulation for the EVA Retriever was also developed and tested to provide the capability to experiment with grasping strategies for various objects and initial conditions.

The Phase I SBIR effort has shown that the development of a tactile-sensor and joint-torque-instrumented robot arm grasping system appears feasible for the EVA Retriever system. Information gained from this research effort will be utilized in developing and demonstrating whole arm manipulation capability for the EVA Retriever test article located at JSC.
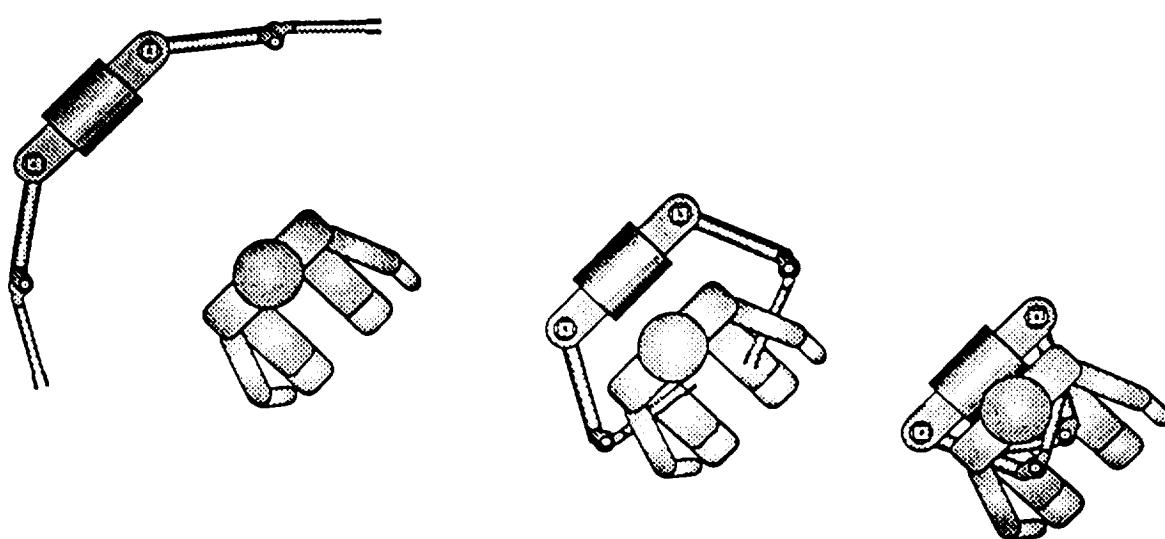
The EVA Retriever approaching, enclosing, and, by using sensorized robotic arms, gently grasping a stranded crewmember.

Automatic Grasping: An Investigation of Reflexive Behaviors

PI: Clifford W. Hess/EC5
Reference SST 23

Research Grant NAG 9-319 was awarded to the Massachusetts Institute of Technology's (MIT's) Artificial Intelligence Laboratory, with Dr. J. K. Salisbury as the principal investigator, to examine the development of automatic grasping capabilities for robotic hands by applying the same principles that humans frequently utilize when grabbing everyday objects. To grasp such objects, humans frequently reach out and grab without consciously planning the trajectories of their arms, hands, or fingers. Many of the simple manipulation tasks performed by humans rely upon unconscious behaviors triggered by sensory information. For example, infants close their fingers when pressure is applied on their palm. These basic behaviors seem sufficient to perform a useful range of grasping motions and could have applications in controlling robotic end effectors. One type of robotic system which could utilize such automatic grasping capability is the Extravehicular Activity (EVA) Retriever, a highly autonomous, free-flying robot, being developed at the NASA/Johnson Space Center. The EVA Retriever could rescue a crewmember or equipment that might inadvertently separate from the Space Station.

The first year's research activities were completed in August 1989. The initial research approach utilized a simple model of a robotic hand and established the geometric conditions necessary for achieving force and form closure grasps for a limited class of objects (i.e., cylinders and convex polyhedrons). Force closure restrains the object by friction and provides a less secure grasp than form closure, which structurally restrains the object. A reflexive grasp behavior was defined for this class of objects as a set of arm/hand motions triggered by sensory information on the hand (e.g., tactile, joint force, etc.). The grasping region for an object to be successfully grasped, utilizing reflexive behavior, was also investigated. Grasping regions are the volumes where an object should be located, relative to the hand, prior to grasping, to ensure a successful grasp. The size and shape of the volumes depends upon the hand and object geometry and can be increased by employing sensor-triggered actions (behavior). Both sensorless and sensory behaviors were investigated. Example behaviors were successfully implemented on a Salisbury robotic hand, located at MIT, to demonstrate the feasibility of simple grasping reflexes.

The research grant has been renewed for a second year and will build upon the results of the first year's efforts by extending the theoretical work on defining the grasp region for sensor-driven behaviors along with implementing new developments on an upgraded laboratory robotic arm/hand system.

Grasp region definition for object → Arm/hand approach to object → Hand sensor activation by object → Initiative reflexive grasp action → Grasp of object
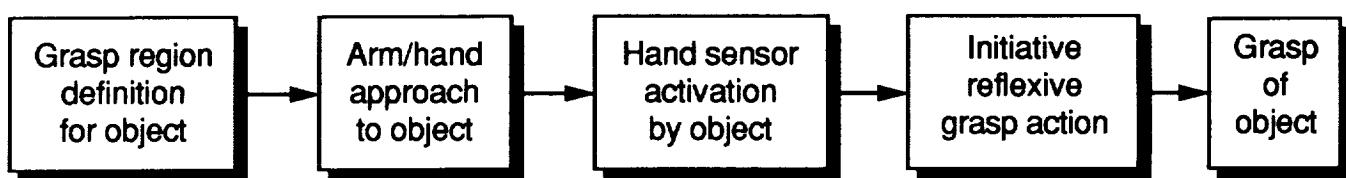
Scheme for grasping an object, using sensor-based reflexive behavior.

Exponential Grids in Robotic Vision

PI: R. D. Juday/EE6
Reference SST 24

Polar exponential sensor arrays are sometimes advantageous over conventional Cartesian raster imaging sensors when wide field of view, high central resolution, and rotation and zoom invariance are desirable. As a sensor translates in a three-dimensional space of imaged objects, image flow (the local velocity vector field of features in the image) can become pure translations for planar surfaces normal to the motion of the sensor platform. Further, making time-to-collision maps (which become distance maps when speed is known) becomes a linearized problem after a polar exponential transformation. Finally, the three-dimensional spatial resolution cells for digital stereopsis have natural expression following transformation from a Cartesian to polar exponential coordinate system, with positive ramifications for economy in the determination of disparity and inference of distance.

Transitions Research Corporation was awarded a Small Business Innovation Research (SBIR) contract. This contractor will deliver a system in the form of a mobile tracking robot, having built-in vision, based on the polar exponential grid. Results of several Johnson Space Center (JSC)-sponsored research efforts in both hardware and algorithms will be incorporated in the technology. The Programmable Remapper is exemplary of the hardware. Algorithmic work includes the digital stereo work done at Texas A&M University by Dr. Normal Griswold, the highly allied research into determination of optimal polar exponential grid parameters under a NASA graduate research fellowship at the University of New Hampshire (Mr. Joe Bailey, under Dr. Richard Messner), and the synthetic estimation filter developed by Drs. Richard Juday and Stanley Monroe (Tracking Techniques Branch and Lockheed Engineering & Sciences Company, respectively).

Applications for the technology include autonomous landing on planetary bodies; spacecraft docking, tracking, and stationkeeping; and mobile robot navigation. This technology also shows considerable promise for commercial adaptations.

Sensor array
(u, v)

Image plane
(x, y)

Three-dimensonal
domain
(x, y, z)
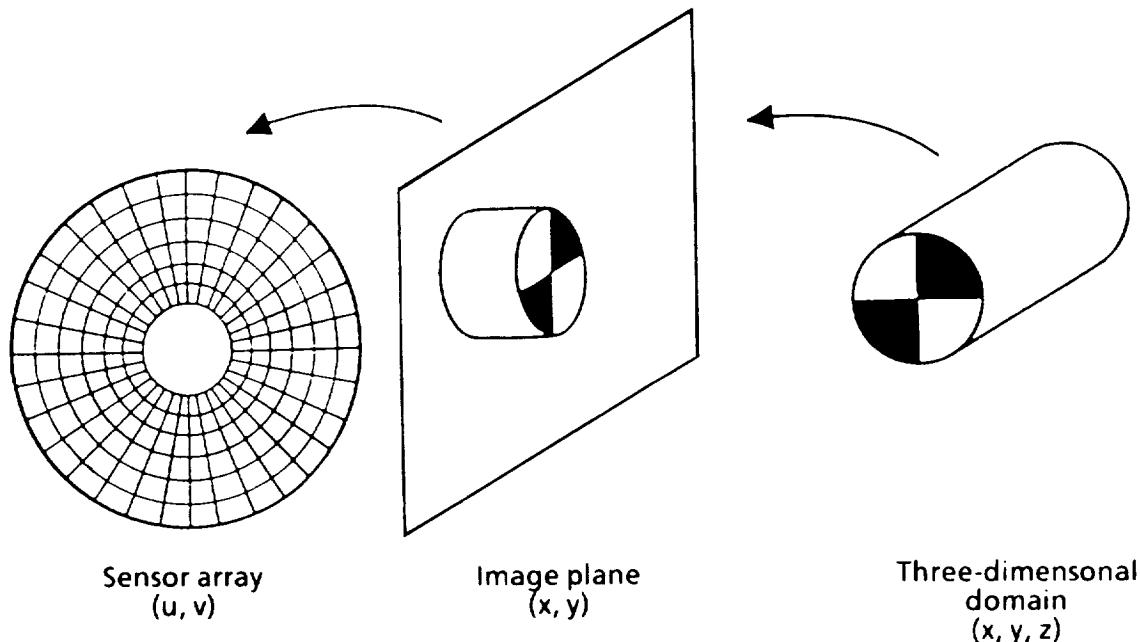
Geometric transformation domains.

157
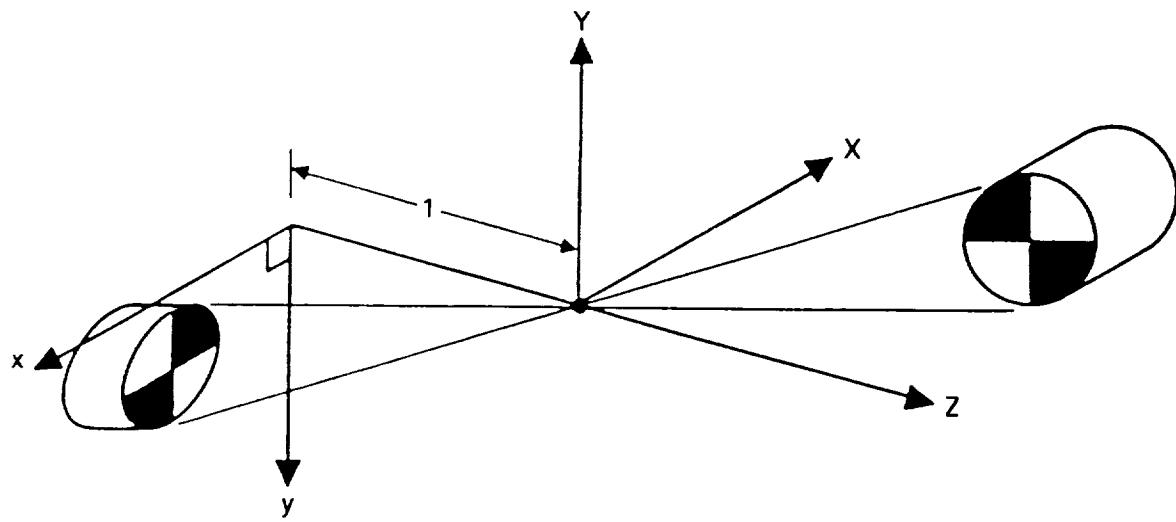
Projection of three-dimensional objects onto image plane.

(Image domain)

(Sensor indices)

$v = 2\pi$

N-Wedges

(q, p)

(q, p)

N-Rows

x

M-Rings

$\log(z)$

e^{w}

o

u

M-Columns

(b) w- plane
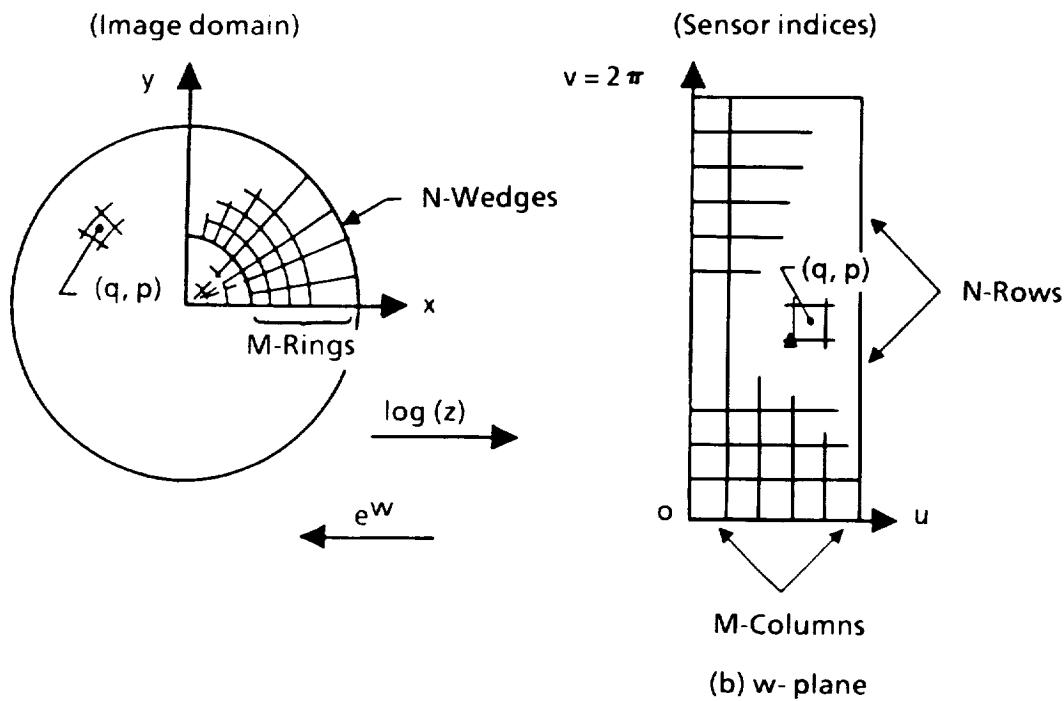
Conformal mapping from image coordinates to sensor array.

Robotic Vision/Tracking Sensors

PI: D. E. Rhoades/EE6
Reference SST 25

It has been recognized that many space-oriented tasks can be enhanced considerably with the use of robotic devices. One of the most important factors in the success of these devices is their ability to see; hence, a robotic vision system. In today's technology, vision systems take many forms and may do a portion of the ultimate task very well; however, the goal of achieving the capability of the human eye/brain combination is only something to strive toward. In some aspects, current technology exceeds the human eye capability, such as infrared night vision devices, long-range lenses, and high-speed shutters. However, in the area of object recognition and identification under varying conditions in an unpredictable environment, the technology is in its infancy.

There is a continuing effort to make progress in the development of a robotic vision system, both in sensors and in processors. Candidate sensor types include video cameras, three-dimensional (3-D) light radar (ladar), millimeter-wave radar, and infrared detectors.

One ongoing project that is implementing a combination of sensors is the Extravehicular Activity (EVA) Retriever. This is a three-phase ground demonstration of a concept that will result in a robotic system to retrieve loose objects in space—from a "dropped" tool to a disabled astronaut. The system consists of a Manned Maneuvering Unit with a robot body attached, including two robotic arms. The first phase was completed with simple target recognition capability using a video tracking system with a 3-D imaging ladar to provide range information. The second phase is currently in progress and has expanded the capability to include obstacle avoidance and path planning and more extensive use of the

3-D ladar data to determine grasp points and orientation for the robotic hands. The video system for phase I had a single CCD camera. Phase II has six video cameras, including one on each hand for grappling information. Also, a turntable for panning the ladar scanner has been added. This allows the robot to look around for obstacles as it is moving toward the prime target for retrieval.

Two new vision systems and associated software have been purchased and are being evaluated to provide more robust target identification and tracking. A contract for offsite development of software to process the 3-D ladar data for target recognition has been awarded and is in progress. A fiber optic link between the Precision Air-Bearing Facility at the Johnson Space Center (where the EVA Retriever ground demonstrations are perform-

ed) and the Optical Processing Laboratory has being installed. This will allow the new vision systems to remotely process EVA Retriever video data and evaluate their application in an operational environment.

The goal of all the above-mentioned activities is to advance the capabilities of the vision/tracking systems for potential applications in many areas of space operations that can be enhanced with some form of robotic vision. These include autonomous target recognition, orientation determination, and tracking to support satellite servicing, crew and equipment retrieval, manipulator approach/grapple/tool handling operations, vehicle inspections, an astronaut "helper" during EVA, and autonomous rendezvous/docking/stationkeeping with non-cooperative satellites.
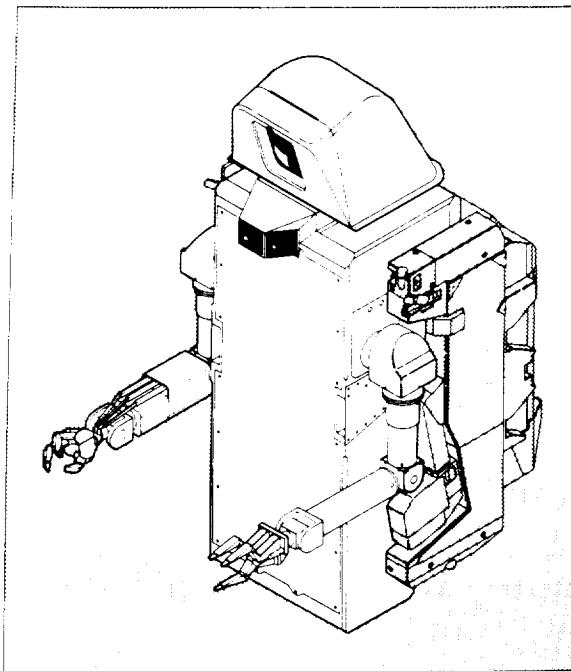
The new EVA Retriever TBD.

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Space Shuttle Remote Manipulator System Advanced Force/Torque Control Task

Reference SST 26

The Space Shuttle Remote Manipulator System (RMS) is a man-in-the-loop, rate-servoed system that has flown on past Shuttle missions. The RMS represents state-of-the-art technology in the operational space manipulator world. It has met and exceeded all of its design requirements for payload deployment and retrieval, Extravehicular Activity (EVA) astronaut support and positioning via a mobile foot restraint attachment, local illumination via mounted lights, and Closed Circuit Television (CCTV) camera positioning.

Current concepts for the on-orbit assembly sequence of the Space Station Freedom involve constrained motion tasks, using the RMS. An example of these tasks is using the RMS to push thermal radiator panels into their respective receptacles that, due to tight tolerances, will offer resistive motion to the RMS. In order to meet these emerging requirements for constrained motion tasks, an upgrade to the RMS is being investigated to provide a closed-loop force/torque control capability.

The investigation started in November of 1988 and is planned to be completed by the end of 1991. Three annual RMS closed-loop force/torque control ground demonstrations are being developed in a series of increasing fidelity. In the first year, various control laws will be analyzed and tested on a Robotics Research 1607 arm. Next year, the second demonstration will be the implementation of the most promising control laws on the full-scale RMS hydraulic manipulator. In the third year, the selected control law will be implemented on a high-fidelity, real-time RMS simulator that will be interfaced to a 6 degree-of-freedom force sensing table to provide the simulated contact forces.

The first year accomplishments can be categorized under three tasks.

Task 1 consists of a survey of the research literature for candidate control algorithms and analyses, based on performance and stability of the algorithms as they are applied to constrained manipulator models. A report was published at mid-year to document the survey results. Mechanical and control characteristics of the RMS and the Robotic Research 1607 arms were also discussed in the report. Analysis efforts are underway for two candidate control algorithms: (1) impedance (where the manipulator position/rate commands are modified by the effect of the force feedback) and (2) hybrid position and force (where the manipulator Cartesian space is divided into those degrees-of-freedom that are explicitly position/rate controlled and those that are explicitly force-controlled). Additional analyses were also carried out using a single RMS joint model to determine the RMS characteristics that would influence the force torque control design. The characteristics that have been identified (link/joint flexibilities, large payload, time delays, and actuator saturation limits) have not yet been either addressed or resolved by the robotics research community.

Task 2 consists of hardware and software modification to the Robotics Research original controller to: (1) provide a digital interface to the low-level servo controller (2) provide a Cartesian motion control interface via hand controllers (3) access force/torque sensing data. Effort 1 was completed. Efforts 2 and 3 are underway.

Task 3 consists of control laws design, implementation, and testing on the Robotics Research arm. In order to design a control law, the arm mass properties and servo parameters must be known. A parameter identification task was completed and arm parameters, such as link and joint mass, joint friction and damping, servo gain, and joint stiffness were identified.
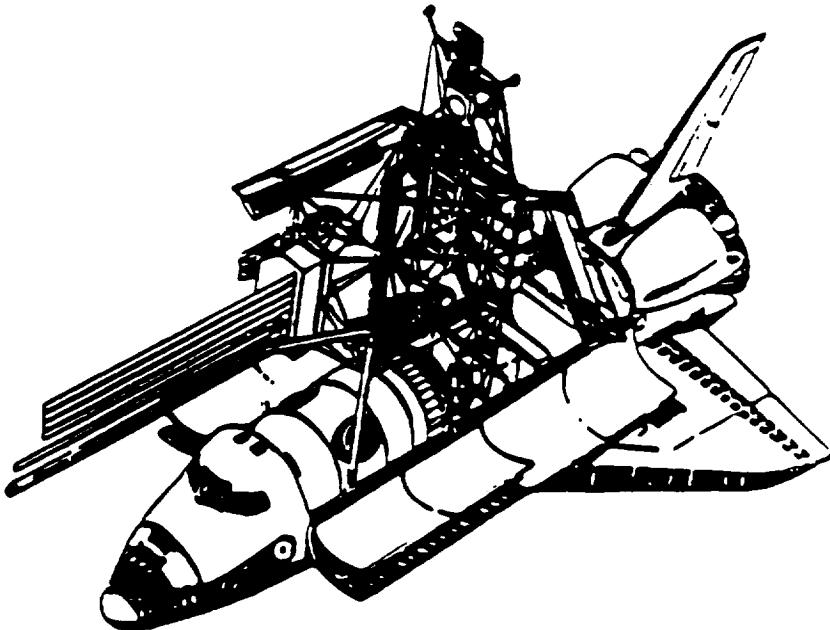
Radiator panel installation with the RMS.

Flexible Arm Control Experiment (FACE)/ Dexterous Manipulator Advanced Control Experiment (DMACE)

PI: Gerald J. Reuter/EF2
Reference SST 27

The objective of the FACE experiment is to (1) advance the state of the art control of large articulated space structures and (2) to support validation of nonlinear/ large angle dynamics and control. The objective of the DMACE experiment is to (1) demonstrate advanced servo control algorithm performance and (2) to develop a knowledge base for flight and ground teleoperation. A manipulator flight test bed was proposed to support rigid and flexible manipulators. The processing system will support varied controls research objectives. The experiment will support both autonomous and teleoperated functions. Emphasis was placed on growth capability.

The FACE experiment consists of the following tests. The System Identification Test is designed to validate the dynamic model of the FACE arm in a zero-g environment. The Large Angle Free Motion Test is intended to accomplish the following objectives: (1) Validate the nonlinear rigid/elastic dynamics of the FACE arm for large angle motion at the joints. and (2) provide a reference baseline to compare the other control algorithms. The Active Modal Control Test is the crucial part of the experiment and involves the following objectives: (1) Demonstrate the feasibility of a high-bandwidth control system, (2) demonstrate the feasibility of a closed loop control mode with an end point sensor, (3) test control algorithms for the generic control structures interaction problem, and (4) test disturbance rejection. The Compliant Control Test will demonstrate the feasibility of actively controlling interaction forces and torques between the manipulator and the payload, and will model the constrained dynamics of the manipulator. The Adaptive Control Test will demonstrate increased performance gained in using adaptive control techniques to compensate for poorly known parameters of the manipulator/payload system.

The DMACE experiment consists of the following tests.

- Teleoperation from the National Space Transportation System (NSTS) or Shuttle aft flight deck. The main objective of this test is to evaluate the human-machine interface during teleoperation in an environment with relatively direct contact between the operator and the experiment.

- Teleoperation from the Ground. This test is designed to evaluate the effects of increased sensory distance between the operator and experiment, while the experiment is embedded in a realistic space environment.

- Free Motion Tests. The automated performance on planned trajectories will be analyzed as a function of controller complexity in a realistic space environment with a wide range of payload conditions.

- Constrained Motion Test. This test is designed to determine the ability of the system to autonomously perform preprogrammed tasks in the space environment.

- Mixed Mode Tests. During these test, analyses of mixed modes of operator control/supervision will be conducted from the orbiter aft flight deck as well as from the ground.

The final report for this effort was received in FY89. Products included requirements definition, conceptual design of the flight test bed, and a program plan and cost estimate.
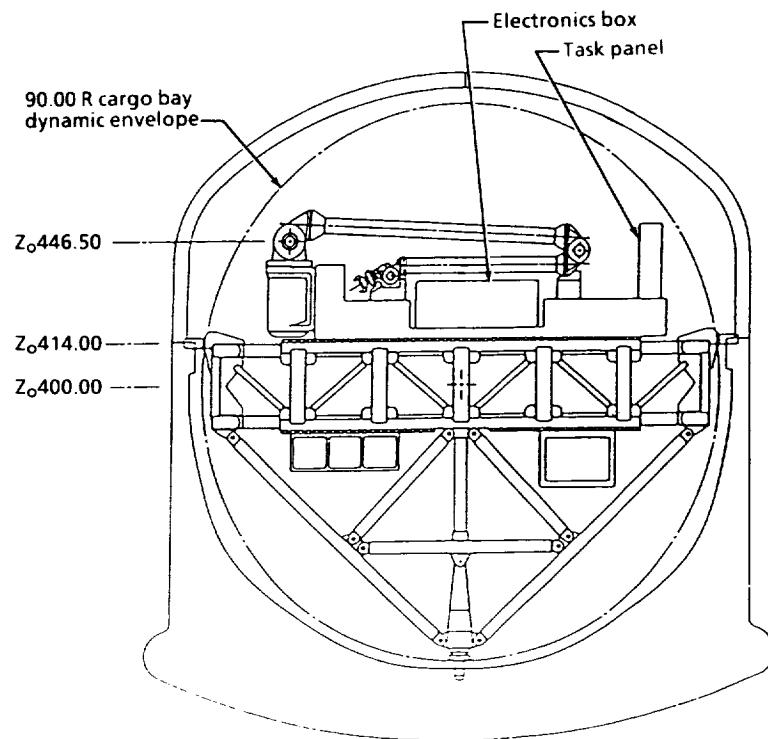
FACE in stowed position.

Labels (top figure): Electronics box, Task panel, 90.00 R cargo bay dynamic envelope, $Z_o446.50$, $Z_o414.00$, $Z_o400.00$

DMACE in stowed position.

Labels (bottom figure): 27.00, 27.00, 27.00, 90.00 R cargo bay dynamic envelope, Electronics box, Task panel, $Z_o414.00$, $Z_o400.00$
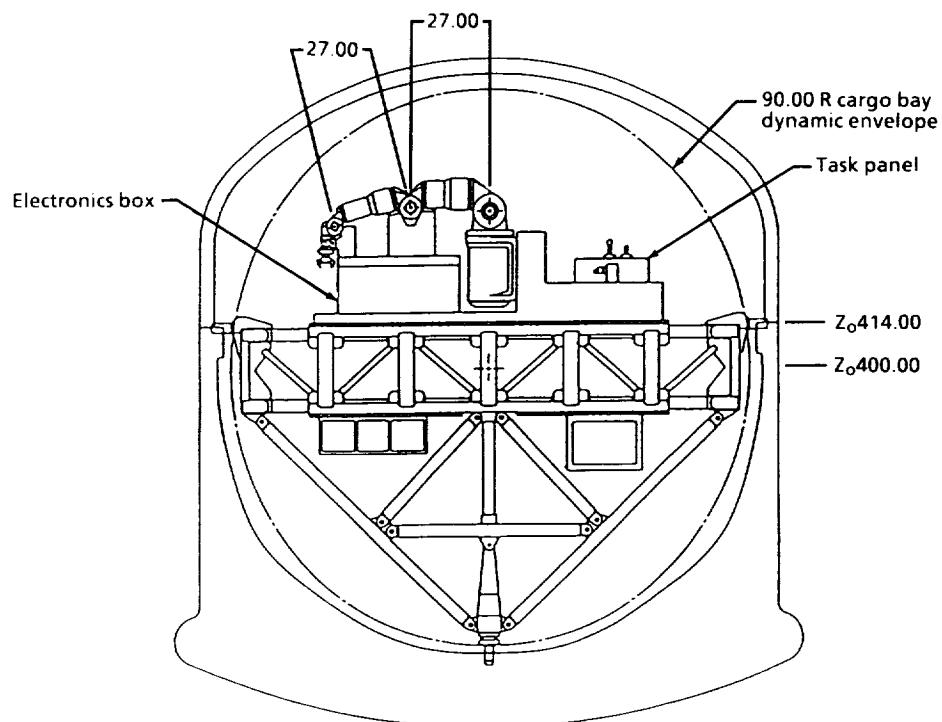
Pathfinder Autonomous Rendezvous and Docking

PI: Stephen Lamkin/EH3
Reference SST 28

Autonomous Rendezvous and Docking (AR&D) technology is being developed under the Office of Aeronautics and Space Technology's (OAST's) Pathfinder Program. AR&D is an enabling technology for unmanned missions and an enhancing capability for manned missions. It offers significant contributions to both manned and unmanned operations in Earth, lunar, and planetary orbits.

The Pathfinder AR&D project has three thrusts: (1) Systems Integration, (2) Guidance and Control, and (3) Sensors and Mechanisms.

Fiscal year 1989 (FY 1989) activities in AR&D are best characterized as "foundation-building." The major effort has been to assess the current state of the art, identify desired elaborations and expansions to this state of the art, and chart a course that will realize the desired objectivities in the future. A major effort in FY 1989 was in developing tools and facilities that will be used to test, refine, and validate basic AR&D elements, in terms of both hardware and software.

In Systems Integration, a significant accomplishment was the definition of Systems Requirements. These define component parts and elements of the AR&D system and establish performance requirements for each of the components. The component is not restricted to hardware, but includes function and functional area. In the course of deriving the requirements, developments in arenas such as the Satellite Servicer System and the Mars Rover Sample Return mission were tracked closely.

An ongoing function was project planning and control in the face of shifting funding in the current year, as well as in forecasts for future years.

Guidance and Control identified improved guidance and targeting algorithms and concurrently developed analytical tools with which to evaluate their performance. The Battin-Vaughan-Lambert rendezvous algorithm has been proposed to supplant the conventional Clohessey-Wilshire formulation. A significant effort has gone into developing the algorithm, quantifying its performance benefits, and developing the 6 and 12 degree-of-freedom (DOF) simulations that will be used in evaluating it.

Development of algorithms controlling automatic proximity operations, docking, and concepts for multivehicle cooperative control began in FY 1989. Collaterally, a detailed analysis of requirements governing the inclusion of artificial intelligence, expert systems, and related technologies was initiated. The requirement for a significant capital expenditure for verification and evaluation tools and resources has been avoided through plans to use existing facilities, with relatively minor modifications to support AR&D development.

Sensors and Mechanisms are crucial to AR&D, in that it encompasses the long-lead hardware items which will shape the basic performance envelope of the final implementation and will pace development of the entire project. Two key tasks have been initiated. A trade study of approaches to and requirements for sensors began in FY 1989 and has made substantial progress. The aim of this study is to characterize the types and numbers of sensors required to support typical AR&D mission scenarios.

Basic mechanism requirements have been identified. The basic approaches to docking, capture, and impact attenuation requirements have been identified, as well as the interrelationship between attributes of the selected mechanisms and the docking algorithms. Miniaturization of existing systems is a major challenge to mechanism designers for AR&D.
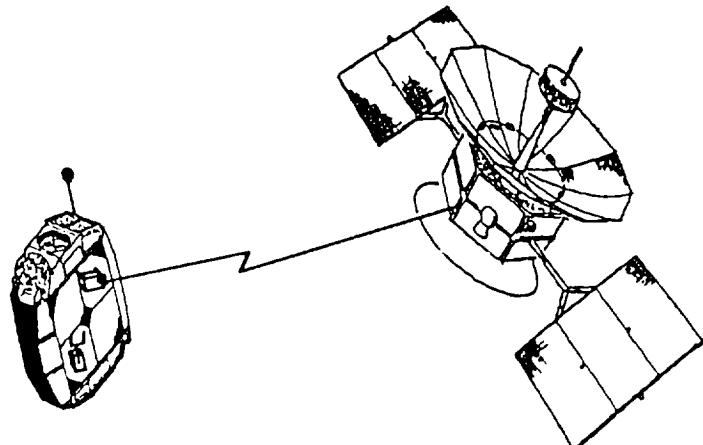
AR&D scenario, supporting satellite servicing.

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Aerobrake Thermal Protection System Robotic Assembly

PI: Reg B. Berka/ES2
Reference SST 29

Trade studies have indicated the advantages of aerodynamic braking in the planetary atmosphere over propulsive braking during orbit capture maneuvers. The aerobrake allows the planet's atmosphere to do work on the vehicle to deplete the overall vehicle energy to a state compatible with orbital trajectories. In performing this mission role, high temperatures are experienced on the outer layer of the aerobrake, due to aerodynamic heating. In addition, potentially high deceleration loads must be curried by the aerobrake primary structure.

Advanced space vehicles, particularly manned planetary vehicles, require aerobrakes that are too large to be flown directly to orbit. Instead, the large size (80 to 160 ft diameter) requires final assembly to take place in low Earth orbit (LEO). Application of the thermal protection system (TPS) to the outer surface of the aerobrake requires precision assembly to achieve the proper aerodynamic surface. The extensive nature of the TPS application would place considerable pressure on limited extravehicular activity (EVA) resources. To counter this problem, a completely automated assembly procedure is being devised that utilizes robots to perform the TPS assembly task.

Designing for robotic assembly requires attention to the limitations of the robot. The design is based on a layering concept that allows components to remain loose until the final stage of assembly. This "looseness" property allows the robot to install the parts with less concern for binding and tolerance interference. The final step in the assembly procedure uses a wedge-type plug to rigidize (through preload) and fasten the TPS components to the primary aerobrake structure. In the end, a smooth TPS surface is achieved, satisfying the aerothermodynamic requirements.

The detail design of the hexagonal TPS panels that cover the aerobrake tetratruss primary structure has been completed. A TPS filler strip that covers gaps between the hex panels has been designed and fabricated. The wedge-type plug that performs the preloading and fastening function has also been designed and manufactured. These parts and the tetratruss primary structure are scheduled for delivery in early December 1989 to support the initial robotic assembly tests. In this test, three hexagonal TPS panels will be assembled to the truss. Three filler strips will be used to fill the gaps between the hex panels. Finally, the plugs will be inserted by the robot to complete the assembly.

Heat shield robotic assembly experiment.

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MS 6   **A Portable Video Imager for High Resolution Digital Analysis
of the Retina**
Funded by: Life Sciences, Code 805-62-20-01
Principal Investigators: Gerry Taylor, Ph.D./SD5
                                Richard Meehan, M.D./Visiting Prof.
                                Michael Caputo/SD5
                                Bob Gibson, O.D./SD5
                                Norwood Hunter/SD5
Task Performed by: Johnson Space Center
                          KRUG International, NAS9-17720

MS 7   **A Contact Lens for the Measurement of Eye Movements**
Funded by: OSSA, Code 106
Principal Investigator: M. Reschke/SD5
Task Performed by: KRUG International, NAS9-17720

MS 8   **A Data Acquisition and Analysis Program for Visual Tracking
and Vestibular Research**
Funded by: OSSA, Code E
            OSF, Code M
Principal Investigators: Deborah L. Harm/SD5
                                Donald Parker, Miami University
                                William G. Crosier/SD5/KRUG
                                Kathleen M. Duncan/SD5/KRUG
Task Performed by: Johnson Space Center
                          KRUG International, NAS9-17729
                          Miami University

MS 9   **Lower Body Negative Pressure and Saline Countermeasure
Development**
Funded by: Johnson Space Center Director's Discretionary Fund
Principal Investigator: Suzanne M. Fortney/SD5
Task Performed by: Johnson Space Center

MS 10   **Biobehavioral Research Laboratory**
Funded by: OSSA, 199
Principal Investigators: Patricia A. Santy, M.D., M.S./SD5
                                Albert W. Holland, Ph.D./SD5
Task Performed by: Johnson Space Center
                          KRUG International, NAS9-17720
                          University Space and Research Association,NAS9-18128

MS 11   **Culture of Brain Microvessel Endothelial Cells and Characterization
of Atrial Notrioretic Peptide Receptors**
Funded by: Code E (UPN 199)
Principal Investigator: Peggy A. Whitson/SD4
Task Performed by: Johnson Space Center
                          KRUG International, NAS9-17720

MS 12   **Iodination of Orbiter Drinking Water**
Funded by: STS: 568-12-HS-04
Principal Investigator: Richard L. Sauer, PE/SD4
Task Performed by: KRUG International, NAS9-17720

MS 13   **Biofilm Formation and Control in a Simulated Spacecraft Water System: Interview Results**
Funded by: Code EBM: 199-04-11
Principal Investigator: Richard L. Sauer, PE/SD4
Task Performed by: KRUG International, NAS9-17720

MS 14   **Bioreactor Incubator Tissue Culture System**
Funded by: Code EN: 694-01-2305
Principal Investigator: David A. Wolf, M.D./SD4
Task Performed by: Johnson Space Center
                  KRUG International, NAS9-17720

MS 15   **Personal Infrared Telemetry System**
Funded by: RTOP
Principal Investigator: Don Stilwell/SE3
Task Performed by: Payload Systems, Inc.
                  General Electric Government Services, P.O. #G890047-J45

MS 16   **Second-Generation Life Sciences Laboratory Equipment (LSLE) Microcomputer**
Funded by: RTOP
Principal Investigator: Don Stilwell/SE3
Task Performed by: Wilton Industries, Inc.
                  General Electric Government Services, P.O. #G89000400-J45

MS 17   **A Stowable Lower Body Negative Pressure Device**
Funded by: RTOP 199-80-21, EDO
Principal Investigators: Barry M. Levitan/SE3
                          John C. Charles/SD5
Task Performed by: Johnson Space Center
                  General Electric Government Services, NAS9-17884

SOLAR SYSTEM SCIENCES

SSS 1

Analysis of Interplanetary Dust Particles for Volatiles and Simple Molecules
Funded by: Planetary Biology (UPN 199)
Principal Investigator: Everett K. Gibson, Jr./SN2
Task Performed by: Johnson Space center

SSS 2

Carbon-Based Chemistry on Mars: Possible First Evidence from Carbonate Minerals in SNC Meteorites
Funded by: Planetary Materials (UPN 152)
Principal Investigator: James L. Gooding/SN21
Task Performed by: Johnson Space Center
Lockheed Engineering and Sciences Co., NAS9-17900

SSS 3

Orbital Debris Program
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigators: Donald Kessler/SN3
Andrew E. Potter/SN3
John Stanley/SN3
Task Performed by: Johnson Space Center

SSS 4

Magnetospheric Effects on the Sodium Atmosphere of Mercury
Funded by: Planetary Astronomy (UPN 196)
Principal Investigator: Andrew E. Potter/SN3
Task Performed by: Johnson Space Center

SSS 5

Mars Sample Receiving Facility
Funded by: (UPN 155)
Principal Investigator: James E. Townsend/SN
Task Performed by: Johnson Space Center

SSS 6

Identification of Phyllosilicate Absorption Features in Primitive Asteroids
Funded by: Planetary Astronomy (UPN 196)
Principal Investigator: Faith Vilas/SN3
Task Performed by: Johnson Space Center

SSS 7

A Shuttle-Based Flight Experiment for Developing Orbital Debris Collision Warning Sensors
Funded by: Space Research and Technology Base (UPN 506)
Principal Investigator: Faith Vilas/SN3
Task Performed by: Johnson Space center
Lockheed Engineering and Sciences Co., NAS9-17900

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Backscatter Mossbauer Spectroscopy for Remote Analysis of Planetary Materials
Funded by: Center Director's Discretionary Fund (UPN 307)
Principal Investigator: Richard Morris/SN2
Task Performed by: Johnson Space Center

SSS 9　　　　**Solid-Support Substrates for Plant Growth at a Lunar Outpost**

Funded by: Life Sciences (UPN 199)

Principal Investigators: Donald L. Henninger/SN14
　　　　　　　　　　　　Douglas W. Ming/SN14

Task Performed by: Johnson Space Center
　　　　　　　　　　Lockheed Engineering and Sciences Co., NAS9-17900

SPACE TRANSPORTATION TECHNOLOGY

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Funded by: OSF-APD (Code M)
Principal Investigator: C. J. Culbert/FR5
Task Performed by: McDonnell Douglas Space Systems Company, NAS9-17885

STT 2   **Automation and Expert Systems Application to Spaceflight Operations**
Funded by: OSF-APD (Code M)
Principal Investigator: Robert T. Savely/FR5
Task Performed by: McDonnell Douglas Space Systems Company, NAS9-17885

STT 3   **Integrated Flight Operations Functional Simulation**
Funded by: OSF-APD (Code M)
Principal Investigator: C. J. Culbert/FR5
Task Performed by: McDonnell Douglas Space Systems Company, NAS9-17885

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Funded by: Office of Space Flight /Code M
          Office of Space Station/Code ST
Principal Investigator: Ernest M. Fridge III/FR5
Task Performed by: Johnson Space Center
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          Knowledge Based Systems Laboratory, Texas A&M University,
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Funded by: Office of Space Flight (Code MD)
Principal Investigators: Robert T. Savely/FR5
          Dr. R. Bowen Loftin/FR5
Task Performed by: Johnson Space Center
          University of Houston, NAG 9-405
          Computer Sciences Corp., NAS9-17885

STT 6   **Fuzzy Logic for Adaptive Control and Operational Decision Making**
Funded by: Code MD
Principal Investigator: Robert N. Lea/FR5
Task Performed by: University of Houston Clear Lake (RICIS), NCC9-16
          LINCOM, NAS9-17885

STT 7   **Photonics for Navigation, Hazard Detection, and Avoidance**
Funded by: Code RC/591-13-31-01
Principal Investigator: Richard D. Juday/EE6
Task Performed by: Johnson Space Center
          Lockheed Engineering and Sciences Co., NAS9-17900

STT 8   **Photonics for Autonomous Rendezvous and Docking**
Funded by: Code RC/591-21-31-01
Principal Investigator: Richard D. Juday/EE6
Task Performed by: Johnson Space Center
          Lockheed Engineering and Sciences Co., NAS9-17900
          Texas Instruments, NAS9-17201

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Funded by: 951-15-KA-98, Code M
Principal Investigators: Elaine M. Stephens/EE8
Wisty L. Olsson, LESC
Dr. Kwei Tu, LESC
Task Performed by: Johnson Space Center
Lockheed Engineering and Sciences Co., NAS9-17900

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Funded by: UPN906
Principal Investigators: C. Teixeira/ED2
C. Mallini/ED2
Task Performed by: Johnson Space Center
Lockheed Engineering and Sciences Co., NAS9-17900

STT 11   **Personnel Launch System**
Funded by: UPN906
Principal Investigator: E. Petro/ED2
Task Performed by: Boeing Aerospace Operations, NAS9-18255

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Funded by: NASA Headquarters, Code M
Principal Investigator: Marilyn W. Kimball/DC46
Task Performed by: Johnson Space Center
Rockwell International
UNISYS Corp.

STT 13   **Surface Insulation Materials Studies**
Funded by: Shuttle Program Office
Principal Investigators: G. D. Arndt/EE3
W. W. Koepsel, Mutronic Systems
Task Performed by: Johnson Space Center
Mutronic Systems, NAS9-17900

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Funded by: Code CU/141-20-20-01
Principal Investigator: K. F. Dekome/EE6
Task Performed by: Wilton Industries, NAS9-18144

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Funded by: Code CR/324-01-EE-85
Principal Investigator: K. F. Dekome/EE6
Task Performed by: APA Optics Inc., NAS9-18084

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Funded by: Code CR/324-02-EA-12
Principal Investigator: James C. Lamoreux/EE6
Task Performed by: Autonomous Technologies Corp., NAS9-18166

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Funded by: Code M/928-25-01-02
Principal Investigator:　Richard D. Juday/EE6
Task Performed by:　Johnson Space Center
　　　　　　　　　　　Lockheed Engineering and Sciences Co., NAS9-17900

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Funded by: Code M/928-50-02-01
Principal Investigator:　J. Prather/EE6
Task Performed by:　Johnson Space Center, NAS9-17900

STT 19　　**Automatic Fluid, Interface Mechanism Evaluation**
Funded by: Satellite Servicer System: 906-30
Principal Investigators:　Laura Louviere /EP4
　　　　　　　　　　　　John P. Masetta/EP4
Task Performed by:　Johnson Space Center

STT 20　　**Hydrazine Hazards Assessment**
Funded by: JSC Internal
Principal Investigator:　Rex Delventhal/EP4
Task Performed by:　Johnson Space Center, White Sands Test Facility

STT 21　　**Primary Remote Control System Direct Acting Valve**
Funded by: Orbiter Project, 551-15-15-02
Principal Investigator:　Dennis L. Wells/EP4
Task Performed by:　Johnson Space Center, White Sands Test Facility
　　　　　　　　　　　The Marquardt Company, NAS9-17704

STT 22　　**Superfluid Helium Orbital Resupply Coupling**
Funded by: MD/Advanced Program Development, 906-30-03
Principal Investigator:　Richard J. Schoenberg/EP4
Task Performed by:　Moog Space Products, NAS9-17872
　　　　　　　　　　　Ball Aerospace, NAS9-18021

STT 23　　**Uprated Orbital Maneuvering System Engine for Upper Stages**
Funded by: MD/Advanced Program Development, 906-77-01
Principal Investigator:　William C. Boyd/EP4
Task Performed by:　Aerojet Techsystems Co., NAS9-17215

STT 24　　**Zero-Gravity Gaging for Cryogenic Fluids**
Funded by: Code RX, Flight Projects Division 506-48-21-01
Principal Investigator:　Nancy E. Munoz/EP4
Task Performed by:　Ball Aerospace Systems Division, NAS9-17378

STT 25　　**Lunar-Based Propulsion System Analysis**
Funded by: Johnson Space Center
Principal Investigator:　Chris Popp/EP4
Task Performed by:　Lockheed Engineering and Sciences Co., NAS9-17900
　　　　　　　　　　　Orbital Technologies Corporation (ORBITEC)

STT 26　　**Space Station Integration Propulsion Test Article**
Funded by: 472-28-06-02
Principal Investigators: John Applewhite/EP4
　　　　　　　　　　　　Rex Delventhal/EP4
Task Performed by: Johnson Space Center

STT 27　　**Electronically Variable Pressure Regulator**
Funded by: MD Advanced program Development, 928-30-03
Principal Investigator: Eric Hurlbert/EP4
Task Performed by: Eaton Consolidated Controls, NAS9-17907

STT 28　　**Magnetic Grapple Using the Force Torque Sensor and the Magnetic End Effector**
Funded By: Office of Space Flight, Code MD
Principal Investigator: Leo Monford/IC
Task Performed by: Lockheed Engineering and Sciences Co., NAS9-17900
　　　　　　　　　　　Jet Propulsion Laboratory

SPACE SYSTEMS TECHNOLOGY

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Funded by: OAST, 506-48-41-06-6A-EP2511-EP531
Principal Investigators: Michael Pham/EP5
　　　　　　　　　　　　　Dr. Richard Baldwin/301-1
Task Performed by: Hamilton Standard, NAS9-18001

SST 2 **Humidity Control via Membrane Separation for Advanced Extravehicular Mobility Unit Application**
Funded by: OAST, 506-41-61-01
Principal Investigator: Mariann F. Brown/EC5
Task Performed by: Bend Research Inc., NAS9-17983

SST 3 **Advanced Extravehicular Activity Glove Development**
Funded by: Space Station Freedom Program: 472-47-20-03
Principal Investigator: Joseph J. Kosmo/EC3
Task Performed by: ILC/Dover, NAS9-17776
　　　　　　　　　　　David Clark Co., NAS9-17637

SST 4 **Space Suit Testing**
Funded by: Space Station Freedom Program, 472-47-22-01
Principal Investigator: Philip R. West/EC3
Task Performed by: Rockwell International, NAS9-17699
　　　　　　　　　　　Lockheed Engineering and Sciences Co., NAS9-17900
　　　　　　　　　　　McDonnell Douglas Space Systems Co., NAS9-18200

SST 5 **Mark III 8.3 psi Space Suit Development**
Funded by: Space Station Freedom Program: 472-47-20-02
Principal Investigator: Joseph J. Kosmo/EC3
Task Performed by: ILC/Dover, NAS9-17260

SST 6 **Variable Transmittance Electrochromic Space Suit Visor**
Funded by: SBIR
Principal Investigator: Susan Schentrup/EC3
Task Performed by: EIC Laboratories, NAS9-18169

SST 7 **Research in Human-Computer Interaction**
Funded by: OAST, 506-47-11-01, 591-32
Principal Investigator: Marianne Rudisill, Ph.D./SP34
Task Performed by: Lockheed Engineering and Sciences Co., NAS9-17900

SST 8 **Non-Intrusive Data Collection System**
Funded by: OSSA, 199-06-11-33
Principal Investigator: Frances E. Mount/SP34
Task Performed by: Lockheed Engineering and Sciences Co., NAS9-17900

SST 9 **Single-Phase Laundry System**
Funded by: Office of Commercial Programs (SBIR), 324-02
Principal Investigator: Phyllis Grounds/SP44
Task Performed by: Umpqua Research Co., NAS9-17996

SST 10   **Inventory Tracking into the Next Decade**
Funded by: Office of Commercial Programs (SBIR), 324-02
Principal Investigator: L. W. Lew/SP33
Task Performed by: Lockheed Air Terminal, Inc., IWT 02880038
                   Direct Current Light, Inc., NAS9-18090
                   Digital Signal Corp., NAS9-18089

SST 11   **Hair Cleansing System**
Funded by: OSF, 928-20-01-01
Principal Investigator: Rafael Garcia/SP4
Task Performed by: Johnson Space Center

SST 12   **Toolkit for Computer-Aided Engineering and Operation of
Intelligent Systems for Monitoring and Fault Management**
Funded by: Johnson Space Center
Principal Investigator: Jane T. Malin/EF5
Task Performed by: Johnson Space Center
                   MITRE, F19628-86-C-0001
                   Lockheed Engineering and Sciences Co., NAS9-17900

SST 13   **Techniques for Estimating Space Station Aerodynamics**
Funded by: 472-12
Principal Investigators: Robert Matthew Ondler/ED3
                        Dr. R. Thomas, TA&M
Task Performed by: Johnson Space Center
                   Texas A&M University, NAG9-386

SST 14   **Autonomous Lander Project**
Funded by: Code RC/591/13
Principal Investigators: Ken Baker/EF5
                        Gene McSwain/EH2
                        Bill Culpepper/EE6
                        Richard Juday/EE6
Task Performed by: Johnson Space Center
                   Lockheed Engineering and Sciences Co., NAS9-17900
                   Draper Lab., NAS9-17560
                   Environmental Research Institute of Michigan,
                   DOD Contract DLA900-88-D-03

SST 15   **Substructural Controller Synthesis for the Control Design of Flexible
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Funded by: OAST, 506-46-11-50
Principal Investigator: John W. Sunkel/EH2
Task Performed by: Johnson Space Center
                   The University of Texas, NAG9-357

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Funded by: SBIR, Phase I
Principal Investigator: Stephen Jacobs/ES5
Task Performed by: Boundary Technologies, Inc., NAS9-18067

SST 17   **Shuttle Main Propulsion System Gaseous Oxygen Flow Control**
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              Funded by: NSTS Orbiter and GFE Projects Office
              Principal Investigator: Chris Popp/EP4
              Task Performed by: Johnson Space Center, White Sands Test Facility, NAS9-14000

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              Funded by: Office of Space Science and Applications, 694-01-24
              Principal Investigator: Nancy E. Munoz/EP4
              Task Performed by: University of Houston, NAS9-17442

SST 19   **Superfluid Helium Orbital Resupply Coupling**
              Funded by: MD/Advanced Program Development, 906-30-03
              Principal Investigator: Richard J. Schoenberg/EP4
              Task Performed by: Moog Space Products, NAS9-17872
                              Ball Aerospace, NAS9-18021

SST 20   **Shuttle Infrared Leeside Temperature Sensing Experiment**
              Funded by: OAST/RX
              Principal Investigators: E. Vincent Zoby, Mail Stop 366, LaRC
                              David A. Throckmorton, Mail Stop 366, LaRC
              Task Performed by: NASA Langley Research Center

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              Funded by: OAST/RX
              Principal Investigator: Paul M. Siemers III, Mail Stop 436, LaRC
              Task Performed by: NASA Langley Research Center

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              Principal Investigator: Clifford W. Hess/EC5
              Task Performed by: Johnson Space Center,
                              Intelligent Automation Systems, Inc., NAS9-18097

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              Task Performed by: Johnson Space Center
                              MIT-Artificial Intelligence Laboratory,NAS9-319

SST 24   **Exponential Grids in Robotic Vision**
              Funded by: Code CR/324-02-EA-09
              Principal Investigator: R. D. Juday/EE6
              Task Performed by: Transitions Research Corporation, NAS9-17990

SST 25   **Robotic Vision/Tracking Sensors**
              Funded by: Code MD/906-30-03-30
              Principal Investigator: D. E. Rhoades/EE6
              Task Performed by: Johnson Space Center
                              Lockheed Engineering and Sciences Co.,NAS9-17900
                              McDonnell Douglas Space Systems Co., NAS9-18200: CCA #4

SST 26   **Space Shuttle Remote Manipulator System Advanced Force/Torque Control Task**
Funded by: OAST/Code R (UPN 590)
Principal Investigators: G. Reuter/EF2
                        D. Barron/EF2
Task Performed by: Lockheed Engineering and Sciences Co., NAS9-17900

SST 27   **Flexible Arm Control Experiment/Dexterous Manipulator Advanced Control Experiment**
Funded by: Instep/OAST/RX/Flight Projects Division (UPN 506)
Principal Investigator: Gerald J. Reuter/EF2
Task Performed by: Marin Marietta Denver Aerospace, NAS9-17970

SST 28   **Pathfinder Autonomous Rendezvous and Docking**
Funded by: NASA Headquarters/Code RC (591-21)
Principal Investigator: Stephen Lamkin/EH3
Task Performed by: Johnson Space Center
                        Lockheed Engineering and Sciences Co., NAS9-17900
                        C.S. Draper, NAS9-18147
                        McDonnell Douglas Space Systems Co., NAS9-17885

SST 29   **Aerobrake Thermal Protection System Robotic Assembly**
Funded by: Pathfinder: 591-22-21-01
Principal Investigator: Reginald B. Berka./ES2
Task Performed by: Johnson Space Center
                        Lockheed Engineering and Sciences Co., NAS9-17900

REPORT DOCUMENTATION PAGE

1. Report No. NASA TM 102 161	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Research and Technology 1989 Annual Report of the Lyndon B. Johnson Space Center	5. Report Date March 1990
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No. F-603

9. Performing Organization Name and Address Lyndon B. Johnson Space Center Houston, Texas 77058	10. Work Unit No. 992-15-00-00-72
	11. Contract or Grant No.

12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	13. Type of Report and Period Covered Technical Memorandum
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Johnson Space Center (JSC) accomplishments in new and advanced concepts during 1989 are highlighted. This year, reports are grouped in sections, Medical Science, Solar System Sciences, Space Transportation Technology, and Space Systems Technology. Summary sections describing the role of JSC in each program are followed by descriptions of significant tasks. Descriptions are suitable for external consumption, free of technical jargon, and illustrated to increase ease of comprehension.

17. Key Words (Suggested by Author(s)) Research and Technology R&T Advanced Programs	18. Distribution Statement Unclassified – Unlimited Subject Category: 99

19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of pages 181	22. Price

JSC Form 1424 (Rev Jan 88) (Ethernet Jan 88)